

**DOCKETED**

<b>Docket Number:</b>	19-AB-2127
<b>Project Title:</b>	Implementation of AB 2127 Electric Vehicle Charging Infrastructure Assessments
<b>TN #:</b>	251866
<b>Document Title:</b>	Assembly Bill 2127 Electric Vehicle Charging Infrastructure Second Assessment Staff Draft Report
<b>Description:</b>	N/A
<b>Filer:</b>	Adam Davis
<b>Organization:</b>	California Energy Commission
<b>Submitter Role:</b>	Commission Staff
<b>Submission Date:</b>	8/24/2023 2:51:31 PM
<b>Docketed Date:</b>	8/24/2023



**CALIFORNIA  
ENERGY COMMISSION**



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NATURAL  
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California Energy Commission

## **STAFF REPORT**

# **Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment**

**Assessing Charging Needs to Support Zero-  
Emission Vehicles in 2030 and 2035**

**August 2023 | CEC-600-2023-048**



# California Energy Commission

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## **ACKNOWLEDGEMENTS**

The following California Energy Commission staff members contributed to developing this *Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment*: Aniss Bahreinian, Brendan Burns, Anita Carraher, Maggie Deng, Quentin Gee, Michael Nicholas, Taylor Nguyen, Kiel Pratt, Kristi Villareal.

The authors appreciate the analytical expertise of these research collaborators: Eric Wood, Yanbo Ge, Tim Jonas, Dong-Yeon Lee, and Fan Yang (National Renewable Energy Laboratory); Wanshi Hong and Bin Wang (Lawrence Berkeley National Laboratory); and Gil Tal and Alan Jenn (University of California, Davis).

The authors value the ongoing interagency coordination on infrastructure efforts and the input and feedback from Analisa Bevan, Banpreet Bhambra, Yachun Chow, Adrienne Harris, Andrew Martinez, and Anna Wong (California Air Resources Board); Paul Douglas, Paula Gruending, Joshua Huneycutt, Jennifer Kalafut, Karolina Maslanka, Audrey Neuman, Stephanie Seki, and Michael Truax (California Public Utilities Commission); Sherry Mung and Pradeep Kotamraju (California Workforce Development Board) and Courtney Copeland, Heather Hickerson, and Elsa Wright (California Governor's Office of Business and Economic Development).



# ABSTRACT

The second *Assembly Bill (AB) 2127 Electric Vehicle Charging Infrastructure Assessment* examines charging needs to support California's zero-emission vehicles in 2030 and 2035. Pursuant to AB 2127, the California Energy Commission is required to publish a biennial report on the charging infrastructure needed for California to meet its zero-emission vehicle targets by 2030. In September 2020, Governor Gavin Newsom issued Executive Order (EO) N-79-20, which expanded zero-emission vehicle adoption targets, including 100% zero-emission vehicle sales for light-duty vehicles and zero-emission vehicle sales and operations targets for drayage trucks and off-road vehicles and equipment by 2035; and 100% zero-emission medium- and heavy-duty vehicle sales and operations by 2045 where feasible. A pathway to reaching the goals reflected in EO N-79-20 has been set by the California Air Resources Board's Advanced Clean Cars II, Advanced Clean Trucks, and Advanced Clean Fleets regulations.

Because Assembly Bill 2127 requires the California Energy Commission to assess charging infrastructure needs, this report focuses on plug-in electric vehicles, which are a subset of zero-emission vehicles and include battery-electric vehicles and plug-in hybrid electric vehicles. The analysis presented in this report projects that California will need 1.01 million chargers (including 39,000 direct current fast chargers) to support 7.1 million light-duty plug-in electric vehicles in 2030. By 2035, the state will need 2.11 million chargers (including 83,000 direct current fast chargers) to support 15.2 million light-duty plug-in electric vehicles. To support medium- and heavy-duty plug-in electric vehicles, California will need about 109,000 depot chargers and 5,500 public chargers for 155,000 vehicles in 2030, and 256,000 depot chargers and 8,500 public chargers for 377,000 vehicles in 2035.

This expansion of charging will require widespread investment in the grid and effective management of California's electrical grid to reduce potential impacts. Improving charger and vehicle technology along with grid upgrades will make it possible to accommodate charging in ways that will minimize the grid impact.

Installing these chargers will require investments in labor and workforce training and development, as up to 71,500 job-years will be needed for charger installation by 2035. The transition to ZEVs and supporting infrastructure will support jobs of the future.

**Keywords:** charging, infrastructure, transportation electrification, electric vehicle, network planning

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# EXECUTIVE SUMMARY

California's transportation-related emissions contribute roughly half of the state's greenhouse gas emissions, when accounting for emissions from fuel production and vehicle use. Transportation is also a major source of the state's air pollution, contributing nearly 80 percent of smog-forming nitrogen oxides and 95 percent of toxic diesel particulate matter. To achieve the state's long-term air quality and emissions reduction goals, California must rapidly transition toward the widespread use of zero-emission vehicles powered by clean energy. In support of this transition, in September 2020, Governor Gavin Newsom issued Executive Order N-79-20, setting the following targets:

- By 2035, 100 percent zero-emission vehicle sales for new passenger cars and trucks, 100 percent zero-emission vehicle operations for drayage trucks, and 100 percent zero-emission off-road vehicles and equipment where feasible.
- By 2045, 100 percent zero-emission vehicle operations for medium- and heavy-duty vehicles where feasible.

Since then, the California Air Resources Board has established pathways to reaching the requirements of Executive Order N-79-20 by issuing a series of regulations affecting the sale and operation of vehicles in California:

- Advanced Clean Cars II, adopted in 2022, requires an increasing proportion of new passenger vehicle sales to be zero-emission vehicles each year, reaching 100 percent in 2035.
- Advanced Clean Trucks, adopted in 2021, requires an increasing fraction of truck sales to be zero-emission vehicles through 2035, with specific targets for each vehicle class.
- Advanced Clean Fleets, adopted in 2023, requires fleet operators in certain segments to reach 100 percent zero-emission vehicles by 2035 or 2040.

Assembly Bill 2127 (Ting, Chapter 365, Statutes of 2018) requires the California Energy Commission (CEC) to prepare statewide assessments of the charging infrastructure needed to meet the state's zero-emission vehicle goals through 2030. Executive Order N-79-20 updated the requirement to include higher targets through 2035. Because AB 2127 requires the CEC to assess charging infrastructure needs, this report focuses on plug-in electric vehicles, which include battery-electric vehicles and plug-in hybrid electric vehicles. The text of AB 2127 is included in Appendix B.

The CEC published the inaugural AB 2127 report in July 2021. This draft 2023 report differs from the first report in several important ways. First, this report extends the analysis of charger needs to 2035, when all new passenger vehicles and on-road drayage trucks are required to be zero emission. Second, this report relies upon updated zero-emission vehicle fleet projections from CEC's transportation energy demand forecast in the *2022 Integrated Energy Policy Report* (Additional Achievable Transportation Electrification 3 scenario), which incorporates the expected impact of vehicle regulations implemented by the California Air Resources Board. The modeling also accounts for shifting consumer preference for and availability of longer-range plug-in electric vehicles, as well as increases in charger power

levels, resulting in drivers of all vehicle types preferring charging that is either long-duration or high-powered and charging less frequently overall.

For passenger vehicles, this analysis models charger needs beyond single-family homes, specifically public locations and “shared private” locations, which include private lots at workplaces and multifamily dwellings. While today's average electric passenger vehicle driver charges at home in a single-family dwelling, many Californians do not have convenient access to this option. People who live in multifamily dwellings or have no access to electricity where they park need convenient charging options. In addition, all electric vehicle drivers will need charging on long trips.

This analysis also evaluates the number chargers of different speeds that will be needed for passenger plug-in electric vehicles, including slower Level 1 and Level 2 charging and faster direct-current fast charging. The slowest charging option is Level 1 (providing about 3–5 miles of range per hour), which is an option for home charging but has less of a role at other locations. Level 2 (providing between 5 and 60 miles of range per hour, depending on the amp rating) is appropriate for longer dwell times, particularly workplaces and overnight parking. High-powered direct-current fast charging will be increasingly important as long-range battery-electric vehicles make up a larger share of the fleet. Fast charging may also be important for people who do not have convenient charging at home or at their workplace. Direct current fast charging speeds vary from 50 kilowatts (kW, providing about 145 miles of range per hour) to 350 kW (providing a full charge in about 20 minutes) or more.

In 2030, this report projects that California's 7.1 million plug-in electric passenger vehicles will need 1.01 million chargers, including 39,000 direct-current fast chargers. In 2035, California's 15.2 million plug-in electric passenger vehicles will need 2.11 million chargers, including 83,000 direct-current fast chargers. Light-duty vehicle charger needs will be impacted by the types of zero-emission vehicle technologies that make up the fleet in the future. Charger needs will also be affected by the mix of slow versus fast chargers that are deployed by the market.

For medium- and heavy-duty electric vehicles, the report evaluates the number of chargers needed at depots and public locations for charging on route. Depot chargers are chargers located at trip destinations, including the locations where vehicles are stored overnight. Because vehicles spend longer periods at these locations, depot chargers can provide lower-powered charging (20 kW to 150 kW in this analysis). Some vehicles make trips beyond the range of the batteries and rely on public chargers to replenish range quickly on route. To support rapid charging, public chargers must provide higher-powered charging than depots (350 kW to 1,500 kW in this analysis). A wide mix of charging speeds will be necessary to ensure that all medium- and heavy-duty vehicles can meet charging requirements.

In 2030, this analysis finds that California's 155,000 medium- and heavy-duty plug-in electric vehicles will need about 114,500 chargers: 109,000 lower-powered (20 kW – 150 kW) depot chargers and 5,500 higher-powered (350 kW – 1,500 kW) public chargers. In 2035, California's 377,000 medium- and heavy-duty plug-in electric vehicles will need 264,500 chargers: 256,000 lower-powered depot chargers and 8,500 higher-powered public chargers.

California has made progress towards meeting these charger needs. There are approximately 92,000 public and shared private chargers for light duty vehicles in California. Between existing chargers and chargers for which funding has been allocated, the state is on track to meet the Executive Order B-48-18 goal of 250,000 chargers by 2025. Over 9,000 DC fast chargers are currently in operation in California, and the state is ahead of schedule to meet the goal of 10,000 chargers set under Executive Order B-48-18.

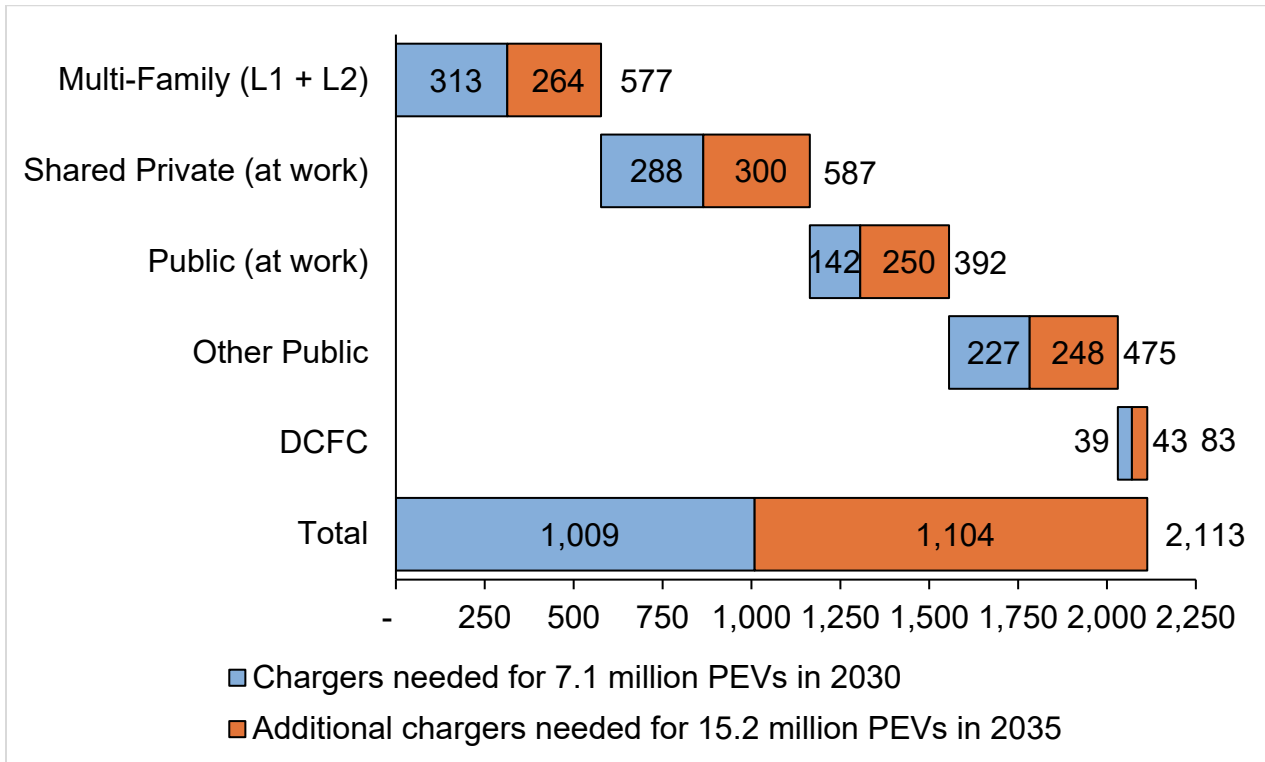
## **Light-Duty Electric Vehicles Will Need 2.1 Million Public and Shared Chargers by 2035**

Since the publication of the first AB 2127 assessment, light-duty zero-emission vehicle adoption has accelerated rapidly in California, with the sales share of zero-emission vehicles more than doubling between 2020 and 2022. Through the first quarter of 2023, cumulative sales in California have reached 1.5 million zero-emission vehicles. Zero-emission vehicles made up 18.8 percent of all light-duty vehicles sold in the state in 2022 and rose to 21.1 percent of light-duty vehicle sales in the first quarter of 2023. Battery-electric vehicles make up an increasing proportion of these sales, accounting for 84.6 percent of zero-emission vehicle sales in 2022 compared to 62.9 percent in previous years. In 2022, plug-in hybrids made up 14.7 percent of zero-emission vehicle sales, and hydrogen fuel cell electric vehicles made up the remaining 0.7 percent of zero-emission vehicle sales. There has also been a trend toward long-range battery electric vehicles; almost all battery electric vehicles sold in 2022 had more than 200 miles of electric range. Zero-emission vehicle sales have begun to accelerate in larger vehicle segments, indicating that zero-emission vehicles are now able to meet the needs of a wider range of households.

As zero-emission vehicles sales expand under the Advanced Clean Cars II regulation, the California Energy Commission projects that California's light-duty plug-in electric vehicle population will increase to 7.1 million vehicles in 2030 and 15.2 million in 2035. To support these vehicles, the state will need about 2.1 million chargers by 2035 across a range of power levels and location types. Figure 1 provides a breakdown of the types of chargers needed to support light-duty plug-in electric vehicles by 2030 and 2035.

The first AB 2127 assessment relied on the Mobile Source Strategy estimate of 8 million zero-emission vehicles (including 7.5 million plug-in vehicles) in 2030. This AB 2127 assessment uses the transportation energy demand forecast for the *2022 Integrated Energy Policy Report Update* (Additional Achievable Transportation Electrification 3 scenario), which projects of 7.1 million zero-emission vehicles (of which more than 99 percent are plug-in vehicles) in 2030. This updated assessment finds a decrease in the number of Level 2 chargers away from home and an increase in the number of direct-current fast chargers compared to the inaugural report. Among Level 2 chargers, more serve long-duration workplace charging events, and fewer serve shorter-duration charging events away from home. These changes largely reflect the shift from plug-in hybrid electric vehicles to long-range battery-electric vehicles in the market and under the Advanced Clean Cars II regulation, as well as refinements to the behavioral model underlying this assessment. While plug-in hybrid electric vehicles must either charge frequently or rely on internal combustion engines for longer travel days, long-range battery-electric vehicles can charge less frequently and use higher-speed charging when they need to charge away from home.

**Figure 1: Chargers Needed for Light-Duty Plug-In Electric Vehicles in 2030 and 2035**



**Models project that California will need more than 1 million public and shared private chargers in 2030 to support 7.1 million plug-in electric vehicles and 2.1 million chargers in 2035 to support 15.2 million plug-in electric vehicles.**

Source: CEC staff

## Supporting Equitable Charging Access and Aligning Charging With Grid Needs Are Priorities for Light-Duty Vehicle Electrification

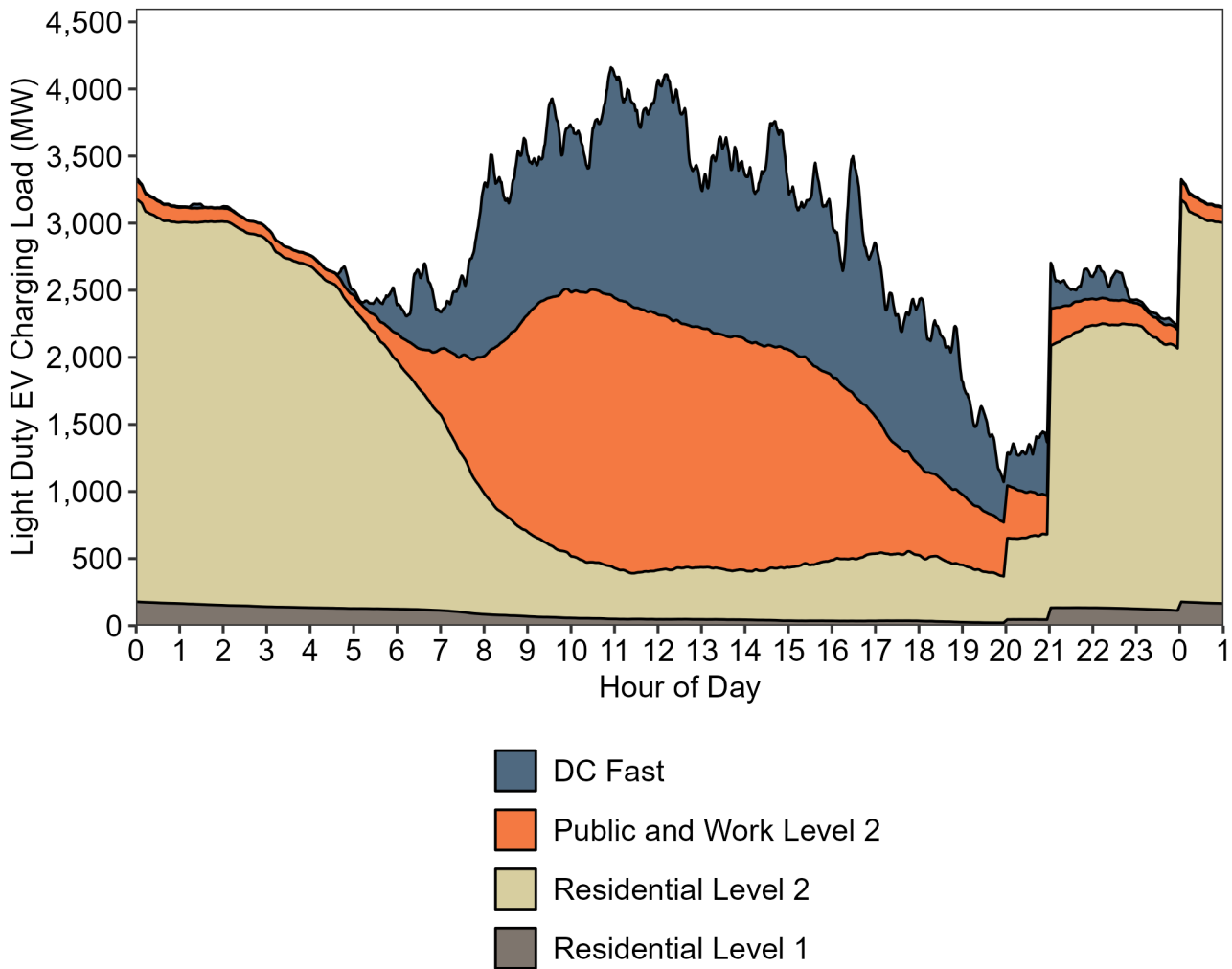
As plug-in electric vehicles make up a larger share of light-duty vehicles on the road, it will be increasingly important to prioritize charging that is grid-friendly and cost-effective while ensuring that the transition to electric vehicles is equitable. This report explores a range of alternative models for the future of charging infrastructure but pays particular attention to two key questions:

- What are the options for routine charging for households that cannot currently charge at home? The report examines scenarios to explore the potential effects of expanded home charging access and increase the presence of DC fast charging.
- How can charging loads be managed to best make use of lower-cost and lower-emission energy and reduce the capacity strain on the grid?

Figure 2 shows the projected statewide power demand for light-duty vehicle charging on a typical weekday in 2030. The load reaches about 4,000 MW at the peak between 11 a.m. and 1 p.m. The *2022 Integrated Energy Policy Report Update* planning forecast anticipates vehicle charging to account for less than 10 percent of daily average load and less than 5 percent of load at peak in 2030; this forecast anticipates that vehicle charging will account for less than 20 percent of daily average load and less than 10 percent of load at peak in 2035. Utility-

specific time-of-use rates are expected to move some charging away from peak hours in the late evening and early morning but may not be sufficient to shift charging into midday, when solar energy is most plentiful.

**Figure 2: Projected Statewide Power for Light-Duty Vehicle Charging for 7.1 Million Zero-Emission Vehicles on a Typical 2030 Weekday**



**Charging management strategies will be needed to spread electric vehicle charging throughout the day and align loads with generation and grid capacity. Charging away from home occurs mostly during the day, which aligns with renewable generation. Residential charging technologies should be coordinated with distribution systems to lessen the impact of charging. The steep increase in home charging load at various points in the evening correspond to regional time-of-use rate changes, which many drivers use to time their charging. Dynamic rates and managed charging could help eliminate these timer spikes.**

Source: CEC and NREL

## **Medium- and Heavy-Duty Electric Vehicles Will Need 264,500 Chargers by 2035**

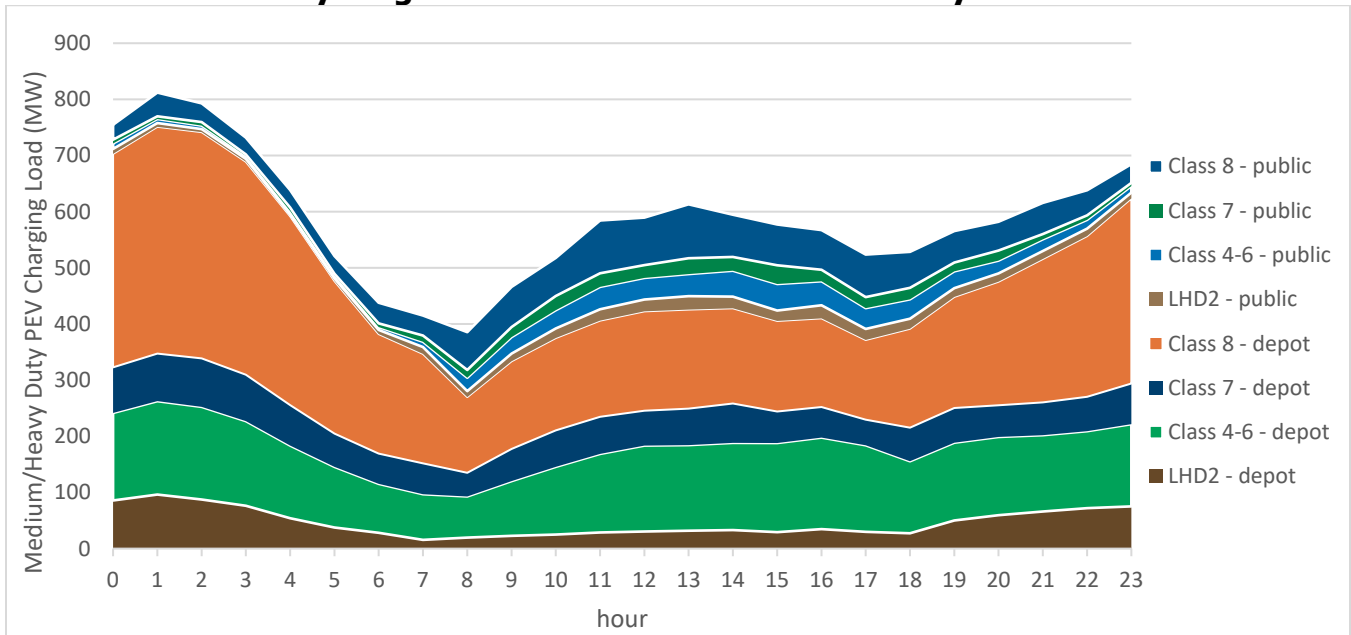
Advanced Clean Trucks and Advanced Clean Fleets regulations will greatly accelerate the pace of medium- and heavy-duty zero-emission vehicle adoption. As of June 2022, there were 1,882

plug-in electric trucks, buses, and delivery vans registered in California and 61 fuel cell buses. The Integrated Energy Policy Report Additional Achievable Transportation Electrification 3 scenario, which is aligned with the Advanced Clean Trucks and Advanced Clean Fleets regulations, is used as the baseline scenario in this report. CEC modeling for the transportation energy demand forecast in the *2022 Integrated Energy Policy Report Update* finds there will be about 155,000 medium- and heavy-duty plug-in electric vehicles in 2030 and 377,000 medium- and heavy-duty plug-in electric vehicles in 2035, with these vehicles spread across a wide range of sectors. These vehicles will require 109,000 depot chargers and 5,500 public chargers in 2030, which grows to 256,000 depot chargers and 8,500 public chargers in 2035.

These requirements differ from the previous assessment because of updates that have been made to the medium- and heavy-duty vehicle charging infrastructure modeling framework. In this assessment, charger power levels are broken down into more diverse increments and use vehicle simulation methods to generate energy demand and charging needs at a finer resolution than before. The primary scenario in this assessment includes a larger proportion of smaller and lower-mileage vehicles than in the first AB 2127 assessment, and vehicle efficiency assumptions have been updated. Compared to the first assessment, a smaller number of chargers are projected since medium- and heavy-duty vehicle energy demand can be better satisfied by higher charging power levels. In this assessment, depot chargers are broken down into powers ranging from 20 kW to 150 kW, whereas public chargers range from 350 kW to 1.5 megawatts (MW).

Moreover, the report compares charging load profiles for managed and unmanaged charging cases for medium- and heavy-duty vehicles in this assessment to evaluate the effect of shifting peak load to different times throughout the day. Public charging load is difficult to manage because it is opportunistic. Therefore, since depot charging makes up a little more than 82 percent of the total daily medium- and heavy-duty vehicle charging load projected by the models used in this report, altering depot charging behavior and shifting the associated load have the biggest impact on the grid. Figure 3 shows the projected statewide medium- and heavy-duty vehicle charging demand on a typical weekday. By altering parking flexibility, deferring charging events, and using dynamic pricing schemes, the 6 p.m. ramp peaking at 1 p.m. can be shifted to earlier hours in the day when overall energy demand is lower to ease the stress on electrical grid equipment.

**Figure 3: Projected Statewide Charging Demand for 155,000 Medium- and Heavy-Duty Plug-In Electric Vehicles on a Weekday in 2030**



**The highest demand for medium- and heavy-duty vehicle charging will occur overnight starting around 6 p.m. and peaking at 1 a.m. This demand can be shifted to times of the day when demand is lower by using dynamic utility pricing schemes, more flexible parking, and deferral of charging events to avoid periods of high demand. (LHD2 refers to light-heavy-duty trucks with a gross vehicle weight rating between 10,001 and 14,000 pounds)**

Source: CEC and LBNL

Increased load from charging medium- and heavy-duty vehicles can present a unique challenge compared to light-duty passenger vehicle charging. However, larger charging stations for passenger vehicles may share some characteristics of medium- and heavy-duty vehicle charging. Specifically, electric utilities, the state, and stakeholders should ensure the grid is ready for incorporating new load through appropriate grid upgrades and load-integration strategies. As the number of chargers throughout the state grows over time, it will likely require coordinated planning and upgrades to components of the distribution system such as transformers, primary and secondary circuits, and substations to adapt to the additional load resulting from vehicle electrification. State agencies have, and will continue to, coordinate efforts to meet state goals.

State agencies are refining existing tools and adding new tools to address this new load proactively. The transportation demand forecast in the *2022 Integrated Energy Policy Report Update* (Additional Achievable Transportation Electrification 3 scenario) considers an increased amount of electric vehicle adoption that is used for resource procurement and grid planning in the utilities' integrated resource plans. Coordination on resource assumptions in the CEC's demand forecast also takes place in the Joint Agency Steering Committee, which is a group of interagency staff members working together to address key barriers in the context of long-term procurement and transmission planning processes. Through the EVSE Deployment and Grid Evaluation (EDGE) tool, the CEC is seeking to help project managers deploy charging infrastructure throughout the state by providing them with access to the most current grid information. This tool is under development and will be designed to help users identify good



locations to install chargers that will support rapid electric vehicle growth rates within California soon. The tool has the potential to aid stakeholders in identifying areas where there may be excess capacity or where proactive upgrades should be made.

## **Improving Vehicle-Grid Integration Can Benefit Drivers and the Grid**

Widespread vehicle-grid integration, where vehicles and charging systems are responsive to grid conditions, can help ensure California can achieve cost-effective and timely decarbonization of its electric power and transportation systems. *Vehicle-grid integration* describes technologies and strategies that alter the charging behavior of plug-in electric vehicles in a manner that benefits the grid while ensuring driver needs are met. For example, vehicle-grid integration can help ensure that drivers charge up on the cleanest and cheapest electricity available, and at times that reduces constraint on the electric system. More advanced functionality of vehicle-grid integration includes the ability to enable vehicles to power buildings or the grid when needed.

Despite the immense potential of vehicle-grid integration, the products, services, electricity rates, and policies that exist today are nascent and must continue to develop to support customer-friendly and widespread vehicle-grid integration. The expanded adoption of vehicle-grid integration will require continued coordinated contributions from state agencies, utilities, charging providers, automakers, customers, and others. Specifically, California must continue to develop compensation programs, customer products and services, site electrical readiness, vehicle and grid planning processes, and customer education to support widespread vehicle-grid integration.

## **Labor and Workforce Training and Development Support for Electric Vehicle Charging Infrastructure Deployment Is Critical**

Current and projected investments for charger deployments require that the state thoughtfully consider the range of labor and workforce training and development issues involved in providing this infrastructure to meet the state's zero-emission vehicle goals and realize other benefits. Electric vehicle charging infrastructure career pathways must be intentionally cultivated with collaboration among the state's workforce entities, employers, training partners, trades, and workers. In addition, the state should take a high-road economic approach that embeds equity, climate, and jobs priorities for businesses and workers and expand workforce opportunities for underserved communities and populations that can participate in the electric vehicle supply equipment industry.

# CHAPTER 1:

## Background

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### Policy Context

Despite progress in reducing statewide greenhouse gas (GHG) emissions, California's transportation-related emissions contribute roughly half of the state's GHG emissions when accounting for emissions from fuel production as well as fuel use in the vehicle. Transportation is a major source of the state's air pollution, contributing nearly 80 percent of smog-forming nitrogen oxides (NOx) and 95 percent of toxic diesel particulate matter.<sup>1</sup> To achieve the state's long-term air quality and GHG emissions reduction goals, California must rapidly transition toward the widespread use of zero-emission vehicles (ZEVs) powered by clean energy. In support of this transition, in September 2020, Governor Gavin Newsom issued Executive Order N-79-20,<sup>2</sup> which calls for:

- All in-state sales of new passenger cars and trucks to be zero-emission by 2035.
- All drayage trucks operating in the state to be zero-emission by 2035.
- All medium- and heavy-duty vehicles operating in the state to be zero-emission by 2045, where feasible.
- All off-road vehicles and equipment to be zero-emission by 2035, where feasible.

The California Air Resources Board (CARB) has established pathways to reaching the requirements of Executive Order N-79-20 by issuing a series of regulations affecting the sale and operation of vehicles in California:

- Advanced Clean Cars II (ACCII), adopted in 2022, requires an increasing proportion of new passenger vehicle sales to be ZEVs each year, reaching 100 percent in 2035.<sup>3</sup>
- Advanced Clean Trucks (ACT), adopted in 2021, requires an increasing fraction of truck sales to be ZEVs through 2035, with specific targets for each vehicle class.<sup>4</sup>
- Advanced Clean Fleets (ACF), adopted in 2023, requires fleet operators in certain segments to reach 100 percent ZEVs by 2035 or 2040.<sup>5</sup>

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1 California Energy Commission staff. 2019. [2019 Integrated Energy Policy Report](https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2019-integrated-energy-policy-report). California Energy Commission. Publication Number: CEC-100-2019-001-CMF. Available at <https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2019-integrated-energy-policy-report>.

2 Governor Gavin Newsom. [Executive Order N-79-20](https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-text.pdf). Issued September 23, 2020. <https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-text.pdf>.

3 California Air Resources Board. ["Advanced Clean Cars II Regulations: All New Passenger Vehicle Sold in California to Be Zero Emission by 2035,"](https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii) <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii>.

4 California Air Resources Board. ["Advanced Clean Trucks Fact Sheet: Accelerating Zero-Emission Truck Markets,"](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet) <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet>.

5 California Air Resources Board. ["Advanced Clean Fleets Regulation Summary: Accelerating Zero-Emission Truck Markets,"](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary) <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary>

Preceding N-79-20, former Governor Edmund G. Brown Jr. issued Executive Order B-48-18,<sup>6</sup> which directed California to install 250,000 electric vehicle chargers, including 10,000 direct current (DC) fast chargers, to support 1.5 million ZEVs statewide by 2025. B-48-18 further established a target of 5 million ZEVs statewide by 2030. The 5 million ZEVs goal represents the level of vehicle adoption consistent with ensuring that statewide greenhouse gas emissions are reduced to 40 percent below the 1990 level by 2030.<sup>7</sup> In 2018, Assembly Bill (AB) 2127<sup>8</sup> codified this 2030 ZEV target and tasked the California Energy Commission (CEC) with preparing biennial assessments of the charging infrastructure needed to meet these goals. While vehicles fueled by electricity or hydrogen are considered ZEVs, the AB 2127 assessment focuses exclusively on plug-in electric vehicles (PEVs), which include battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The evaluations in this report represent a high case, where almost all ZEVs are PEVs; as other ZEV technologies mature, the forecasted need for chargers may be reduced.

## First AB 2127 Assessment Findings

The first AB 2127 assessment,<sup>9</sup> published in July 2021, examined the existing and future charging infrastructure needs throughout California. These needs include the chargers, make-ready<sup>10</sup> electrical equipment, supporting hardware and software, and other programs for on-road and off-road vehicle categories.

The AB 2127 report used vehicle population projections from the *Draft 2020 Mobile Source Strategy* from the CARB, which was the only analysis at the time that addressed the EO N-79-20 goals. This analysis estimated that 8 million light-duty ZEVs and 180,000 medium- and heavy-duty ZEVs would be needed in 2030 to meet the EO N-79-20 goals.

Key findings from the first AB 2127 assessment included the following:

- To support 5 million and 8 million light-duty passenger ZEVs, respectively, in 2030, California needs more than 700,000 and nearly 1.2 million public and shared private chargers.
- California needs about 157,000 chargers to support 180,000 medium- and heavy-duty ZEVs in 2030.

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6 Governor Edmund G. Brown, Jr. [Executive Order B-48-18](https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html). Issued January 26, 2018. <https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html>.

7 California Air Resources Board staff. 2021. [Revised Draft 2020 Mobile Source Strategy](https://ww2.arb.ca.gov/sites/default/files/2021-04/Revised_Draft_2020_Mobile_Source_Strategy.pdf). California Air Resources Board. [chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ww2.arb.ca.gov/sites/default/files/2021-04/Revised\\_Draft\\_2020\\_Mobile\\_Source\\_Strategy.pdf](https://ww2.arb.ca.gov/sites/default/files/2021-04/Revised_Draft_2020_Mobile_Source_Strategy.pdf).

8 [Assembly Bill 2127 \(Ting, Chapter 365, Statutes of 2018\)](https://leginfo.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB2127). [https://leginfo.ca.gov/faces/billTextClient.xhtml?bill\\_id=201720180AB2127](https://leginfo.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB2127).

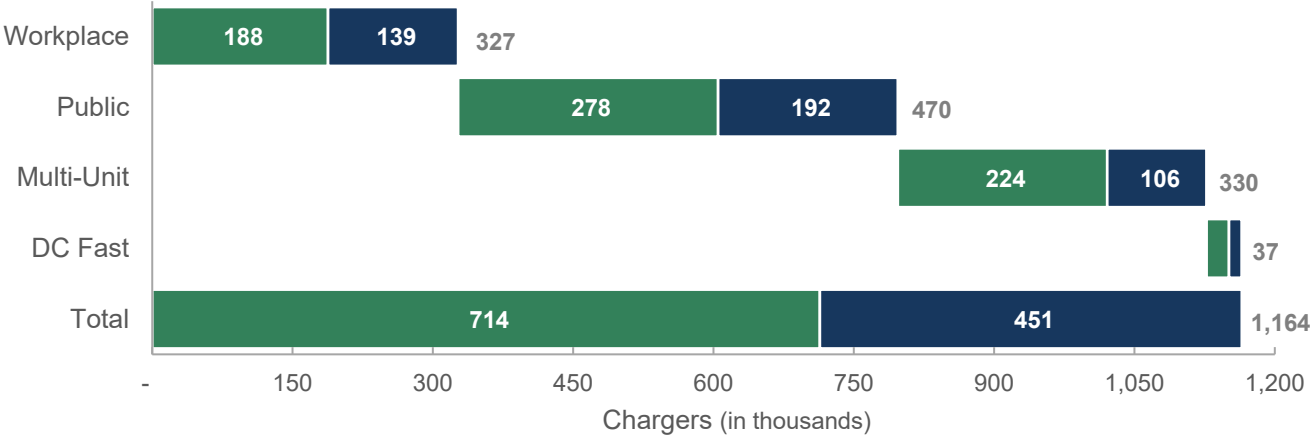
9 Alexander, Matt, Noel Crisostomo, Wendell Krell, Jeffrey Lu, and Raja Ramesh. July 2021. [Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment: Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030 – Commission Report](https://efiling.energy.ca.gov/getdocument.aspx?tn=238853). California Energy Commission. Publication Number: CEC-600-2021-001-CMR. <https://efiling.energy.ca.gov/getdocument.aspx?tn=238853>.

10 "Make-ready" refers to the electrical infrastructure required to operate a charger, such as transformers or wiring.

- Light-duty vehicle charging was projected to reach around 5,500 megawatts (MW) at the peak around midnight and 4,600 MW at a daytime peak around 10 a.m. on a typical weekday in 2030.
- Medium- and heavy-duty vehicle charging was projected to reach around 2,000 MW at the peak around 5 p.m. on a typical weekday in 2030, though significant variation exists among vehicle types.

Figure 4 shows the composition of the projected 2030 light-duty charging infrastructure network in the first AB 2127 assessment, while Figure 5 illustrates the projected statewide load profile in 2030 from light-duty charging.

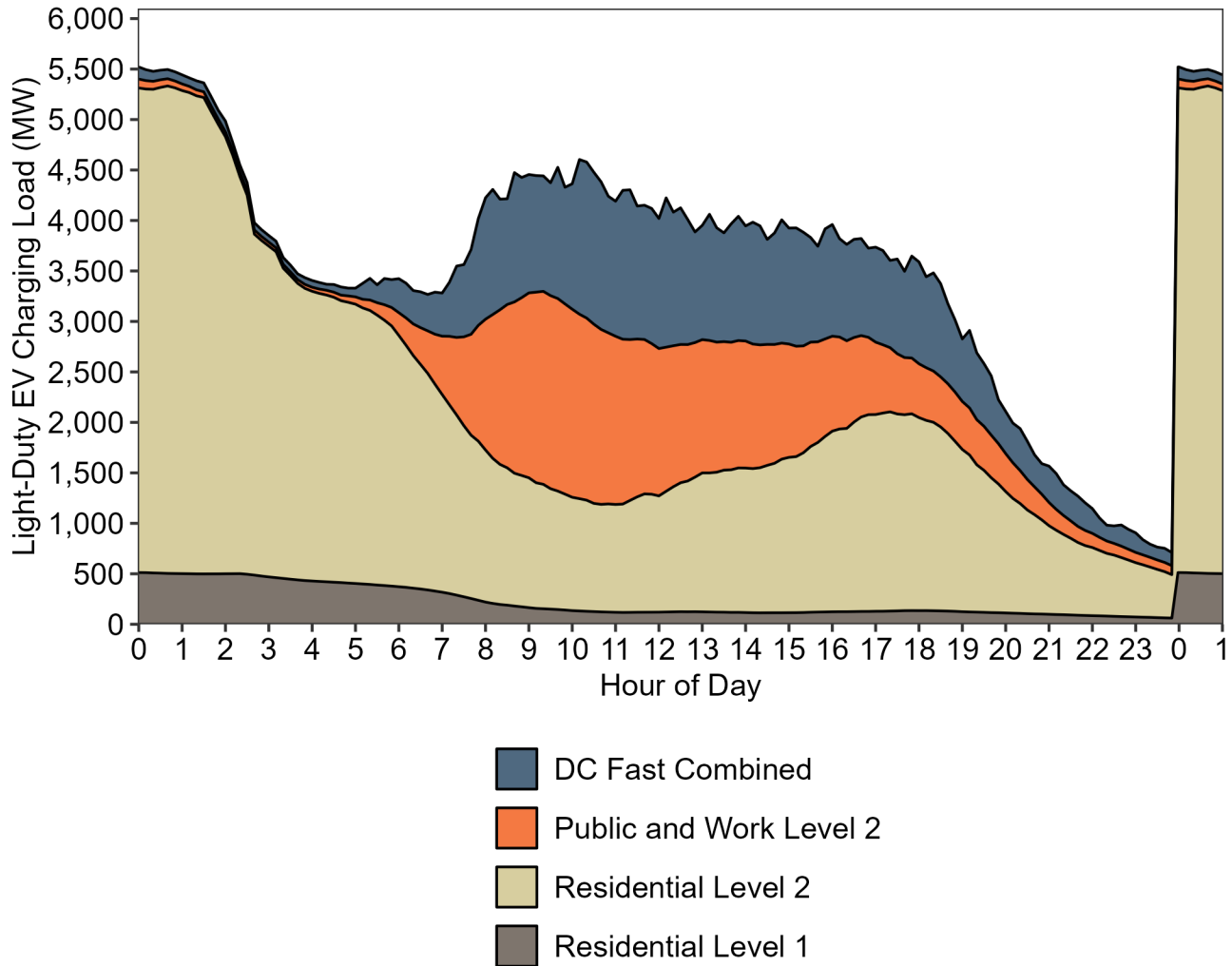
**Figure 4: Projected 2030 Charger Counts to Support 5 Million and 8 Million Light-Duty Zero-Emission Vehicles from the First AB 2127 Assessment**



**The first AB 2127 assessment projected that California would need more than 700,000 shared private and public chargers in 2030 to support 5 million ZEVs as called for in AB 2127 and nearly 1.2 million chargers to support 8 million ZEVs to achieve the goals of the Executive Order N-79-20. Counts for chargers at workplaces, public destinations, and multiunit dwellings generally indicate the number of Level 2 chargers needed. In some cases, Level 1 chargers may be sufficient at select multiunit dwellings. These values do not include chargers at single-family homes.**

Source: CEC and National Renewable Energy Laboratory

**Figure 5: Projected Statewide Power for Light-Duty Charging for 8 Million ZEVs on a Typical 2030 Weekday from the First AB 2127 Assessment**



**The first AB 2127 assessment found that light-duty charging would peak around 5.5 GW at midnight and 4.6 GW at 10 a.m. Demand for DC fast charging, as well as public and work Level 2 charging, occurs mostly during the day. Assuming timed midnight residential charging resulted in a large spike in charging load at midnight, illustrated with a twenty-fifth hour on the right.**

Source: CEC, National Renewable Energy Laboratory, and UC Davis

Beyond these key findings, the first report identified several actions to support the widespread deployment of charging infrastructure:

- Continue public support for charger deployment, using public funds to leverage private funds, and eventually transition to a self-sustaining private market.
- Continue modeling efforts to project the quantities, locations, and electrical grid loads of chargers needed to meet statewide travel demand.
- Support innovative charging solutions and financing mechanisms.
- Support local efforts to prepare for transportation electrification.
- Ensure equitable distribution of charger deployment throughout the state.

- Align charging with renewable generation and grid needs.
- Prioritize standardized charger connectors and, for networked charging, prioritize hardware capable of standardized communications protocols.

## **Second AB 2127 Assessment**

The second AB 2127 assessment reports on progress toward meeting the state's goals and supporting the actions identified above. This report discusses new quantitative modeling of projected charger demand based on updated adoption scenarios and improved assumptions. It also introduces topics not discussed in the first assessment, such as workforce needs and reliability of charging infrastructure.

**Chapter 2** describes current trends in the zero-emission vehicle market and highlights the progress made toward meeting California's transportation electrification targets through rules like Advanced Clean Cars II, Advanced Clean Trucks, and Advanced Clean Fleets.

**Chapter 3** describes the state of existing charging infrastructure in California, including a discussion of the CEC's Counting Chargers effort, charger reliability standards, and the SB 1000 investigation of equity concerns in PEV charging.

**Chapter 4** presents the modeling results for charging infrastructure needs through 2035. EVI-Pro 3 and WIRED are used to assess the infrastructure needed to support light-duty PEVs. HEVI-LOAD addresses the needs of medium- and heavy-duty PEVs. EDGE explores the potential impacts of PEV charging on the grid across a range of scales.

**Chapter 5** discusses the tradeoffs between scenarios presented in Chapter 4 and identifies focus areas for future charging infrastructure investments.

**Chapter 6** explores vehicle-grid integration and the potential of technological advances in vehicles and chargers to improve outcomes of vehicle charging on the electrical grid.

**Chapter 7** discusses the labor and workforce aspects of the expansion of charging infrastructure, including analysis of total workforce needs and the training and apprenticeship programs necessary to meet these needs.

**Chapter 8** summarizes the results of the report and highlights the major policy directions necessary to ensure that the future of PEV charging is efficient, reliable, and equitable.

# CHAPTER 2:

## Zero-Emission Vehicle Trends and Market Evolution

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### Introduction

Transportation electrification<sup>11</sup> (TE) continues to gain momentum among state governments, utilities, industry, and consumers. Purchases of PEVs are growing rapidly, driven by policy, a wider range of available models, and more chargers installed. California is supporting TE with legislation, policy, regulation, and public funding. Since the first AB 2127 Report in 2021:

- CPUC issued a decision on its Transportation Electrification Framework,<sup>12</sup> which established a five-year funding cycle approach to utility TE funding, adopted a further defined role for utilities in advancing TE, and authorized an additional \$600 million (with the opportunity to spend up to \$1 billion) for light-, medium-, and heavy-duty charging infrastructure starting in 2025.<sup>13</sup>
- CARB issued the Advanced Clean Cars II<sup>14</sup> and Advanced Clean Fleets<sup>15</sup> regulations, which aligned with Governor Newsom’s mandate for 100 percent ZEV sales by 2035 for light duty vehicles, 100 percent ZEV operations for drayage trucks by 2035, and 100 percent ZEV operations for medium- and heavy-duty vehicles by 2045, where feasible.
- CEC has received more than \$1 billion to invest in ZEV infrastructure.<sup>16</sup>
- Vehicle manufacturers have committed to an electric future,<sup>17</sup> and California is now home to 55 manufacturers of ZEVs and ZEV-related equipment, including eight battery manufacturers.<sup>18</sup>

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11 While this report focuses on battery-electric vehicles, fuel cell electric vehicles are another zero-emission technology expected to play a role in transportation electrification, such as for large trucks.

12 CPUC Decision (D.) 22-11-040:

<https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M499/K005/499005805.PDF>.

13 California Public Utilities Commission. [“Transportation Electrification.”](https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification) <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification>.

14 California Air Resources Board. [“Advanced Clean Cars II Regulations: All New Passenger Vehicle Sold in California to Be Zero Emission by 2035,”](https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii) <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii>.

15 California Air Resources Board. [“Advanced Clean Fleets Regulation Summary: Accelerating Zero-Emission Truck Markets.”](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary) <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary>.

16 California Energy Commission Staff. 2021. [2021–2023 Investment Plan Update for the Clean Transportation Program](https://efiling.energy.ca.gov/GetDocument.aspx?tn=240977), <https://efiling.energy.ca.gov/GetDocument.aspx?tn=240977>.

17 See, for example, [COP26 DECLARATION ON ACCELERATING THE TRANSITION TO 100% ZERO EMISSION CARS AND VANS, 2021, signed by GM, Ford, and global manufacturers.](https://ukcop26.org/cop26-declaration-on-accelerating-the-transition-to-100-zero-emission-cars-and-vans/) <https://ukcop26.org/cop26-declaration-on-accelerating-the-transition-to-100-zero-emission-cars-and-vans/>.

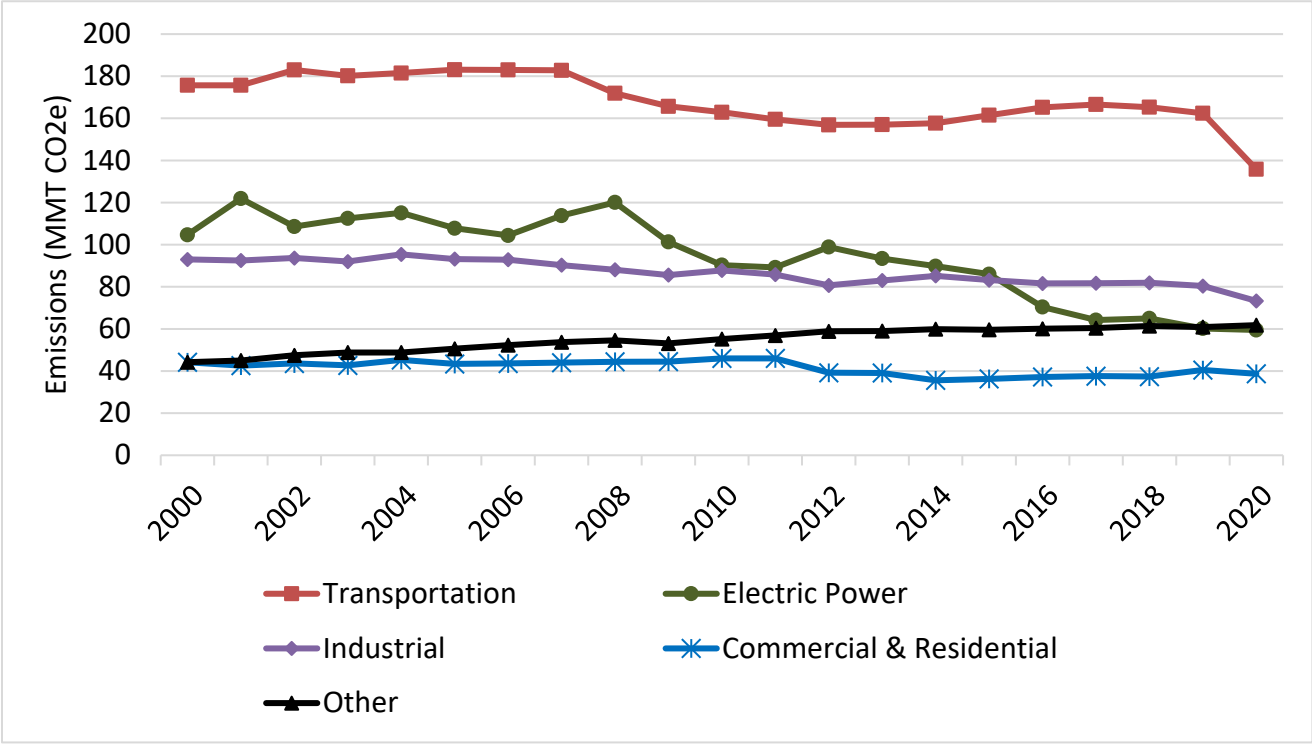
18 Retrieved from the Energy Commission [ZEV-Related Manufacturing Dashboard](https://experience.arcgis.com/experience/b2f1969d31274eb3a56418336bb23561), January 2023 <https://experience.arcgis.com/experience/b2f1969d31274eb3a56418336bb23561>.

- The charging industry is maturing, with increased attention to interoperability and reliability, and continuing to grow and create good jobs across a range of segments, including innovation, manufacturing, construction and installation, and service and maintenance. Both investor-owned and publicly owned electric utilities are executing pilots to experiment with vehicle-grid integration<sup>19</sup> and planning for growth in electricity demand.

### Greenhouse Gases and Other Pollutants

Transportation accounts for about half of California’s greenhouse gas emissions, more than from any other sector, and trended upward between the mid- and late 2010s, even as overall emissions declined (Figure 6). However, transportation emissions declined more in the pandemic year of 2020 than did overall emissions, as vehicle miles traveled in California fell 13 percent. In 2021, vehicle miles traveled rebounded to 95 percent of prepandemic levels and remained steady in 2022.<sup>20</sup>

**Figure 6: California Greenhouse Gas Emissions, 2000–2020**



**California GHG emissions have decreased overall since 2020, with a decrease in emissions from the transportation sector accounting for much of this change. (High GWP are gases with high global warming potential, such as methane.)**

Source: CARB, "GHG Emissions Inventory 2000–2020," 2022. [Online]. Available: <https://ww2.arb.ca.gov/ghg-inventory-data>

19 Investor-owned utility pilots are tracked at <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification/vehicle-grid-integration-activities>

20 From September 2022 Department of Transportation *Vehicle Miles Traveled Report*, available by request from <https://dot.ca.gov/programs/traffic-operations/census/mvmt>.



If all vehicles were electric today, there would still be emissions from fossil fuels used in the generation of California's electricity. However, state law calls for retail sales of electricity to be carbon-free by the end of 2045,<sup>21</sup> potentially eliminating transportation emissions.

Mobile sources (primarily cars and trucks) account for more than half of emissions contributing to unhealthy ozone and particulate matter pollution,<sup>22</sup> and policy makers are increasingly turning to electrification to address pollution concerns, especially in low-income and disadvantaged communities. For example, the South Coast Air Quality Management District, with CARB and CEC funding, administers the Joint Electric Truck Scaling Initiative, putting 100 electric trucks on the road for two large fleets of primarily drayage trucks. The effort should reduce pollution in the neighborhoods near the ports of Los Angeles and Long Beach.<sup>23</sup>

Transportation electrification is not the only policy for addressing pollution and other problems due to transportation. It is CARB policy to reduce vehicle miles traveled per capita<sup>24</sup> via walking, biking, carpooling, and public transportation. These policies address the same greenhouse gas and other pollution concerns as TE does while providing additional economic, environmental, and personal benefits.

## **Light-Duty ZEV Sales and Market Evolution**

As the light-duty ZEV market has matured, several trends have emerged that may push charging needs toward higher-powered charging infrastructure, which CEC staff and researchers have attempted to reflect in the charging infrastructure models that form the core of this report. BEV sales have increased more rapidly than PHEV and FCEV sales, a trend that may continue under the ACCII regulations that cap PHEV sales at 20 percent of ZEV sales beginning in 2026. If this trend continues, charging will continue to supply a large proportion of the energy required by ZEVs. The increased availability of PEV SUVs and pickup trucks, as well as a general market trend toward SUVs, will mean that future PEVs will likely be heavier and therefore require more energy. In addition, vehicle range and battery technology are improving, increasing the number of vehicles capable of higher-powered charging. Larger batteries also encourage increased speed of the onboard charger, creating a potential to increase charging speed and capability of L2 chargers. The above vehicle changes signal a general trend of faster charging with fewer stops to charge.

While only about 12 percent of the U.S. population, California accounts for about 40 percent of ZEV ownership nationwide, and 2022 sales data show this ratio persisting. ZEV sales increased rapidly in California in 2021 and 2022, comprising 18.8 percent of all new light-duty vehicle sales in 2022 (Figure 7). While BEV sales continue to grow, PHEV sales leveled off at about

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21 [Senate Bill 100 \(2018\)](https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100), [https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill\\_id=201720180SB100](https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100).

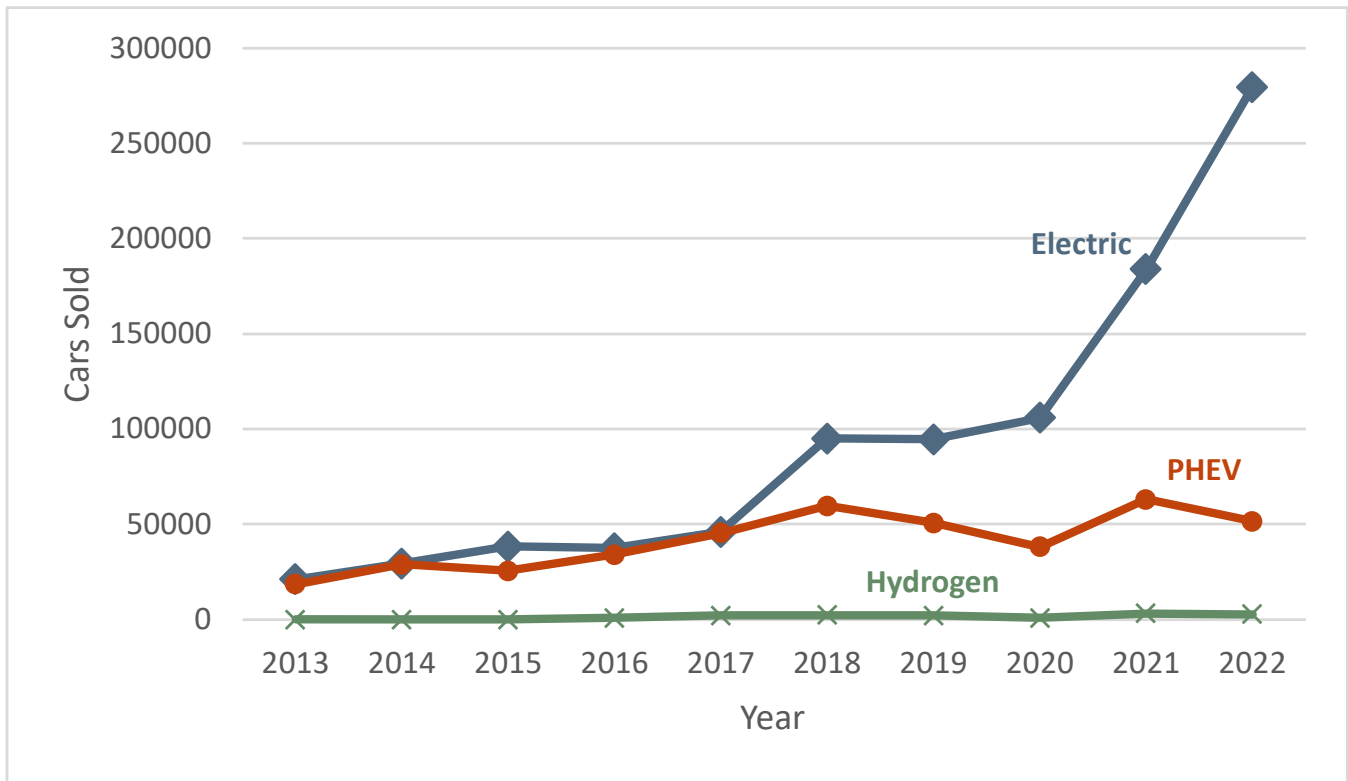
22 California Air Resources Board. "[Low Emission Vehicle Program](https://ww2.arb.ca.gov/our-work/programs/low-emission-vehicle-program)," <https://ww2.arb.ca.gov/our-work/programs/low-emission-vehicle-program>.

23 California Air Resources Board. "[LCTI: Joint Electrification Truck Scaling Initiative \(JETSII\)](https://ww2.arb.ca.gov/lcti-joint-electric-truck-scaling-initiative-jetsi)," <https://ww2.arb.ca.gov/lcti-joint-electric-truck-scaling-initiative-jetsi>.

24 California Air Resources Board. "[CARB 2017 Scoping Plan-Identified VMT Reductions and Relationship to State Climate Goals](https://ww2.arb.ca.gov/resources/documents/carb-2017-scoping-plan-identified-vmt-reductions-and-relationship-state-climate)," <https://ww2.arb.ca.gov/resources/documents/carb-2017-scoping-plan-identified-vmt-reductions-and-relationship-state-climate>; the draft 2022 Scoping Plan calls for a 25 percent reduction in VMT by 2030.

50,000 vehicles per year for the last few years. Hydrogen-powered fuel cell electric vehicles have not increased in sales like BEVs or PHEVs. U.S. drivers now have 134 ZEV models to choose from, up from 7 in 2012.<sup>25</sup>

**Figure 7: California ZEV Sales by Fuel Type**



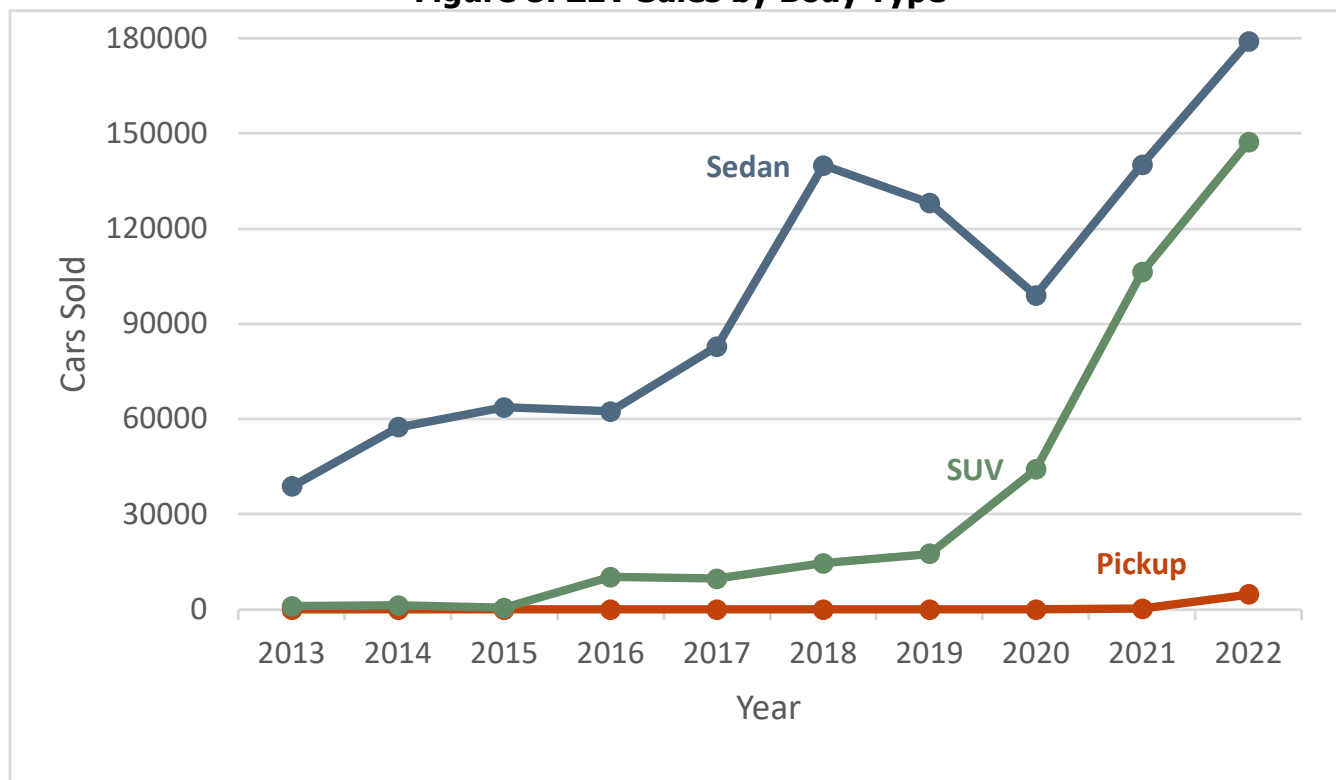
**For each year, the number of all-electric, plug-in hybrid electric and hydrogen-fueled car sales is shown. Sales of battery electric vehicles have increased much more rapidly than sales of PHEVs. Hydrogen powered vehicles do not make up a significant part of light-duty ZEV sales in California.**

Source: Derived from California Energy Commission ZEV Dashboard; raw data is available at <https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data>

Beginning in 2020, SUVs began to claim an increasing share of ZEV sales in California (Figure 8). Manufacturers greatly expanded the number of SUV models available, going from about 20 percent of all models in 2020 to about 50 percent of announced models for 2024. SUVs generally get lower mileage than sedans, so this trend may affect the amount and speed of charging needed (Chapter 5).

<sup>25</sup> ["Light-Duty Offerings by Fuel Type,"](https://afdc.energy.gov/data/10303) <https://afdc.energy.gov/data/10303>. Includes plugin hybrids but not other hybrids.

**Figure 8: ZEV Sales by Body Type**



**For each year, the number of ZEV sedan, pickup, and SUV sales is shown. While almost all ZEVs sold before 2019 were sedans, an increasing share of new ZEVs are SUVs, and sales of ZEV pickup trucks have also begun to increase.**

Source: Derived from California Energy Commission ZEV Dashboard; [raw data](https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data) are available at <https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data>.

Battery-electric vehicle ranges have increased substantially in recent years, making the vehicles a better option for long-distance travel and necessitating higher charging speeds. CEC staff has worked with researchers to ensure that the models presented in this report reflect this emphasis on long-range vehicles and high-speed charging. The average range among available 2023 BEV models is about 249 miles, and the maximum is 520 miles.<sup>26</sup> The average has grown steadily since it was 100 miles in 2015.<sup>27</sup> Despite the growing ranges, a 2021 survey of drivers found “range anxiety” is still a barrier to purchasing BEVs, and most drivers overestimated the range required by their driving habits.<sup>28</sup> If battery pack prices continue to decline, prices of EVs are projected reaching parity with comparable gas vehicles by about

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26 For cars under \$30,000 the longest range is 258 miles; for cars under \$60,000 the longest range is 358 miles. Kane, Mark. 2022. [“US Electric Car Prices: Cheapest To Most Expensive,”](https://insideevs.com/news/565883/electric-car-prices-us-20220207/) Inside EVs. <https://insideevs.com/news/565883/electric-car-prices-us-20220207/>.

27 EPRI, [Systemic Challenges and Barriers to Consumer EV Adoption](https://www.epri.com/research/products/000000003002025413), 2022. <https://www.epri.com/research/products/000000003002025413>.

28 Herberz, M., Hahnel, U.J.J. & Brosch, T. [“Counteracting electric vehicle range concern with a scalable behavioural intervention.”](https://doi.org/10.1038/s41560-022-01028-3) *Nat Energy* **7**, 503–510 (2022). <https://doi.org/10.1038/s41560-022-01028-3>

2030, and sooner in some vehicle segments. In response to rising battery costs, some manufacturers plan to offer models with lowered battery capacity and less range.<sup>29</sup>

## **Medium- and Heavy-Duty ZEV Sales and Market Evolution**

The zero-emission truck market is in the early stages but growing rapidly. As of mid-2022, there were nearly 2,000 medium- and heavy-duty ZEVs operating in California, including 1,369 buses, 306 trucks, and 268 delivery vans.<sup>30</sup> California is the largest American market for these vehicles, but adoption is increasing throughout the country. As shown in Figure 9, CALSTART counted 1,215 medium- and heavy-duty ZEV trucks in service in the United States as of December 2021; more than half (738) were in California.<sup>31</sup> Medium- and heavy-duty ZEVs are more common in Europe, where deployments are in the tens of thousands, and China, which has hundreds of thousands of ZEV trucks and buses.<sup>32</sup> However, in the United States, there were 140,000 orders for new ZEV trucks to be delivered in the coming months and years,<sup>33</sup> and the number of models available to order had grown from 19 in 2019 to 164 in 2021.<sup>34</sup> While electrified medium-duty truck deployments have been growing since 2010, heavy-duty deployments began in 2019. Nearly all these trucks were BEVs, but deployment of hydrogen fuel cell trucks is coming, with 30 funded by the joint CARB/CEC Zero Emission Drayage Truck and Infrastructure Pilot Project.<sup>35</sup>

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29 Fischer, Justin. 2022. "[The Average Price of an Electric Car,](https://caredge.com/guides/average-price-of-an-electric-car)" Car Edge. <https://caredge.com/guides/average-price-of-an-electric-car>.

30 California Energy Commission. 2022. "[Medium- and Heavy-Duty Zero-Emission Vehicles in California.](https://www.energy.ca.gov/zevstats)" Data last updated July 26, 2022. Retrieved January 25, 2023, from <https://www.energy.ca.gov/zevstats>.

31 CALSTART. January 2022. "[Zeroing in on Zero-Emission Trucks,](https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report_Updated-Final-II.pdf)" [https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report\\_Updated-Final-II.pdf](https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report_Updated-Final-II.pdf).

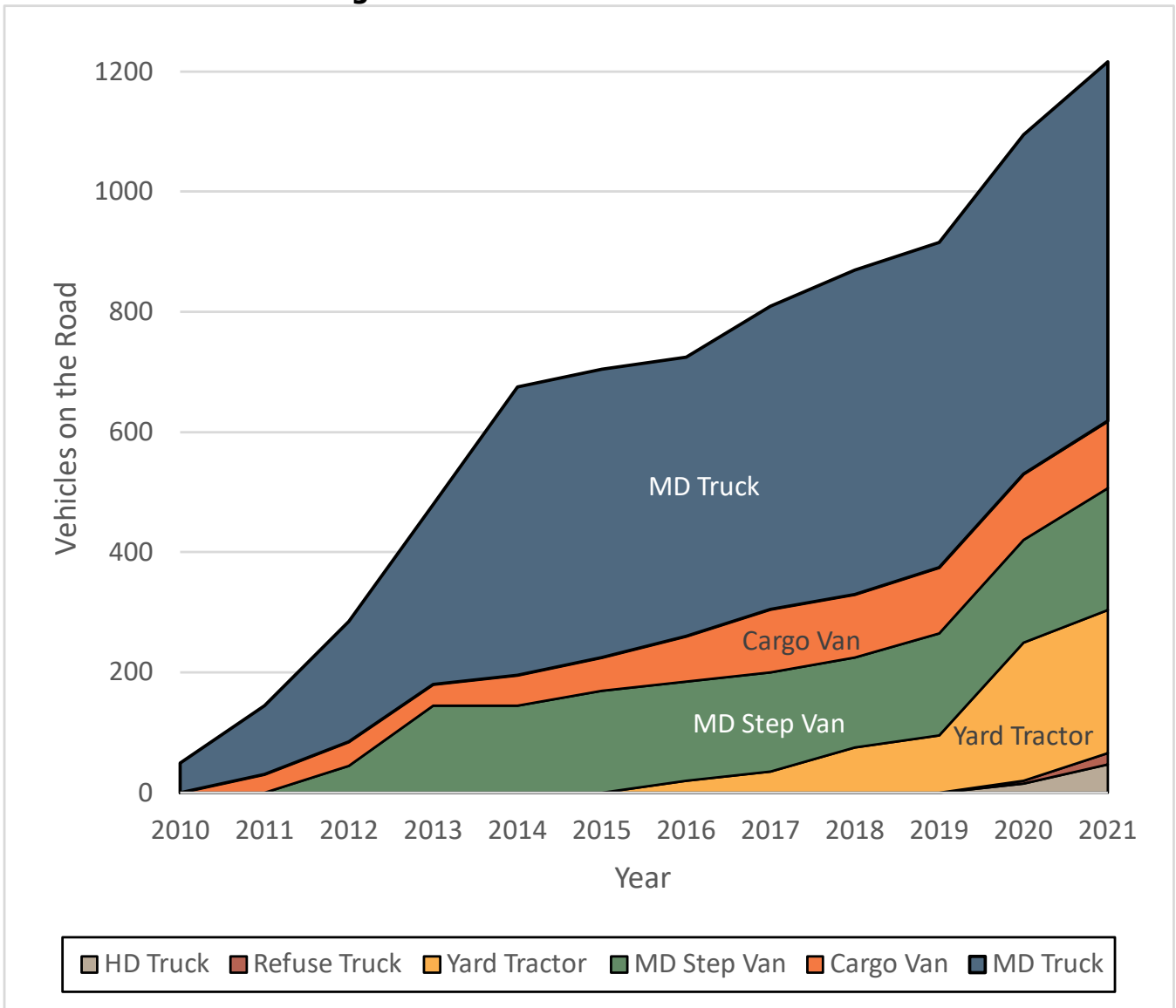
32 CALSTART. October 2022. "[Zero-Emission Truck and Bus Update,](https://globaldrivetozero.org/site/wp-content/uploads/2022/10/ZE_TruckBus_update.pdf)" [https://globaldrivetozero.org/site/wp-content/uploads/2022/10/ZE\\_TruckBus\\_update.pdf](https://globaldrivetozero.org/site/wp-content/uploads/2022/10/ZE_TruckBus_update.pdf).

33 [Zeroing in on Zero-Emission Trucks](https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report_Updated-Final-II.pdf), *op. cit.*

34 [Zeroing in on Zero-Emission Trucks](https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report_Updated-Final-II.pdf), *op. cit.*

35 [Zeroing in on Zero-emission Trucks](https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report_Updated-Final-II.pdf), *op. cit.*

**Figure 9: Zero-Emission Truck Trends**



**Deployment of zero-emission trucks in the United States by category, by year.**

Source: CALSTART, *Zeroing in on Zero-Emission Trucks*, 2022

In 2021, battery packs were three to six times more expensive per kilowatt-hour for trucks than for cars. Truck battery prices will face some of the same supply-chain pressures as car batteries, but CALSTART predicts that cost parity between BEV and diesel trucks will be achieved by 2030.<sup>36</sup> Trucks typically operate more hours per day than cars, and companies may have to modify their duty cycles to make time for charging, so trucks are expected to use DC fast charging more than cars.

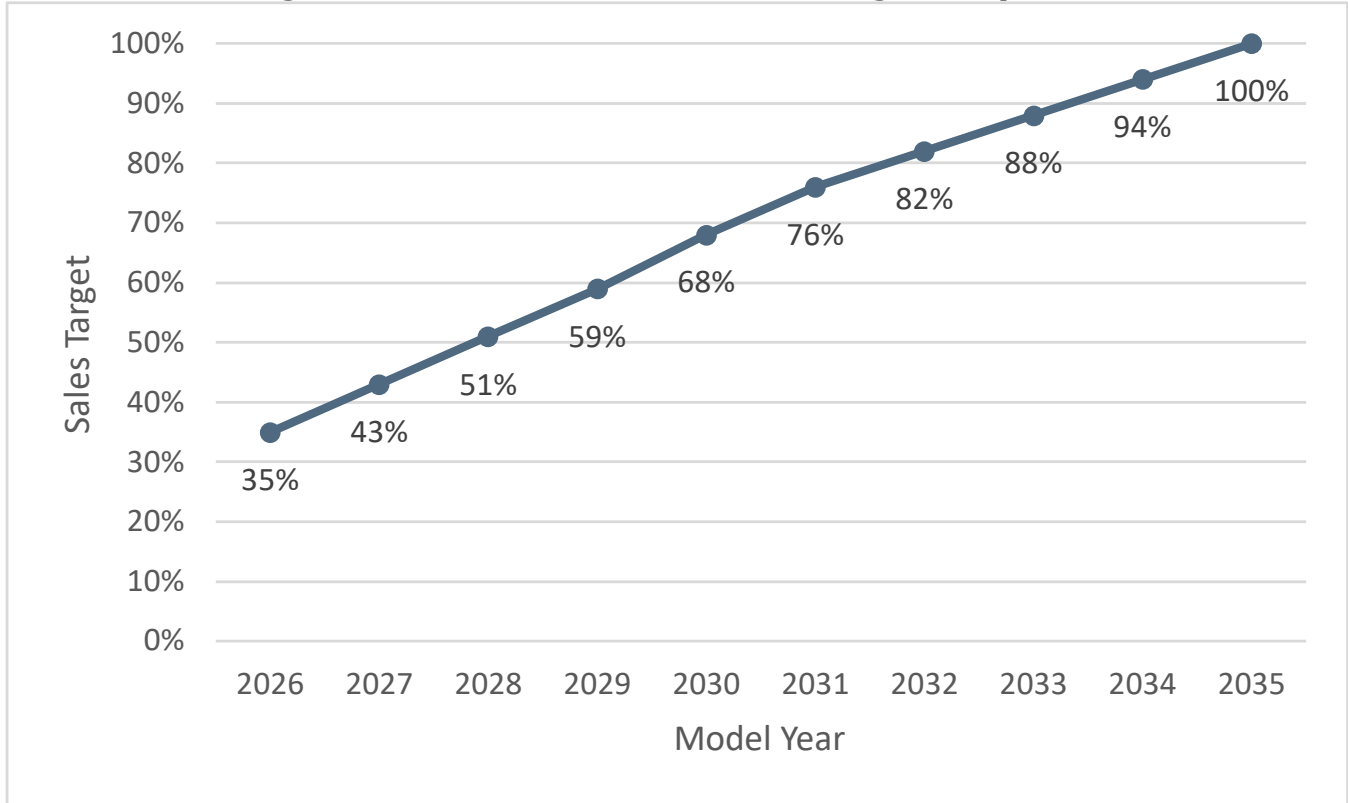
<sup>36</sup> [Zeroing in on Zero-Emission Trucks](#), *op. cit.*

# State EV Adoption Goals

## Advanced Clean Cars II

In 2022, CARB adopted the Advanced Clean Cars II (ACC II) regulation, which requires 100 percent of new passenger vehicles delivered for sale in California to meet a zero-emission standard by 2035, following the path shown in Figure 10. PHEVs may count for up to 20 percent of a manufacturer’s ZEV total, provided the all-electric range of the vehicle is at least 50 miles. Combined with internal combustion emission rules in the same regulation, improved air quality is projected to result in \$13 billion in benefits over the life of the regulation.<sup>37</sup>

**Figure 10: ACC II Sales Schedule for Light-Duty ZEVs**



**The Advanced Clean Cars II regulation requires that 100 percent of all new light-duty vehicles sold in 2035 must be ZEVs.**

Source: CARB. <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii>

## Advanced Clean Trucks and Advanced Clean Fleets

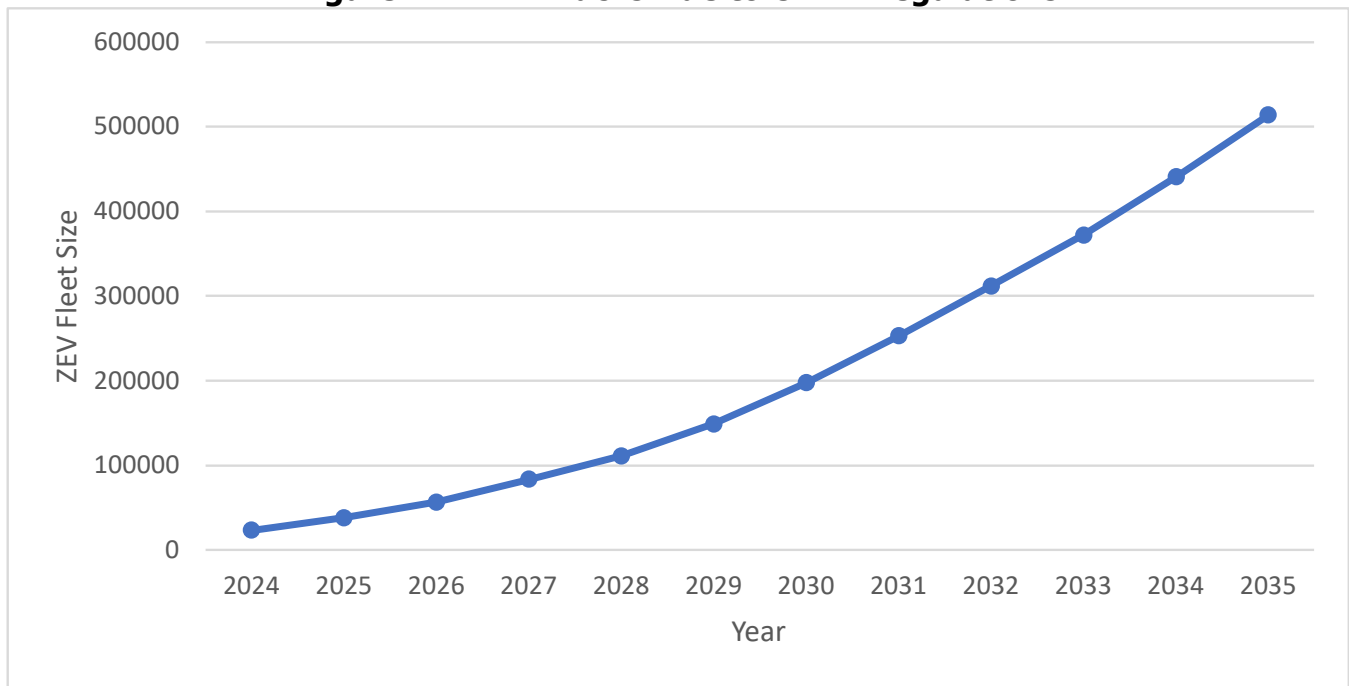
CARB also mandated zero-emission medium-duty and heavy-duty trucks, through rules applying to manufacturers and truck owners. The Advanced Clean Trucks (ACT) regulation,<sup>38</sup> adopted in 2021, requires an increasing fraction of truck sales to be ZEV by 2035, with

37 California Air Resources Board. ["Advanced Clean Cars II Regulations: All New Passenger Vehicle Sold in California to Be Zero Emission by 2035,"](https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii) <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii>.

38 California Air Resources Board. ["Advanced Clean Trucks Fact Sheet: Accelerating Zero-Emission Truck Markets,"](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet) <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet>.

different sales timelines set for different vehicle classes. The Advanced Clean Fleets (ACF) regulation,<sup>39</sup> adopted in 2023, requires 100 percent of medium- and heavy-duty vehicle operations in certain sectors to be ZEVs by 2035 or 2040 and further requires certain fleet owners to achieve targets for the percentage of ZEVs in their fleets on the road, not just new purchases. Advanced Clean Fleets requires faster fleet electrification for certain uses, with drayage fleets being 100 percent ZEV by 2035. Figure 11 shows how the combination of ACT and ACF will affect vehicles on the road according to CARB modeling. For reference, there are 1.8 million medium-duty and heavy-duty vehicles on the road in California.

**Figure 11: ZEV Trucks Due to CARB Regulations**



**Number of ZEV trucks on the road each year as a result of CARB’s ACT and ACF regulations.**

Source: CARB, [“Proposed Advanced Clean Fleets Regulation,”](https://ww2.arb.ca.gov/rulemaking/2022/acf2022) Appendix F, Figure 5.  
<https://ww2.arb.ca.gov/rulemaking/2022/acf2022>

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39 California Air Resources Board. [“Advanced Clean Fleets Regulation Summary: Accelerating Zero-Emission Truck Markets.”](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary) <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary>.

# CHAPTER 3:

## Existing Charging Infrastructure

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California has made good progress in positioning itself as a leader in ZEV adoption. There are likely more than 1 million PEVs<sup>40</sup> on the road that are supported by a range of public, shared, and private chargers throughout the state. However, a strong focus on ZEV infrastructure deployment is required to ensure progress does not stall. This chapter discusses the state of charging in California today and identifies key steps necessary to ensure that the continued expansion of charging is equitable and reliable:

- The CEC’s Counting Chargers project, which provides information for the Zero Emission Vehicle and Infrastructure Statistics EV Chargers dashboard,<sup>41</sup> is key to understanding the current state of charging and identify areas of need. In addition to tabulating publicly accessible chargers, this project has identified shared private chargers, which many drivers rely on for charging while at work or at apartments. CEC staff and NREL researchers used charger counts from this project to calibrate the EVI-Pro 3 model for light-duty charging. CEC staff is developing proposed regulations to gain better data on shared private chargers and medium- and heavy-duty depot chargers.
- Charger reliability is a key concern as more drivers switch to PEVs. The CEC, in collaboration with the CPUC, has begun implementing Assembly Bill 2061 (Ting, Chapter 345, Statutes of 2022) to develop reliability recordkeeping and reporting requirements. Further, the CEC includes reliability performance requirements in CEC funding agreements. These standards will be used to direct CEC funding toward charging projects that are reliable and bring value to the public. The CEC will initiate field testing, slated to begin in early 2024.
- The SB 1000 project assesses whether chargers are disproportionately deployed by income level, population density, or geographical area. The reports issued under this project have highlighted charging inequities in disadvantaged and rural areas.<sup>42</sup> Ensuring that the charger needs identified in the AB 2127 assessment are distributed equitably is key to ensuring California will be able to meet its transportation electrification goals.

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40 According to the CEC’s Zero Emission Vehicle and Infrastructure Statistics dashboards, there were 827,760 light-duty PEVs in California at the end of 2021 and an additional 343,244 were sold in 2022. The PEV population for 2022 is not available yet, but unless PEVs are leaving the fleet at a much higher rate than before, it will exceed 1 million vehicles.

41 California Energy Commission. [“Electric Vehicle Chargers in California,”](https://www.energy.ca.gov/zevstats) <https://www.energy.ca.gov/zevstats>.

42 Disadvantaged communities are census tracts that score within the top twenty-fifth percentile of the Office of Environmental Health Hazards Assessment’s California Communities Environmental Health Screening Tool (CalEnviroScreen) 3.0 scores, as well as areas of high pollution and low population, such as ports. Rural areas classified using data from the U.S. Census Bureau 2010 Urban and Rural Classifications. At the time of this analysis, disadvantaged community designations under CalEnviroScreen 4.0 and urban and rural classifications from the 2020 census had not yet been finalized.



## Charger Types and Definitions

Chargers, sometimes referred to as electric vehicle supply equipment (EVSE), are manufactured appliances that safely deliver electricity to charge a PEV. When discussing chargers, the CEC uses precise nomenclature to avoid confusion between common terms such as “charger” and “charging station.” These definitions are summarized in Table 1.

**Table 1: Definitions of Common Charging Terms**

<b>Electric Vehicle Supply Equipment (EVSE)</b>	A device with one or more charging ports and connectors for charging EVs.
<b>Charger</b>	The system within an EVSE 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. Also referred to as a charging port.
<b>Connector</b>	A physical socket with a specified pin configuration. A charger may have one or multiple connectors.
<b>Charging Station</b>	A charging station is a physical address where one or more chargers are available for use. This is the same usage as for “gas station.” A charging station can be public, shared private, or private.
<b>Public</b>	A public charging station has parking space(s) designated by a property owner or lessee to be available to and accessible by the public for any period.
<b>Shared Private</b>	A shared private charging station has parking space(s) designated by a property owner or lessee to be available to and accessible by employees, tenants, visitors, and/or residents. Parking spaces are not dedicated to individual drivers or vehicles.
<b>Private</b>	A private charging station has parking space(s) that are privately owned and operated, often dedicated for a specific driver or vehicle (for example, a charger installed in the garage of a single-family home).

Source: CEC

As summarized in Table 2, three categories are used to describe light-duty PEV chargers: Level 1, Level 2, and DC fast charging. Level 1 and Level 2 chargers deliver alternating current (AC) electricity to the vehicle and use the SAE J1772 standard connector. While all PEVs can use the SAE J1772 connector,<sup>43</sup> not all have a separate charging port compatible with direct current (DC) fast charging. DC fast chargers deliver DC electricity to the vehicle. Three types of connectors are used for DC fast charging in the North American market: CHAdeMO, Combined Charging System (CCS), and Tesla. However, CHAdeMO is largely being phased out.

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<sup>43</sup> Tesla vehicles require an adapter supplied at purchase to use the J1772 connector.

**Table 2: Types of Chargers**

<b>Charger Type</b>	<b>Typical Input Voltage</b>	<b>Charge Power</b>	<b>Typical Charge Times<sup>44</sup></b>
Level 1 charger	120 volts AC	Up to 1.4 kilowatts	About 4 miles range added per hour at 1.4 kilowatts
Level 2 charger	208/240 volts AC	Up to 19.2 kilowatts	About 32 miles range added per hour at 9.6 kilowatts
DC charger	Varies <sup>45</sup>	Up to 350 kilowatts with the CCS connector  Up to several megawatts with the Megawatt Charging System connector	About 139 miles range added in 10 minutes at 250 kilowatts

Source: CEC Staff

Historically, most chargers installed in California have been Level 2 chargers, which are appropriate for locations with longer dwell times, such as at homes, schools, movie theaters, some retail, and so on. For drivers who mostly make short trips or who cannot easily access a 208/240 volt circuit at home, Level 1 charging may suffice despite longer charge times. Due to the lower power, Level 1 charging offers less flexibility in the charging schedule and presents limited opportunities for load shift and minimizing electricity cost.<sup>46</sup> Further, Level 1 charging is less electrically efficient than Level 2 charging,<sup>47</sup> and data indicate that drivers who discontinued EV ownership and switched back to a gas vehicle were much more likely to have been limited to Level 1 charging at home.<sup>48</sup> For these reasons, CEC will continue emphasizing Level 2 charging in its own investments while acknowledging that Level 1 charging is sufficient for some drivers.

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44 Calculations assume 3.95 miles per kWh for average vehicle efficiency, typical for passenger cars per EPA fuel economy figures.

45 Most DC chargers for passenger cars require a three-phase, 480-volt AC input. Some chargers may also accommodate DC input, particularly those supporting charge powers exceeding several hundred kilowatts and integrated with on-site storage or generation.

46 Harnessing load flexibility to shift electricity consumption will be critical to realizing California’s decarbonization goals and helping drivers save on charging costs. These topics are described in greater detail in Chapter 4.

47 A study found that Level 2 charging is around 90 percent efficient, while Level 1 charging is less than 84 percent efficient. The lower electrical efficiency of Level 1 chargers means that less electricity consumed from the grid is delivered into the vehicle battery. Sears, Justine, David Roberts, Karen Glitman. 2014. ["A comparison of electric vehicle Level 1 and Level 2 charging efficiency."](https://ieeexplore.ieee.org/document/7046253) IEEE. <https://ieeexplore.ieee.org/document/7046253>.

48 A UC Davis analysis found that Level 1 home charging was more strongly correlated with discontinuation of EV ownership than Level 2 home charging. Hardman, Scott, Gil Tal. 2021. ["Why are Some California Consumers Abandoning Electric Vehicle Ownership?"](https://escholarship.org/uc/item/5s738624) National Center for Sustainable Transportation. <https://escholarship.org/uc/item/5s738624>.

DC fast charging can deliver higher charging powers (and therefore shorter charge times) by bypassing the onboard charger of the vehicle and delivering DC electricity directly to the battery. DC charging is widely used in charging situations with short dwell times such as at highway-adjacent stations serving road trippers, grocery stores, or urban stations serving residents without at-home charging. As battery technology improves and more cars are able to accept higher- powered charging at 150 kW and above, DC chargers will be able to support a quicker “in-and-out” experience similar to what gas stations offer today. For medium- and heavy-duty vehicles, the charging power up to several megawatts will sometimes be necessary to charge batteries used in tractors, buses, and other large vehicles in a reasonable amount of time. However, some medium- and heavy-duty vehicles can charge overnight using a high-powered Level 2 charger.

## **Counting Chargers**

### **Light-Duty Electric Vehicle Charger Counts**

California has set specific goals to increase the supply of zero-emission vehicles and plug-in electric vehicle chargers, including 250,000 electric vehicle chargers (of which 10,000 are direct current fast chargers) by 2025. Tracking and counting the number of electric vehicle chargers, specifically shared private chargers, in California have been challenging, as available data and methods to obtain counts do not provide a comprehensive count of all shared private chargers in California.

CEC staff obtained public charger counts from the Alternative Fuels Data Center (AFDC) Station Locator managed by the National Renewable Energy Laboratory (NREL). State law requires station operators or developers to report data on publicly available chargers to NREL. The AFDC Station Locator has been transitioning the counting system to count locations, ports, and connectors since 2019. The AFDC Station Locator now counts the number of ports available to charge a vehicle rather than the number of connectors, as previously counted. Therefore, a charger with two connectors that can only charge one vehicle at a time is considered one for counting chargers. Previously, AFDC would have considered this two.

CEC staff obtained shared private charger counts using voluntary surveys. The surveys were sent to electric vehicle service providers (EVSP) and non-EVSPs (public agencies and electric utilities). The surveys collected counts of shared private chargers (typically found in workplaces, multifamily housing, fleets, and other nonpublic venues) in the state. These counts did not categorize chargers by market segment (workplace, public, fleet, and so forth) or include dedicated private chargers such as those installed for personal use at single-family homes.

CEC staff aggregated, or collected, charger counts from the surveys with public charger counts from the AFDC to estimate the existing stock of chargers in the state. The results were published onto the CEC’s Zero-Emission Vehicle and Infrastructure Statistics Dashboard.<sup>49</sup>

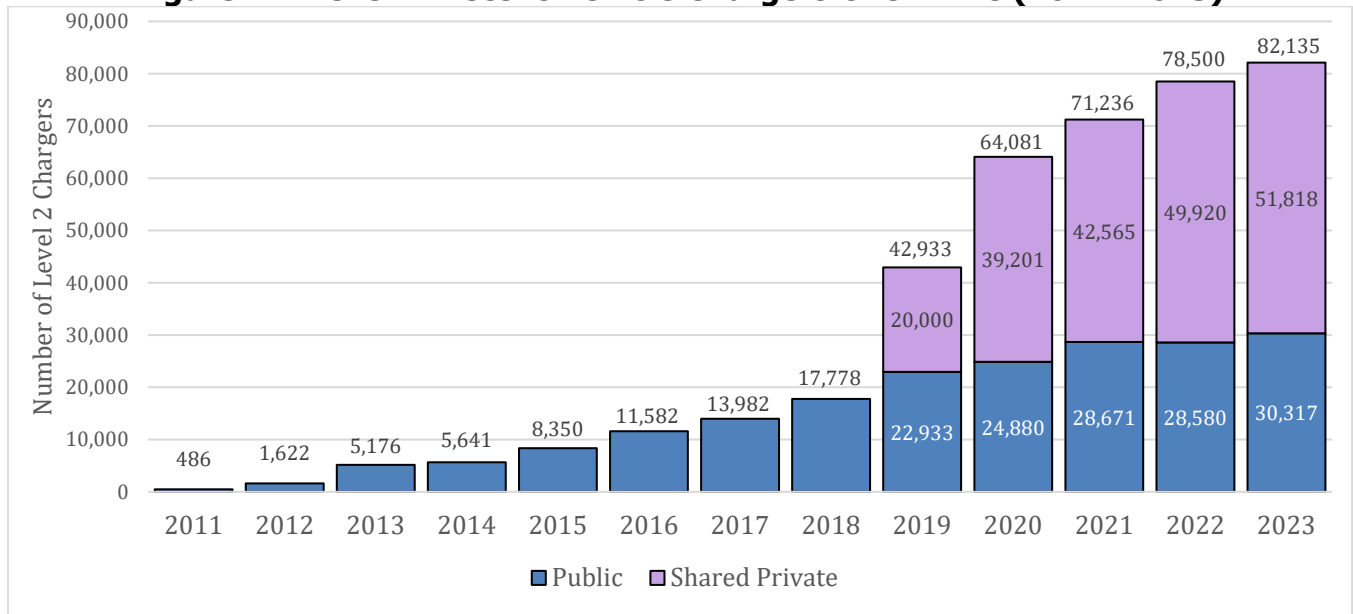
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<sup>49</sup> California Energy Commission. [“Electric Vehicle Chargers in California.”](https://www.energy.ca.gov/zevstats) Data last updated August 22, 2023. Retrieved August 23, 2023, from <https://www.energy.ca.gov/zevstats>.

Because the survey was voluntary, the number of shared private chargers does not represent all the shared private chargers in California.

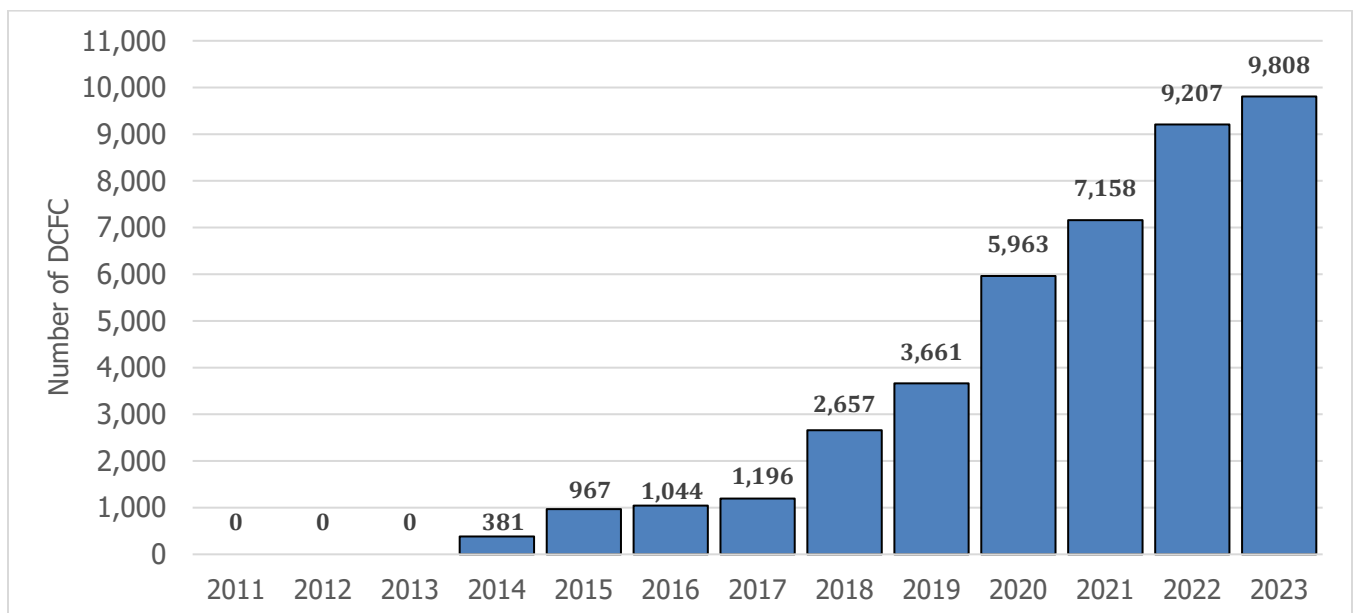
As shown in Figure 12 and 13, as of the middle of 2023, California has approximately 92,000 public and shared private chargers.

**Figure 12: Level 2 Electric Vehicle Chargers Over Time (2011–2023)**



Source: AFDC data and CEC staff analysis

**Figure 13: DC Fast Chargers Over Time (2011–2023)**



**Note: Data for 2013 are available only at the station level and do not provide breakout of Level 2 and DCFC. Although 2013 shows 0 DCFC, some DCFC may be accounted for in Figure 12 above.**

Source: AFDC data and CEC staff analysis

CEC staff is examining tools, including regulatory action, to ensure better data collection. These tools will allow a more accurate accounting of the number of shared private chargers throughout the state.

### **Medium- and Heavy-Duty Vehicle Charging Counts**

CEC staff is exploring how to track charging for medium- and heavy-duty (MDHD) vehicles. CEC staff expects rapid electrification of the state's MDHD vehicles due in part to expanded offerings from manufacturers and new regulations to drive the adoption of zero-emission MDHD vehicles. Tracking charging for these vehicles differ from the light-duty sector due in part to the large variation in vehicle and equipment types and duty cycles. The lack of a unified charging connector standard for MDHD and equipment adds to the complexity of tracking. CEC staff will use tools to collect this information to ensure California can track progress toward state goals.

### **Reliability of Chargers**

The reliability of electric vehicle charging infrastructure (chargers) is a growing concern. CEC staff began investigating the issue in late 2021 and held workshops, met with relevant stakeholders and experts, and conducted technical research on this topic. Staff found that although there is ample anecdotal evidence of industrywide shortcomings in EVSE reliability, there is limited empirical evidence. The CEC has begun to develop reliability-related performance, recordkeeping, and reporting requirements to be included in CEC funding agreements. Staff will work closely with stakeholders to iterate and improve upon these requirements to ensure that chargers funded through these agreements are maintained, reliable, and valuable to the public.

AB 2061 addresses charger reliability and was signed by Governor Newsom on September 16, 2022. This legislation has two key elements. The first is a requirement for the CEC, in coordination with the California Public Utilities Commission (CPUC), to develop uptime recordkeeping and reporting standards for all chargers that received an incentive from a state agency or through a charge on ratepayers. The second requirement is that the CEC assess the uptime of chargers biennially.

For California's investments in EV charging infrastructure to be successful, drivers must be able to charge their electric vehicles reliably. A variety of factors influence whether a consumer will be able to successfully charge their vehicle. Primary among them are the operative state of the charger and related components, the ability for the electric vehicle to successfully communicate with the make and model of the charger, and whether peripheral payment systems can successfully authorize payment. Furthermore, the modeling results in this report assume functioning chargers, and results from the models are used to direct investments and policy decisions. Unreliable chargers would increase the number of chargers needed, affect the efficiency of charger investments, and increase uncertainty around investments and policy decisions regarding charging infrastructure.

This section discusses the steps the CEC has taken to ensure the reliability of chargers that it funds, ways the CEC will work to harmonize existing reliability requirements with those required by AB 2061, and the tools the CEC is developing to assess the uptime of chargers in California.

## Reliability Standards

CEC staff has developed and implemented reliability standards for chargers funded by the CEC. These standards include performance standards, recordkeeping and reporting requirements, and maintenance requirements. AB 2061 requires a formal rulemaking process, which is underway. The standards already developed by staff will be required for CEC solicitations that are released prior to this rulemaking being finalized. They will also guide initial staff proposals for the uptime recordkeeping and reporting requirements, required by AB 2061.

AB 2061 requires the uptime recordkeeping and reporting requirements to be made in coordination with the CPUC. The recordkeeping and reporting requirements of AB 2061 apply to all funded chargers installed after January 1, 2024. Staff has also held workshops to engage with stakeholders and will continue to seek and incorporate public feedback.

## Assessment of Charger Uptime

Beginning January 1, 2025, AB 2061 requires the CEC to conduct a biennial assessment of the uptime of charging station infrastructure. Unlike the recordkeeping and reporting requirements required by AB 2061, this assessment is not limited to publicly funded or ratepayer-funded chargers. The CEC intends to conduct an overall assessment of reliability in the state as outlined in AB 2061. The CEC is considering a range of options to expedite this assessment, including:

1. A field monitoring program to annually test a significant number of chargers in California across disadvantaged, non-disadvantaged,<sup>50</sup> rural, and urban communities.
2. Voluntary data requests to charger network providers and charger operators.
3. A mechanism that would allow consumers to report downed chargers directly to the CEC.
4. Conducting a rulemaking to require all chargers in California to provide uptime and reliability related data to the CEC.

The data from the tools discussed here will allow CEC staff to assess the overall health of the charging network in California. This assessment will give a clearer picture of what parts of the industry are problematic and need addressing, where investments need to be directed, and whether models need additional parameters to account for unreliable chargers. Equally important, the assessment will provide a more transparent view of the success of public investments in electric vehicle charging infrastructure.

## Senate Bill 1000

Senate Bill 1000 (Lara, Chapter 368, Statutes of 2018) requires the CEC, as part of developing the Clean Transportation Program Investment Plan, to assess whether chargers are disproportionately deployed by income level, population density, or geographical area.<sup>51</sup> If the

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<sup>50</sup> Disadvantaged communities defined by CalEnviroScreen 4.0

<sup>51</sup> More [information about the SB 1000 reporting](https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/electric-vehicle-infrastructure) is available at <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/electric-vehicle-infrastructure>

CEC finds that chargers have been disproportionately deployed, the CEC shall use Clean Transportation Program funds and other mechanisms to deploy chargers more proportionately, unless the CEC finds that the disproportionate deployment was reasonable and furthered state energy and environmental policies as articulated by the CEC.

Staff published the first SB 1000 assessment, *California Electric Vehicle Infrastructure Deployment Assessment: Senate Bill 1000 Report*, on December 30, 2020. The report assessed the geographic distribution and density of public Level 2 and direct-current fast chargers by income level and population density. The report concluded that low-income communities,<sup>52</sup> on average, have fewer public chargers per capita than middle- or high-income communities.<sup>53</sup> Public chargers are unevenly distributed across state air districts and counties but correlated with county populations and rates of adoption for plug-in electric vehicles.

CEC staff published the second assessment, *Senate Bill 1000 California Electric Vehicle Infrastructure Deployment Assessment Drive Times to Direct-Current Fast Chargers*, on July 14, 2022. The report assessed drive times from census tract residential population centers to the nearest public fast charging station to identify communities with sparse public fast charging coverage, defined as a drive time of 10 minutes or more. Drive-time analysis allows the identification of charging network gaps that discourage travel within California communities and travel to and from those communities. According to the second report, rural communities have less public fast charging coverage than urban communities<sup>54</sup> (Figure 14). About 88 percent of urban communities are within 10 minutes of a public DC fast charger; in contrast, about 40 percent of rural communities are within 10 minutes of one.

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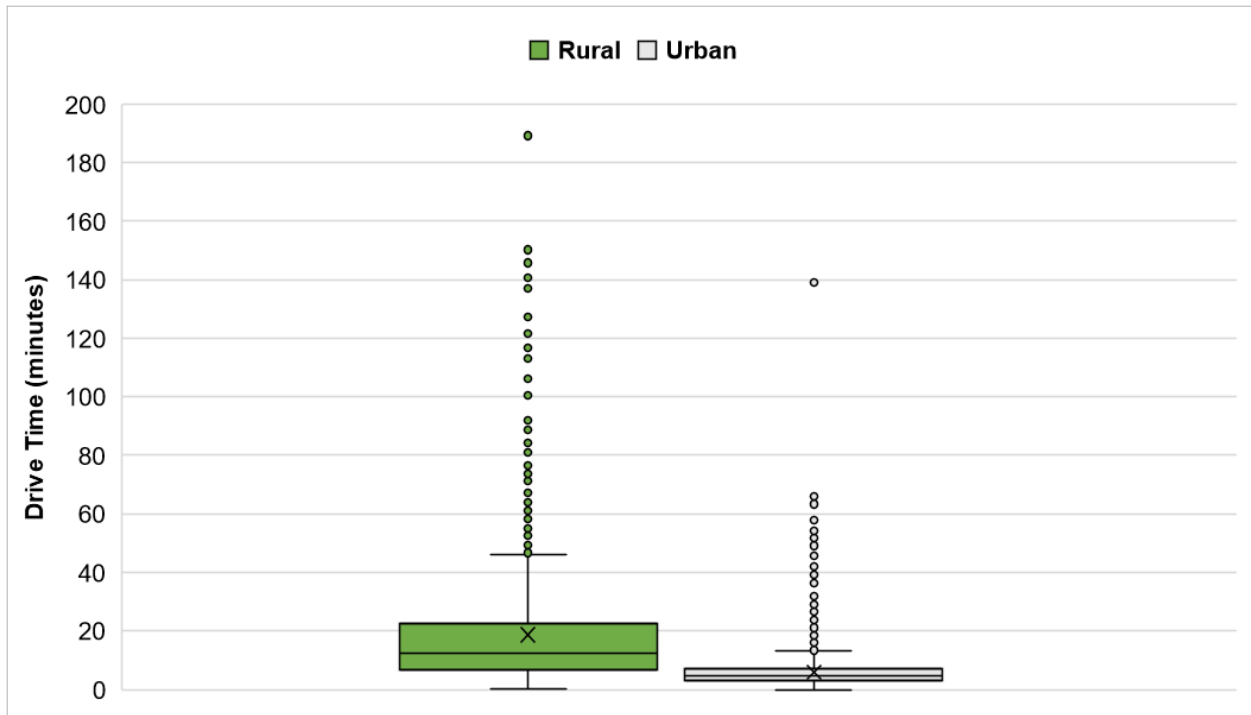
<sup>52</sup> *Low-income communities* are census tracts with median household incomes at or below 80 percent of the statewide median income or with median household incomes at or below the threshold designated as low income by the Department of Housing and Community Development's list of state income limits adopted under Health and Safety Code Section 50093.

<sup>53</sup> *Middle-income communities* are census tracts with median household incomes between 80 to 120 percent of the statewide median income, or with median household incomes between the threshold designated as low- and moderate-income by the Department of Housing and Community Development's list of state income limits adopted under Health and Safety Code Section 50093.

*High-income communities* are census tracts with median household incomes at or above 120 percent of the statewide median income or with median household incomes at or above the threshold designated as moderate-income by the Department of Housing and Community Development's list of state income limits adopted under Health and Safety Code Section 50093.

<sup>54</sup> Rural communities are census tracts where at least 50 percent of the census tract's land area is designated as rural by the U.S. Census Bureau. Urban communities are all other census tracts.

**Figure 14: Drive Time to the Nearest Public DC Fast Charging Station by Urban and Rural Communities**



**Public direct-current fast-charging station coverage is sparser in rural communities than urban communities. Drive times for rural communities range from less than five minutes to more than three hours. Drive times for urban communities range from less than five minutes to more than two hours.<sup>55</sup>**

Source: CEC Staff

About 11 percent of all low-income communities are rural. Low-income rural communities have the least access to public fast charging — 69 percent are 10 minutes or more from a public DC fast charger, which is more than any other group (Table 4).

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<sup>55</sup> Source: California Energy Commission analysis using data from the U.S. Census Bureau 2010 Urban and Rural Classifications, U.S. Department of Energy’s Alternative Fuels Data Center as of February 2, 2021, and California Air Resources Board California Hydrogen Infrastructure Tool roadway data. Underlying data are available on the [SB 1000 webpage](https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/electric-vehicle-infrastructure) at <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/electric-vehicle-infrastructure>.



**Table 3: Drive-Time Ranges by Income Level and Urban or Rural Area**

<b>Income and Community Type</b>	<b>0 to 5 mins</b>	<b>6 to 9 mins</b>	<b>10 plus mins</b>	<b>N/A</b>	<b>Total</b>
<b>Low-Income Rural</b>	16%	14%	69%	1%	100%
<b>Low-Income Urban</b>	61%	28%	11%	0%	100%
<b>Middle-Income Rural</b>	19%	22%	58%	1%	100%
<b>Middle-Income Urban</b>	62%	24%	14%	0%	100%
<b>High-Income Rural</b>	25%	29%	45%	1%	100%
<b>High-Income Urban</b>	54%	32%	14%	0%	100%

**Drive times from rural community population centers are long, especially for low-income rural communities. More than half of all low-income rural communities and more than half of all middle-income rural communities have drive times of 10 minutes or more to a public direct current fast charging station.** <sup>56</sup>

Source: CEC Staff

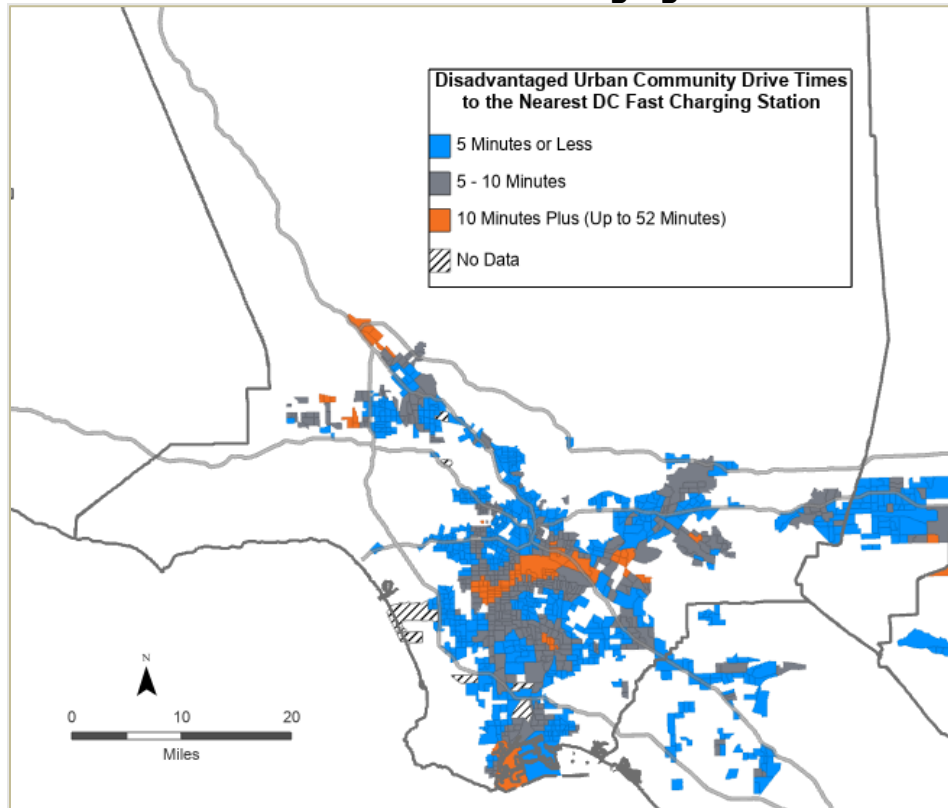
About 92 percent of disadvantaged communities<sup>57</sup> in California are urban and tend to be close to major highways where public direct current fast charging stations are more likely to be found. Despite greater average fast charging station coverage in disadvantaged urban communities than non disadvantaged urban communities, gaps still exist where about 11 percent of disadvantaged urban communities have drive times of 10 minutes or more. Figure 15 shows that several disadvantaged communities in the Los Angeles area have long drives to public fast charging.

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56 Source: California Energy Commission analysis using data from the U.S. Census Bureau 2014-2018 American Community Survey Median Household Income and Average Household Size 5-Year Estimates, California Department of Housing and Community Development 2020 State Income Limits, U.S. Census Bureau 2010 Urban and Rural Classifications, U.S. Department of Energy Alternative Fuels Data Center as of February 2, 2021, and California Air Resources Board California Hydrogen Infrastructure Tool roadway data.

57 Disadvantaged communities are census tracts that score within the top twenty-fifth percentile of the Office of Environmental Health Hazards Assessment’s California Communities Environmental Health Screening Tool (CalEnviroScreen) 3.0 scores, as well as areas of high pollution and low population, such as ports. (At the time of this analysis, disadvantaged community designations under CalEnviroScreen 4.0 had not been finalized.)

**Figure 15: Map of Los Angeles Area Disadvantaged Community Drive Times to the Nearest Public DC Fast Charging Station**



**About 11 percent of disadvantaged urban communities have drive times 10 minutes or more to a public DC fast charging station. Of these, most are between 10 and 30 minutes; 7 percent are between 30 and 46 minutes.<sup>58</sup>**

Source: CEC Staff

Lack of access to charging infrastructure is a significant barrier to EV adoption and use. Despite investments within low-income and disadvantaged communities, charging coverage gaps persist. Solutions to improve charging access will vary and depend on the intersecting characteristics of a community. CEC staff will continue to refine and update the analysis to identify charging network gaps in underserved communities and build charging infrastructure that serves all Californians. The next assessment will build upon the CEC's *Home Charging Access in California* report,<sup>59</sup> published January 7, 2022, and include analysis of existing and potential curbside charging by income level, population density, and geographical area.

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58 Source: California Energy Commission analysis using data from the U.S. Census Bureau 2010 Urban and Rural Classifications, California Environmental Protection Agency disadvantaged community designations using the California Office of Environmental Health Hazard Assessment's CalEnviroScreen 3.0 mapping tool, U.S. Department of Energy Alternative Fuels Data Center as of February 2, 2021, and California Air Resources Board California Hydrogen Infrastructure Tool roadway data. At the time of this analysis, urban and rural classifications from the 2020 census had not yet been finalized.

59 Alexander, Matt. January 2022. [Home Charging Access in California](https://www.energy.ca.gov/publications/2022/home-charging-access-california). California Energy Commission. Publication Number: CEC-600-2022-021. Available at <https://www.energy.ca.gov/publications/2022/home-charging-access-california>.

# CHAPTER 4:

## Modeling California Charging Needs

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This chapter explores the number of chargers that will be needed to meet California’s ZEV goals through 2035. The modeling results presented here project that California will need 1.01 million public and shared private chargers, including 39,000 DCFC chargers, to support 7.1 million light-duty plug-in electric vehicles in 2030, and 2.11 million chargers, including 83,000 DCFC chargers, to support 15.2 million light-duty plug-in electric vehicles in 2035. To support medium- and heavy-duty plug-in electric vehicles, California will need 109,000 depot chargers and 5,500 public chargers for 155,000 vehicles in 2030, and 256,000 depot chargers and 8,500 public chargers for 377,000 vehicles in 2035. The rest of this chapter describes the models and assumptions used to produce these results and identifies the types and locations of chargers that will be key to allowing the state to meet its ZEV goals.

### Modeling Overview

The goal of this analysis is to identify the number and types of PEV chargers that will be needed for the state to meet ZEV adoption targets from now through 2035. These results are intended to help direct statewide and local planning to the most beneficial charging solutions. In doing this, it is important to improve equity and decrease costs, identify charging strategies that support grid health, and ensure that the expansion of charging infrastructure is well-planned and well-integrated with the grid. While a statewide analysis is important, it does not provide a single solution that will be optimal at every location and for every use case. Considering local land use, grid capacity, and at- and near-home charging is necessary to design a system that is usable, affordable, and equitable.

Over the last year, state agencies have formalized many of the state’s ambitious ZEV adoption, climate, and air quality goals. The modeling results presented in this chapter are built around scenarios that comply with the Advanced Clean Cars (ACC) I and II, Advanced Clean Fleets (ACF), and Advanced Clean Trucks (ACT) regulations. For each of the main light-duty and medium- and heavy-duty infrastructure analyses, CEC staff presents a scenario based on CARB’s projections for the impact of its regulations and the Additional Achievable Transportation Electrification 3 (AATE3) scenario developed by the CEC’s Energy Assessments Division for the Integrated Energy Policy Report.

To quantify California’s charging needs at the statewide and local levels, the CEC has partnered with the National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, and the University of California, Davis, to develop quantitative analysis tools covering various vehicle classes, use cases, and local conditions. The models presented in this section build and improve on the models used for the first AB 2127 assessment. Table 4 summarizes the models included in this report.

**Table 4: Summary of CEC Charging Infrastructure Quantitative Analyses**

Model	Description
Electric Vehicle Infrastructure Projection Tool (EVI-Pro 3)	Projects L1, L2, and DC fast charging infrastructure needs to enable electrified routine/intraregional (under 100 miles) travel for vehicles with a gross vehicle weight rating (GVWR) of 10,000 pounds or less.
Electric Vehicle Infrastructure for Road Trips (EVI-RoadTrip)	Projects DC fast charging infrastructure needs to enable electrified long-distance/interregional (at least 100 miles) travel for vehicles with a gross vehicle weight rating (GVWR) of 10,000 pounds or less.
Widespread Infrastructure for Ride-Hailing PEV Deployment (WIRED)	Projects additional charging infrastructure needs to enable electrification of ride-hailing services via transportation network companies.
Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operation, and Deployment (HEVI-LOAD)	Projects charging infrastructure needs to enable electrification of on-road medium- and heavy-duty vehicles with a GVWR of 10,001 pounds and above.
EVSE Deployment and Grid Evaluation (EDGE) Model	Geospatially analyzes to track local grid capacity, travel demand, and vehicle load.

Source: CEC staff

### **EVI-Pro 3**

The Electric Vehicle Infrastructure Projection tool (EVI-Pro 3) projects the number, locations, and types of chargers required to meet the needs of California’s light-duty PEV drivers for intraregional trips (under 100 miles). EVI-Pro 3 uses travel survey data, vehicle characteristics, and charging costs to estimate the charging demand from travel by light-duty PEVs and design a supply of shared Level 1, Level 2, and DC fast chargers capable of meeting the charging needs without requiring significant changes to people’s daily schedules.

The original EVI-Pro 1 model, developed in 2016 through a collaboration between the CEC and the National Renewable Energy Laboratory (NREL), set the standard for charging infrastructure assessments in California<sup>60</sup> and across the United States.<sup>61</sup> The EVI-Pro 2 model built on this foundation, incorporating evolving technology and market conditions, and was

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60 Bedir, Abdulkadir, Noel Crisostomo, Jennifer Allen, Eric Wood, and Clément Rames. 2018. [California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025](#). California Energy Commission. Publication Number: CEC-600-2018-001. <https://efiling.energy.ca.gov/getdocument.aspx?tn=222986>.

61 [Electric Vehicle Infrastructure Projection Tool \(EVI-Pro\) Lite](#). U.S. Department of Energy Alternative Fuels Data Center, November 30, 2020. <https://afdc.energy.gov/evi-pro-lite>.

used to estimate the charging infrastructure needed to support nearly 8 million ZEVs by 2030 as part of the first AB 2127 assessment published in 2021.<sup>62</sup>

### Changes to the EVI-Pro 3 Model

EVI-Pro 3 has been upgraded to provide a more realistic depiction of charging behavior, deliver results at a higher level of geographic detail, and address changes in PEV ownership and technology from now to 2035.

- **Heterogeneous depiction of charging behavior:** Simulated drivers have a range of preferences for how to charge their vehicles rather than behaving homogeneously. Model simulates a wider range of activity types.
- **Level of detail:** The model produces separate charger counts for public and shared private chargers at commute destinations of various types, based on the proportion of California's population working in different economic sectors, according to the California Employment Development Department.<sup>63</sup> The model estimates infrastructure needs at the level of traffic analysis zones (TAZs),<sup>64</sup> which are used for transportation planning in the California Statewide Travel Demand Model. Because EVI-Pro 3 produces infrastructure estimates at the TAZ level, its outputs can be harmonized with those of the RoadTrip model, which is used to estimate the amount of infrastructure needed to support long distance travel.
- **Changes in PEV ownership and technology:** The model simulates a wider range of vehicle body styles and electric ranges. The model incorporates higher-powered AC and DC charging types and produces DC fast charger needs broken down by power level (50, 150, 250, and 350 kW).

The decision to split charging at commute destinations into public and shared private charging and differentiate by workplace type is particularly worth highlighting. In addition to providing a more complete depiction of charging needs, this change allowed CEC staff and NREL to compare the results of the model with the findings of the CEC's Counting Chargers effort.

In the first AB 2127 Assessment, EVI-Pro 2 provided charger needs estimates separately for four types of L2 charging: home (single-family), home (multifamily), work, and public. Work charging was defined by the activity done while charging, not the location type. Because many potential locations of public charging (shopping centers, downtowns, entertainment

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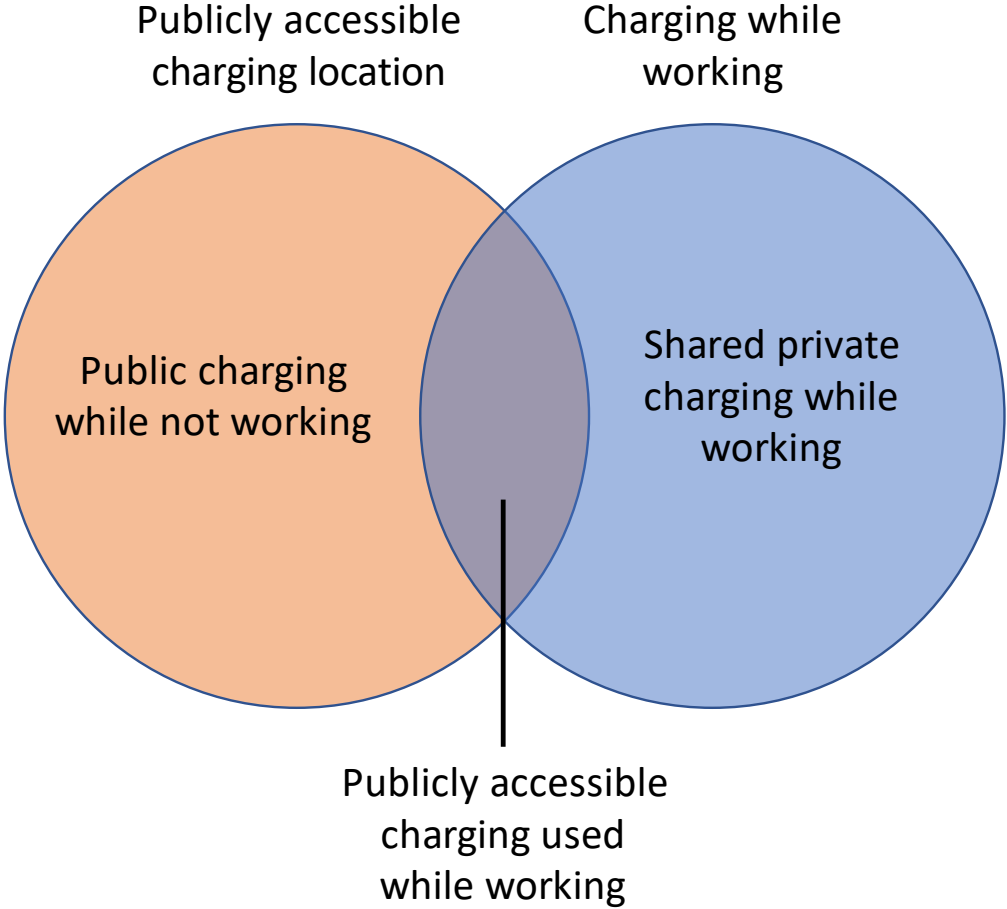
<sup>62</sup> Alexander, Matt, Noel Crisostomo, Wendell Krell, Jeffrey Lu, and Raja Ramesh. July 2021. [Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment: Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030 – Commission Report](https://efiling.energy.ca.gov/getdocument.aspx?tn=238853). California Energy Commission. Publication Number: CEC-600-2021-001-CMR. <https://efiling.energy.ca.gov/getdocument.aspx?tn=238853>.

<sup>63</sup> California Employment Development Department. 2023. ["Industry Employment & Labor Force March 2022 Benchmark."](https://labormarketinfo.edd.ca.gov/data/employment-projections.html) <https://labormarketinfo.edd.ca.gov/data/employment-projections.html>.

<sup>64</sup> Traffic Analysis Zones (TAZs) are geographic units used in transportation planning, including in the transportation models that are used as data sources for the charging models presented in this report. Transportation models use TAZs as origin and destination locations rather than modeling trips between all possible pairs of locations. Different transportation models use different sizes of TAZs depending on the desired complexity of the model, but in general, TAZs are smaller in densely developed areas and larger in sparsely developed areas.

destinations, and so forth) are also work locations, EVI-Pro 3 has been updated to provide results both by location/activity type and access type. The reasoning behind this change is that while some charging locations serve only specific activities and users, other charging locations can serve a wide range of potential users. Figure 16 shows the intersection of publicly accessible charging with charging while working. The left circle depicts all publicly accessible charging; the right circle depicts charging while working. The intersection represents when people use public chargers while working. Publicly accessible charging locations that people can use to charge their vehicles while they are at work include parking garages in downtowns, retail establishments whose employees use chargers while working, and other publicly accessible locations.

**Figure 16: Venn Diagram of the Relationship Between Publicly Accessible Charging and Charging While at Work**



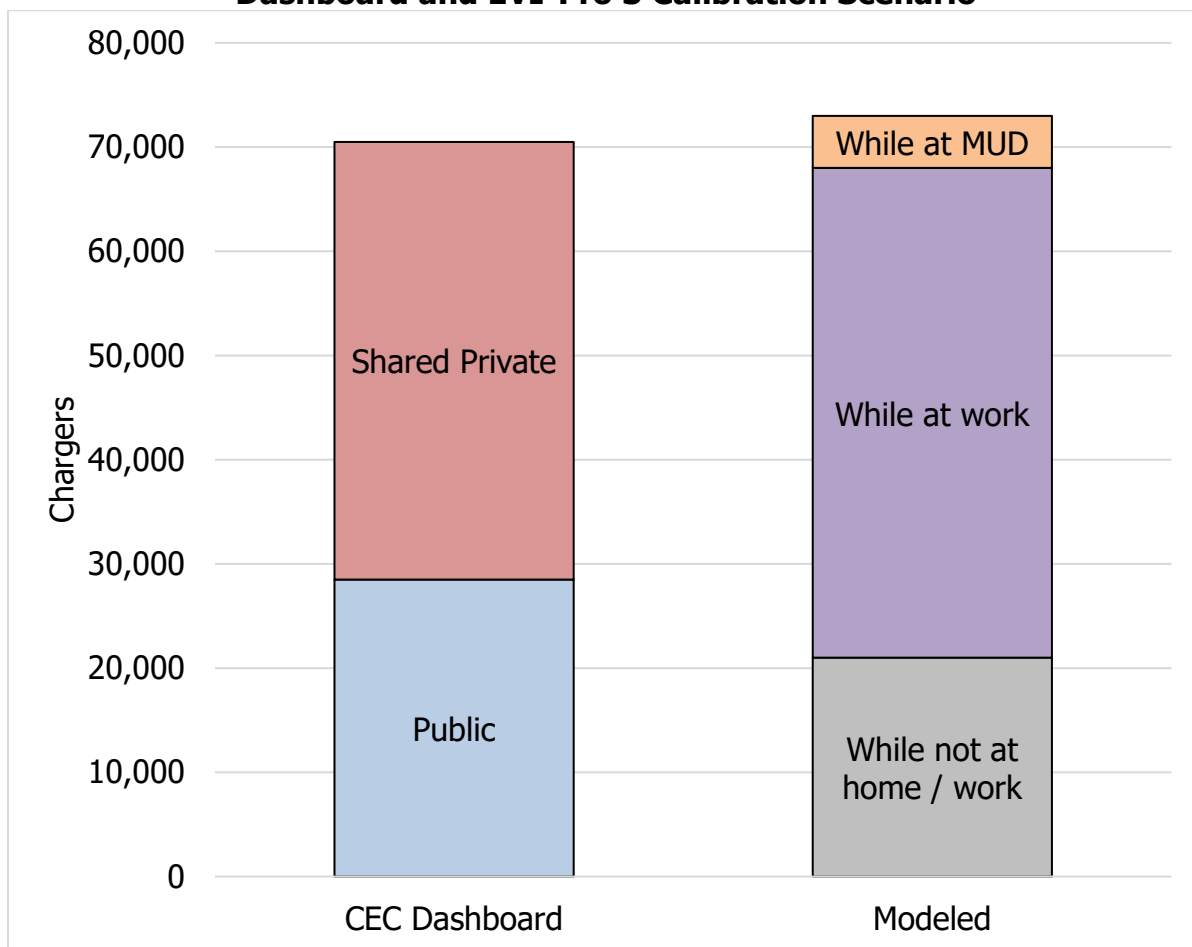
**While some people work at locations where shared private charging makes sense, many people work at businesses and location types where publicly accessible chargers shared with customers or workers at nearby businesses could meet their needs.**

Source: CEC

While early market workplace charging may have catered to commuters working in office jobs with private parking lots, characterizing workplace charging in proportion to the occupations of all Californians will make this category of publicly accessible workplace charging grow and better reflect the needs for wider vehicle adoption.

This change also has the benefit of better harmonizing with the CEC’s Counting Chargers effort, which classifies chargers as either public access or shared-private access. To develop this aspect of the model, CEC staff and NREL developed a validation scenario to compare the estimate of charging needs of the EVI-Pro 3 for 2021 with the number of chargers identified by counting chargers, the results of which are shown in Figure 17. This analysis sought to understand the link between the charger access categories included in Counting Chargers and the behavioral categories used by EVI-Pro 3 and check that the model was producing reasonable results. Charging at multifamily housing (“While at MUD” in the figure) likely relies on shared private chargers accessible only to the residents of a building. Charging while at retail, entertainment, or other locations relies primarily on public chargers. Charging while at work can use either kind of charger, depending on work location. This analysis suggests that charging while at work corresponds mostly to shared private charging locations, but this may change as PEV ownership expands.

**Figure 17: Shared Charging Comparison Between CEC Counting Chargers Dashboard and EVI-Pro 3 Calibration Scenario**



**The EVI-Pro 3 back casting exercise attempted to link existing shared charging infrastructure to modeled activity locations. This exercise showed that while most charging “while at work” likely uses shared private chargers, other charging uses public chargers.**

Source: National Renewable Energy Lab

### Light-Duty PEV Adoption Scenarios

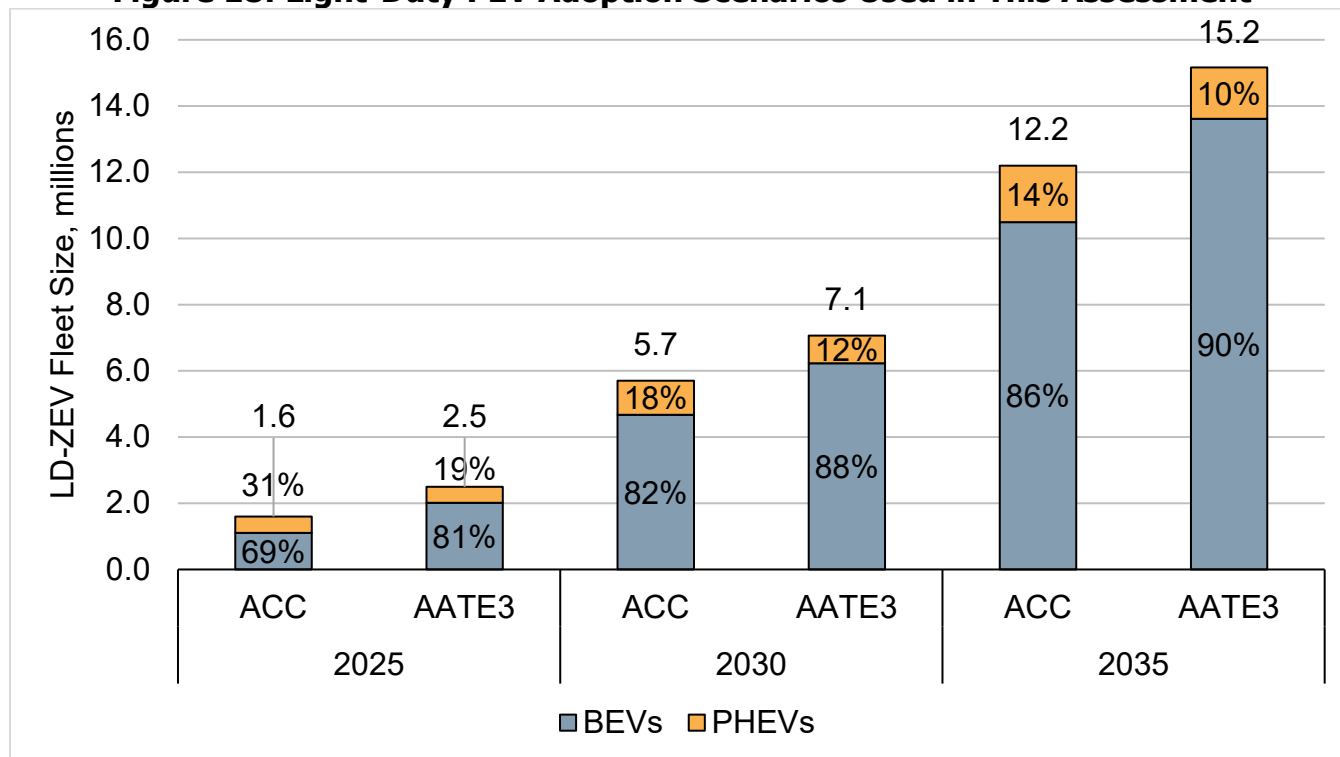
California has made significant progress toward electrifying light-duty transportation since the publication of the first AB 2127 Assessment in 2021. There are more than a million light-duty ZEVs on the roads in California, and ZEVs made up nearly 19 percent of new light-duty vehicles sold in the state in 2022. In addition, the Advanced Clean Cars II regulation puts California on a path to reaching 100 percent light-duty ZEV sales by 2035.

Because of this progress, CEC staff and NREL were able to develop a narrower range of EV adoption scenarios for EVI-Pro 3 than in the first assessment. The first assessment included three main scenarios for light-duty ZEV adoption: the CEC's IEPR low forecast, the CEC's IEPR high forecast and CARB's Mobile Source Strategy. CARB's Mobile Source Strategy was included to project the necessary vehicle population to meet state air quality and climate policy goals, including 100 percent zero-emission new passenger car sales by 2035 per Executive Order N-79-20. The IEPR low forecast included 1.9 million ZEVs, the IEPR high forecast included 5.0 million ZEVs, and the Mobile Source Strategy included 8 million vehicles. PEVs made up 95 to 96 percent of the light duty ZEV population in each scenario. In this assessment, CEC staff presents two scenarios for light-duty vehicles: CARB's projections of the minimum PEV fleet size resulting from the Advanced Clean Cars II regulations and the CEC's Energy Assessments Division Additional Achievable Transportation Electrification 3 (AATE3) scenario developed for the 2022 Integrated Energy Policy Report (IEPR). The scenario derived from CARB has a PEV population of 5.7 million in 2030, and the AATE3 scenario has a PEV population of 7.1 million in 2030.

The AATE3 scenario is treated as the primary scenario in this report because this scenario allows staff to account for the potential needs of a larger fleet if PEV adoption continues to accelerate, whereas the ACC scenario represents the minimum possible impact of the ACC II regulation. The AATE3 scenario complies with the ACC II regulation but is based on a larger total light-duty vehicle (LDV) population and assumes higher annual LDV sales and an overall greater trend toward BEVs. Figure 18 shows the light-duty CARB scenario as ACC II and the CEC scenario as AATE3 for BEVs and PHEVs (including both plug-in vehicles that have an internal combustion engine and a small number of plug-in vehicles that also use hydrogen fuel cell technology).



**Figure 18: Light-Duty PEV Adoption Scenarios Used in This Assessment**



**This assessment uses two scenarios for the number of light-duty PEVs in California in 2025, 2030, and 2035. The lower ACC scenario corresponds to CARB’s projections of the minimum PEV fleet size resulting from the Advanced Clean Cars regulations. The higher AATE3 scenario corresponds to the CEC’s Energy Assessments Division’s AATE3 scenario, which complies with the Advanced Clean Cars regulations but assumes a larger total fleet size and a higher proportion of BEVs in all years.**

Source: CEC staff

In addition to updating the ZEV fleet size, the CEC staff and NREL have made several changes to other key modeling assumptions for EVI-Pro 3 to bring the model up to date:

- Hydrogen fuel cell electric vehicles (FCEVs) are expected to play a smaller role in the electrification of light-duty vehicles compared to medium- and heavy-duty vehicles. The adoption scenario used in this assessment assume that FCEVs will make up between 1 percent and 1.4 percent of the light-duty ZEV fleet from 2023 to 2035.
- A small number of plug-in FCEVs are included in the AATE3 scenario starting in 2024. By 2035, plug-in FCEVs will make up roughly one-quarter of FCEVs and 0.27 percent of all ZEVs. Plug-in hydrogen fuel cell vehicles will be assumed to behave the same as PHEVs with internal combustion engines in EVI-Pro 3.
- BEVs will make up a larger share of light-duty ZEVs than anticipated. This change is due both to ACCII capping PHEV sales at a lower value than was assumed in scenarios for the first AB 2127 report and a shift in the market away from PHEVs and short-range BEVs toward long-range BEVs.

- Access to charging at home will decrease as the PEV fleet increases in size. CEC staff derives this assumption from a CEC study based on a charging access survey conducted by NREL.<sup>65</sup>
- EVI-Pro 3 uses updated vehicle ranges and energy efficiency ratings.

As in the first assessment, this assessment includes “alternative future” scenarios to address the uncertainties inherent in projecting infrastructure needs a decade in the future. Each of these scenarios modifies the inputs and assumptions of the 2030 AATE3 scenario to generate a new set of network infrastructure and load profile results.

Compared to the adoption scenarios used in the first AB 2127 assessment, this scenario includes slightly fewer total ZEVs but a larger share of BEVs, particularly long-range BEVs that can accept higher charging speeds. Table 5 outlines critical modeling differences between EVI-Pro 1, EVI-Pro 2, and EVI-Pro 3. Appendix B provides more details on parameters and inputs used in EVI-Pro 3 for the baseline scenarios and alternative future scenarios.

**Table 5: Comparison of Primary Input Parameters for EVI-Pro 1-3**

Input	EVI-Pro 1	EVI-Pro 2	EVI-Pro 3
<b>ZEV Population</b>	1.5 million in 2025	8 million in 2030	7.1 million in 2030 and 15.3 million in 2035
<b>PEV (BEVs + PHEVs) Population</b>	1.25 million in 2025	7.5 million in 2030	7.1 million in 2030 and 15.2 million in 2035
<b>Within ZEVs, PEV / Hydrogen Fuel Cell Electric Vehicle Split</b>	87%/13% in 2025	95%/5% in 2030	99%/1% in 2030 and 2035
<b>Within PEVs, PHEV / BEV Split</b>	45%/55% in 2025	33%/67% in 2025 30%/70% in 2030	19%/81% in 2025 12%/88% in 2030 10%/90% in 2035
<b>PEVs w/ Home Charging</b>	92% in 2025	67% in 2030	78% in 2025 66% in 2030 60% in 2035
<b>Time-of-Use Rate Participation</b>	Not included	67% in 2030	50% in 2025 100% in 2030 and 2035

Source: CEC and National Renewable Energy Laboratory

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65 Alexander, Matt. January 2022. [Home Charging Access in California](https://www.energy.ca.gov/publications/2022/home-charging-access-california). California Energy Commission. Publication Number: CEC-600-2022-021. Available at <https://www.energy.ca.gov/publications/2022/home-charging-access-california>.

## Charging Infrastructure Needs

EVI-Pro 3 projects that to support routine intraregional travel by 7.1 million BEVs and PHEVs in 2030, California will need to install 313,000 shared private L1 and L2 chargers at multifamily housing sites, 656,000 public and shared private L2 chargers at commute destinations and other activity locations, and 32,800 DCFC chargers.<sup>66</sup>

To support 15.2 million light-duty BEVs and PHEVs in 2035, California will need to install 577,000 shared private L1 and L2 chargers at multifamily housing sites, 1.45 million public and shared private L2 chargers at commute destinations and other activity locations, and 72,800 public DCFC chargers<sup>67</sup> across a range of location types.

Compared to the first AB 2127 assessment Mobile Source Strategy scenario, which included 7.5 million light-duty PEVs in 2030, the AATE3 scenario for 7.1 million PEVs in 2030 has slightly lower total L1 and L2 charger counts and slightly higher DCFC charger counts. This change reflects changes in the adoption scenario and model assumptions:

- EVI-Pro 3 projects that California will need about 4 percent fewer chargers at multifamily housing sites (313,000 chargers compared to 327,000). This number generally matches the change between the AATE3 scenario, which contains 7.1 million PEVs, and the Mobile Source Strategy scenario, which contains 7.5 million PEVs.
- EVI-Pro 3 projects a need for about 18 percent fewer total L2 chargers at work and public sites (656,000 compared to 797,000). This change can be attributed to the decline in totals PEVs and the shift away from PHEVs, which used large amounts of L2 away from home in the first assessment, to long-range BEVs, which need to charge less often away from home and often use DCFC when they do.
- EVI-Pro 3 projects a need for 7 percent more DC fast chargers (32,800 compared to 30,600). This change mirrors the change in L2 charging away from home — more BEVs means more demand for high-speed charging and less demand for low-speed charging away from home.

Table 6 shows the total numbers of Level 1, Level 2, and DC fast chargers needed in 2025, 2030, and 2035 under the AATE3 scenario. EVI-Pro 3 produces a range of values for each scenario to provide a sense of the uncertainty about future travel behavior and charging needs. The text, tables, and figures in the body of the report are based on the average value for each scenario. Appendix D contains high and low values for statewide charger counts, annual results for the AATE3 scenario from 2025 to 2035, and county-by-county results for the baseline scenario and ACC II scenarios.

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66 This number is the count of DCFC chargers needed to support routine/intraregional travel by BEVs in 2030. DCFC counts for long-distance/interregional travel and transportation network company vehicles are provided in the sections on EVI-RoadTrip and WIRED, respectively, and the section titled "Combined DC Fast Charging Needs for Light-Duty Vehicles" provides combined results for all three models.

67 As with the DCFC count for 2030, this number is for routine/intraregional travel only. Other DCFC needs are covered in later sections.

**Table 6: Total Number of Chargers for Routine Intraregional Travel by Privately Owned Light-Duty Vehicles in 2025, 2030, and 2035 Under AATE3 Scenario**

<b>Category and Location</b>	<b>Plug Type</b>	<b>2025</b>	<b>2030</b>	<b>2035</b>
<b>Single-Family Housing</b>	<b>Level 1</b>	703,993	1,373,064	2,328,896
<b>Single-Family Housing</b>	<b>Level 2</b>	1,078,200	2,728,362	5,717,384
<b>Multifamily Housing</b>	<b>Level 1</b>	21,738	121,975	196,388
<b>Multifamily Housing</b>	<b>Level 2</b>	26,284	191,346	380,628
<b>Shared Private (While at Work)</b>	<b>Level 2</b>	116,227	287,713	587,384
<b>Public (While at Work)</b>	<b>Level 2</b>	40,837	141,710	391,590
<b>Public (Nonwork Activities)</b>	<b>Level 2</b>	36,899	226,761	474,732
<b>Total Public and Shared Private</b>	<b>Level 1 and Level 2</b>	241,984	969,505	2,030,721
<b>Total for Routine Intraregional Travel</b>	<b>DCFC</b>	12,343	32,831	72,768

Source: National Renewable Energy Lab

Table 7 breaks down the number of L2 chargers at nonhome locations for work and nonwork activities. Work chargers are allocated to three location types based on the proportion of California’s population working in different economic sectors. Chargers associated with nonwork activities are allocated to “Retail” and “Other” locations. As PEV adoption expands, an increasing share of workplace charging events will take place at locations like retail and entertainment establishments where public charging may be able to serve workers and customers.

**Table 7: Number of Public and Shared Private Level 2 Chargers Serving Work and Nonwork Charging Events Away From Home Under the AATE3 Scenario**

Access	Location	2025	2030	2035
Shared Private	Office	102,091	206,123	293,692
Shared Private	Retail	6,283	34,354	129,225
Shared Private	Other	7,853	47,237	164,468
Public	Office	31,413	85,885	195,795
Public	Retail	23,161	139,146	323,516
Public	Other	23,161	143,440	347,011

Source: National Renewable Energy Lab

Table 8 shows the number of DCFC chargers needed by power level. Because DCFC charging events usually take place during trips rather than at the destination, EVI-Pro 3 assumes drivers prefer speed and assign vehicles to the highest-powered charger that their vehicles can accept. Improving vehicle technology means that more vehicles will be able to accept higher-powered charging, and the declining number of lower-powered (150 kW or less) DC fast chargers after 2025 reflects an increased share of vehicles able to accept higher charging speeds, rather than an absolute decreased demand for lower-powered DCFC. Demand for lower-powered chargers may persist if they offer less costly charging than higher-powered DC fast chargers and if some drivers do not require the extra charging speed.

EVI-Pro 3 estimates the number of DCFC chargers to support routine intraregional travel by BEVs. However, the total number of DCFC chargers needed in California also includes the results of the EVI-RoadTrip and WIRED models, which estimated DCFC needs for long-distance travel and transportation network company vehicles, respectively. DCFC needs from EVI-RoadTrip, WIRED, and the combination of all three models are covered later in this chapter.

**Table 8: Number of DC Fast Chargers of Different Power Levels Needed to Support Routine Intraregional Travel Under the AATE3 Scenario**

DCFC Power Level	2025	2030	2035
<b>150 kW or less</b>	2,482	4,268	4,910
<b>250 kW</b>	5,429	10,731	21,462
<b>350 kW</b>	4,433	17,833	46,396

Source: National Renewable Energy Lab

### **Grid-Friendly Charging**

As PEV ownership expands, vehicle charging will comprise an increasing share of California’s energy demand. Coordinated investments in the grid and charging infrastructure will support charging and community needs locally and statewide. EVI-Pro 3 produces load curves covering all charging of privately owned light-duty PEVs based on the assumption that drivers will

generally choose the lowest-cost, most convenient charging option that works with their schedule. Under this assumption, charging at home is the first choice when available, followed by L2 charging at work, L2 charging at other locations, and then DCFC. Some drivers are assumed to prefer DCFC over other nonhome charging locations. Appendix C identifies the full mix of charging behaviors for drivers in this model.

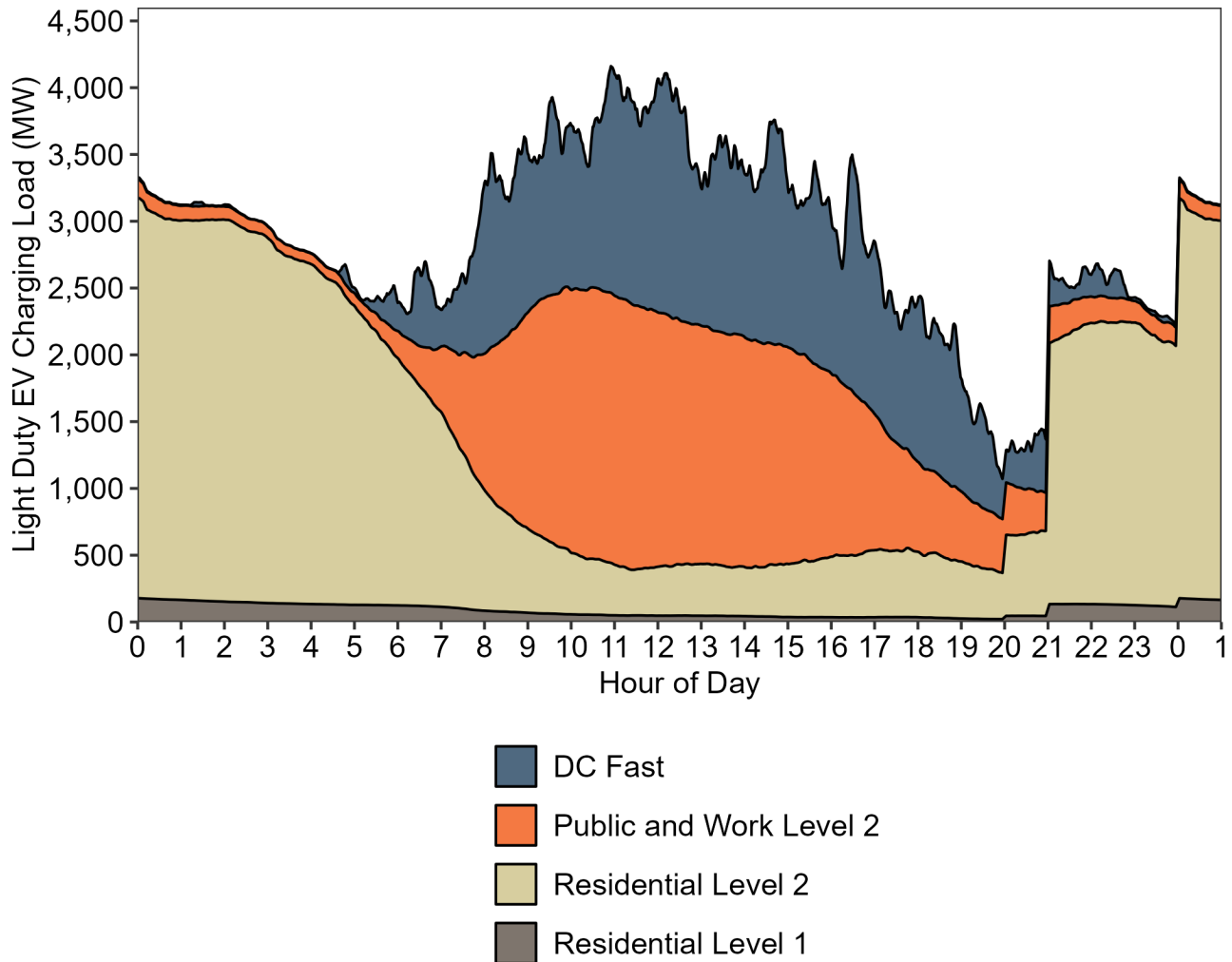
Most PEV charging is done at home, so optimizing home charging is particularly important for the grid. Because home charging has the most flexible schedule, some can be adjusted to integrate with the grid and make the best use of clean energy. The primary scenario produced by EVI-Pro 3 assumes that most people will seek to charge their vehicles at less expensive times of day, taking advantage of whatever time-of-use (TOU) rates apply in their region.

Figure 19 shows the load curve for light-duty charging on a typical weekday in 2030. In this scenario, charging is split into three groups: some drivers start charging after the peak period ends for their region, some wait until the lowest-cost period starts, and some delay charging until later in the night, leaving just enough time to ensure that their vehicle will be sufficiently charged by the time they leave home. Because all drivers in the first two behavior groups plan to start charging at the same time in each region, their behavior causes “timer spikes,”<sup>68</sup> where many vehicles in an area start charging simultaneously, causing a sudden increase in energy demand. Under this scenario, the timer spikes are smaller than the single spike at midnight presented in the first AB 2127 assessment, and the overall peak of charging is in midday.

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68 The CPUC’s proposed decision concerning implementation of SB 676 identifies EV participation in demand response as a near-term policy action with broad support, and notes that “EV charging load’s demand responsiveness could be a source of local or system capacity ... through either a tariff-based mechanism or by allowing EVs to bid into resource adequacy markets.” CPUC. (November 2020). “[Proposed Decision Concerning Implementation of Senate Bill 676 and Vehicle-To-Grid Integration Strategies](https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M350/K963/350963223.PDF),” <https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M350/K963/350963223.PDF>.

**Figure 19: EVI-Pro 3 Load Curve From PEV Charging in 2030 Under Primary Scenario**



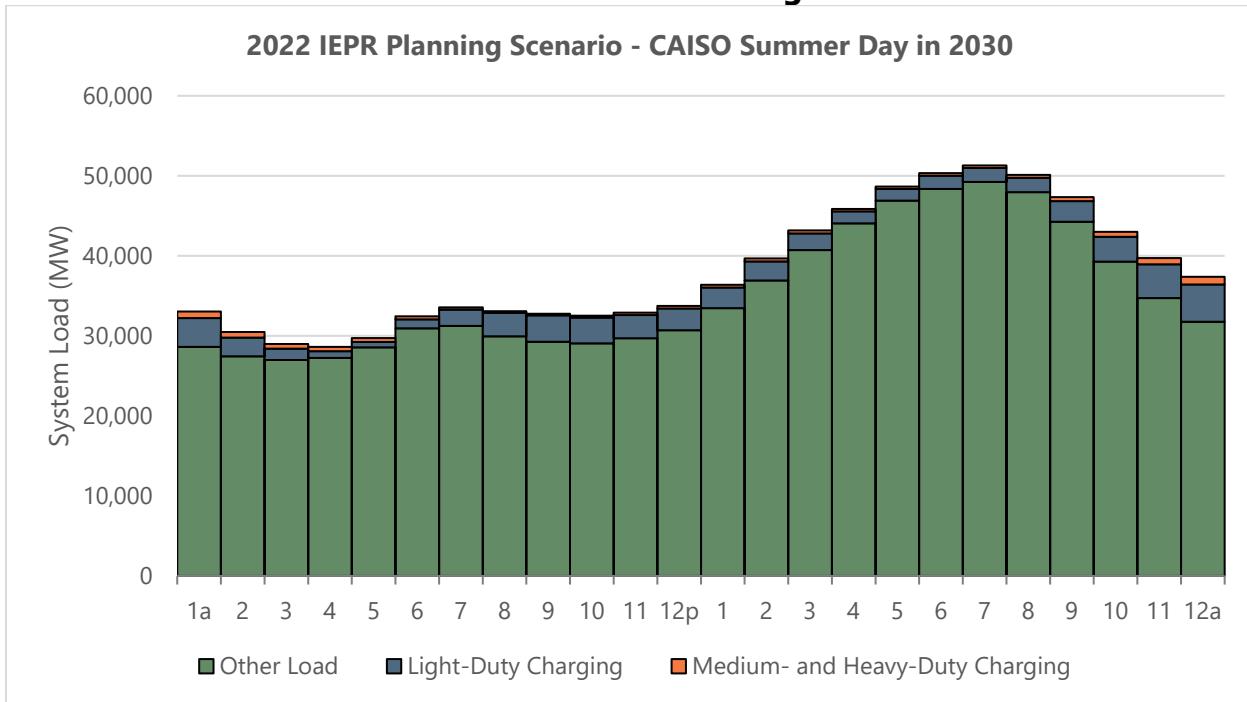
**Under the baseline scenario, TOU rates have the effect of spreading home charging throughout the evening and night. The overall peak charging load occurs in midday when many cars are charging at commute destinations and DC fast charging is near the peak.**

Source: CEC and NREL

To explore the effects of different home charging patterns on energy use, CEC staff and NREL developed alternative future scenarios specifically targeted at home charging. As light-duty PEV ownership increases, managing charging loads to adapt to changes in the fleet of PEVs will be increasingly important for grid planning and investments. Appendix E contains load curves for all alternative future scenarios.

A systemwide load analysis as part of the 2022 IEPR Planning Scenario, which incorporates the AATE 3 scenario used in this report, anticipates vehicle charging to account for less than 10 percent of daily average load and less than 5 percent of load peak in 2030. This systemwide load analysis anticipates that vehicle charging will account for less than 20 percent of daily average load and less than 10 percent of load at peak in 2035. Figure 20 shows the total systemwide load from all sources on a summer day in 2030 under the IEPR planning scenario.

**Figure 20: Systemwide Load From All Sources, Including Vehicle Charging, in 2030 Under the IEPR Planning Scenario**



Source: CEC

### Areas of Focus

As PEVs make up a larger share of light-duty vehicles on the road, it will be increasingly important to focus charging investments in the areas that are most grid-friendly and cost-effective while ensuring that the transition to PEVs is equitable and convenient for drivers. To support this analysis, CEC staff and NREL developed “alternative futures” scenarios for EVI-Pro 3 built around specific changes to PEV charging priorities or policy, as was done in the first AB 2127 assessment. This section describes two of those scenarios and summarizes the remaining scenarios. Appendix E contains a list of assumptions and complete results from all alternative futures scenarios developed for this report.

### Alternatives to Conventional Home Charging

As highlighted in the CEC’s *Zero-Emission Vehicle Infrastructure Plan*, maximizing access to home charging is a CEC priority.<sup>69</sup> Charging at home can be the cheapest and most convenient option for fueling a PEV, but it may not be an option for all households. A CEC analysis based on a survey conducted by NREL found that even under the most optimistic scenario, no more than 70 percent of vehicles would have access to charging at home. Furthermore, home charging access is particularly challenging for households in multifamily housing or with many

69 Lopez, Thanh and Madison Jarvis. 2022. [Zero-Emission Vehicle Infrastructure Plan \(ZIP\)](https://www.energy.ca.gov/sites/default/files/2022-12/600-2022-054-REV.pdf). California Energy Commission. Publication Number: CEC-600-2022-054-REV. <https://www.energy.ca.gov/sites/default/files/2022-12/600-2022-054-REV.pdf>.



vehicles that require charging.<sup>70</sup> For the state to meet its emissions goals and ensure that the transition to PEVs is equitable, there must be a way for households currently without access to home charging to charge their vehicles conveniently.

The primary scenario assumes that most people will use public and shared private L2 chargers at work and public destinations as their primary means of charging away from home. Under this scenario, DCFC is used either if they do not spend enough time at any destination with charging to refuel their vehicle or if they need fast charging along a travel corridor to reach a distant destination. This section explores two possible alternatives: higher home access and a DCFC-focused approach sometimes referred to as the “gas station model.”

### **Higher Home Access**

One way to ensure that charging is not a barrier to PEV adoption is to expand the range of charging options available near homes. Options to achieving this expansion include supporting more charging in parking lots of multifamily housing structures and promoting curbside charging and neighborhood charging. A limited amount of charging in multifamily housing is considered part of the primary scenario for this report but could be an option for more households if additional investments are made. Curbside charging requires installing charging infrastructure along streets to serve vehicles that do not have a private parking location. Neighborhood charging means installing numerous chargers at locations where home charging access is lower, possibly at publicly owned facilities like schools, parks, and libraries. Expanding near-home charging would require a varied mix of options in different parts of California, depending on the specific land use, parking, and electrical grid conditions present in a location.

To explore the effect of expanded near-home charging access on the state’s overall charging infrastructure needs, CEC and NREL developed an alternative future scenario assuming a higher level of residential charging access (77 percent as opposed to 67 percent for the baseline scenario). This scenario indicates that for 2030, if more residents of single-family homes were able to install charging and 130,000 more L1 and L2 chargers were installed near multifamily housing, the need for L2 chargers at other locations would decrease by 40,000, and the need for DCFC chargers would decrease by 4,200.

### **Ubiquitous DCFC/“Gas Station Model”**

Improvements to battery technology and the availability of higher-powered chargers may make expanded DCFC a realistic routine charging option for many people. This approach is sometimes referred to as the “gas station model” because relying on a distributed network of fast chargers might closely resemble the current pattern of refueling for internal combustion engine vehicles.

To explore the effect of expanded DCFC investment on overall infrastructure needs, EVI-Pro generated an alternative future scenario assuming people without access to charging at home use DCFC as their primary means of charging. Under this scenario for 2030, installing 63,000

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70 Alexander, Matt. January 2022. [Home Charging Access in California](https://www.energy.ca.gov/publications/2022/home-charging-access-california). California Energy Commission. Publication Number: CEC-600-2022-021. <https://www.energy.ca.gov/publications/2022/home-charging-access-california>.

additional DCFC chargers throughout the state will decrease the need for public and shared private L2 chargers by 402,000 compared to the primary scenario.

### **Other Alternative Futures Scenarios**

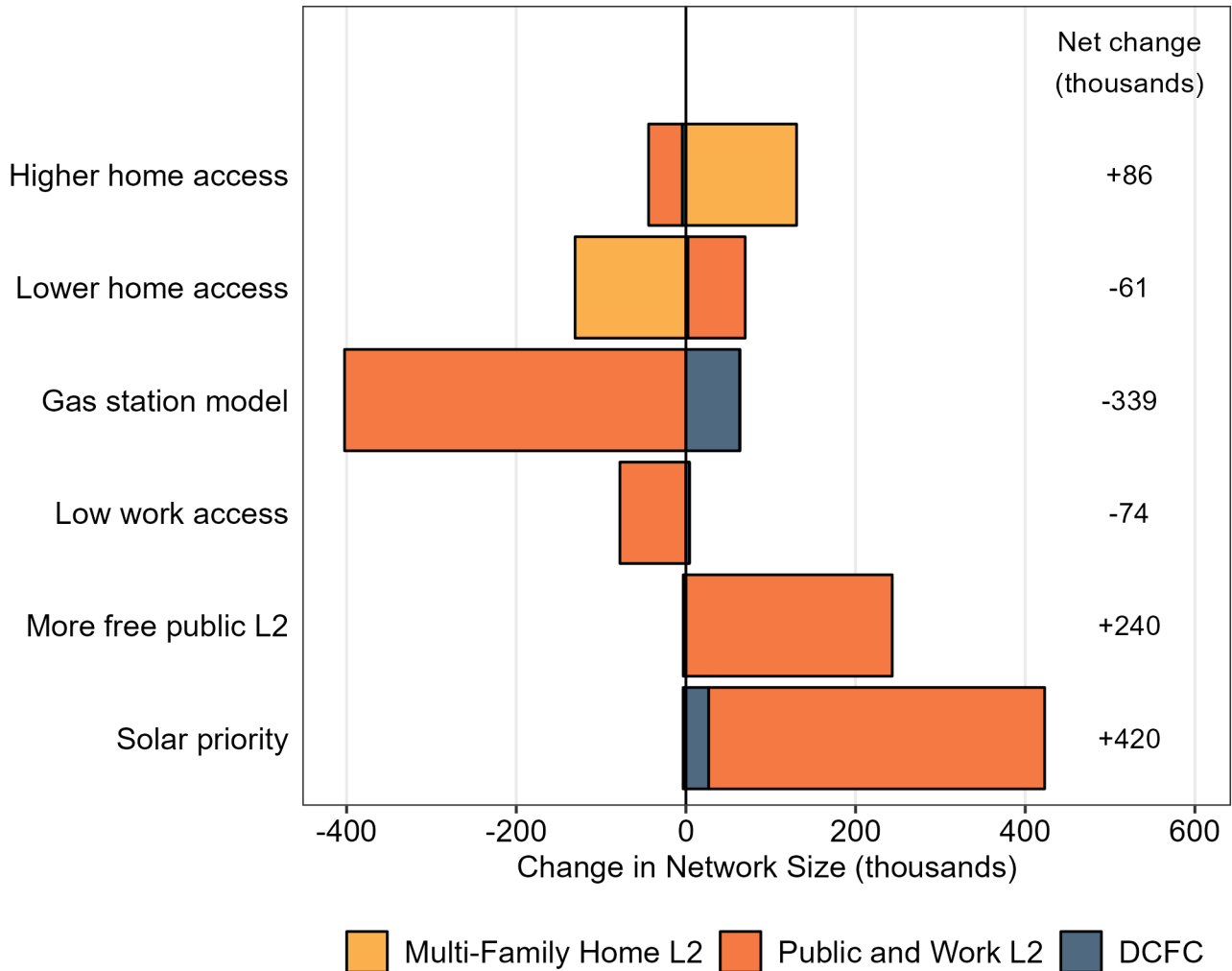
In addition to the expanded at- and near-home home charging and ubiquitous DCFC scenarios, CEC and NREL developed additional alternative future scenarios to explore areas of uncertainty in the AATE3 baseline scenario for 2030. These scenarios explore the impact of decreased charging access at commute destinations, free public L2 provided as an amenity, and various overnight charging patterns implemented through time-of-use (TOU) rates for home charging.

The following alternative future scenarios were developed for this report (the name of each scenario is in **bold** text):

- **Higher home access** and **lower home access** scenarios. These scenarios adjust home charging access by 10 percentage points from the baseline. The **higher home access** scenario assumes 76 percent of vehicles will be able to charge at home. The **lower home access** scenario assumes 56 percent of vehicles will be able to charge at home.
- **Gas station model** scenario. This scenario adjusts the charging priority of drivers without access to charging at home. Under the baseline, drivers use DC fast charging only if it is the only option that works in their schedule. Under this scenario, DC fast charging is the first choice of all drivers who are not able to charge at home.
- **Low-work-access** scenario. This scenario adjusts the commute fraction down from the baseline. Under the baseline, 50 percent of vehicles will be able to charge at a commute destination. Under the **low-work-access** scenario, only 40 percent of vehicles will be able to charge at a commute destination.
- **More free public L2** scenario. This scenario adjusts the availability of free public L2 provided by shopping and entertainment activity locations as an amenity. Under the baseline, 20 percent of drivers have access to free public L2. Under the **more free public L2** scenario, 40 percent of drivers have this option.
- **Solar priority** scenario. This scenario shifts charging behavior to maximize charging between 10 a.m. and 3 p.m., resulting in increased need for chargers at locations where people are present during this time.
- Several **home grid scenarios**. These scenarios adjust the proportion of drivers in the four TOU categories discussed in the section on grid-friendly charging. Because these scenarios apply only to charging while at home, they have minimal effect on the total number of chargers needed.

Aside from the home grid scenarios, all the alternative future scenarios included in this report generate significantly different estimates of the number of chargers needed to support light-duty vehicles in California. Figure 21 shows the change in number of chargers required under each scenario. Charger counts and load curves for all alternative future scenarios are included in Appendix E.

**Figure 21: Difference in 2030 Charger Counts Between Alternative Future Scenarios and Baseline Scenario**



**The mix of charger types and locations powering California PEVs in 2030 may vary substantially depending on what sorts of charging are prioritized. Under the high and low home access scenarios, there is a tradeoff between L1/L2 chargers at homes and L2/DCFC chargers at activity locations. In the gas station model, DCFC is the primary means of charging away from home. Under the solar priority scenario, away-from-home charging options are expanded to shift charging to the daytime.**

Source: CEC and NREL

## **EVI-RoadTrip**

The Electric Vehicle Infrastructure for Road Trips (EVI-RoadTrip) model projects the number and locations of DC fast chargers needed to enable electrified road trips within and across California’s borders. In contrast to EVI-Pro 3, which considers the charging needed to support routine travel by all PEVs, EVI-RoadTrip focuses only on long-distance interregional (100+ mile) trips by BEVs. EVI-RoadTrip analyzes DC fast chargers to support BEVs only. The EVI-RoadTrip model is largely unchanged from the first AB 2127 assessment but has been updated to use the AATE3 scenario.

Table 9 shows the number of DC fast chargers needed to support interregional travel by BEVs under the AATE3 scenario. The EVI-RoadTrip model predicts that California will need 5,461 DC fast chargers to support 6.25 million BEVs in 2030 and 7,685 DC fast chargers to support 13.68 million BEVs in 2035. These estimates represent a slight increase over similar results from the first AB 2127 assessment, largely because BEVs are now predicted to make up a much larger share of the LDV fleet than they were under previous scenarios.

**Table 9: DC Fast Charging Infrastructure Needed to Support Interregional Travel by Light-Duty BEVs Under AATE3 Scenario**

<b>Charger Power</b>	<b>2025 (2.03 million BEVs)</b>	<b>2030 (6.25 million BEVs)</b>	<b>2035 (13.68 million BEVs)</b>
150 kW	1,562	177	31
250kW	1,790	1,475	880
350kW	7	3,809	1,626
450kW	-	-	5,147
Total	3,359	5,461	7,685

## **WIRED**

The Widespread Infrastructure for Ride-Hailing EV Deployment (WIRED) model, developed by UC Davis, assesses the need for additional charging infrastructure to support PEVs operated by transportation network companies (TNCs) statewide beyond what is needed to support other light-duty vehicles. The model provides estimates for the entire state with additional focus in three major California regions that are projected to account for roughly 80 percent of the PEV TNC travel in California:<sup>71</sup> San Diego County, the Greater Los Angeles region, and the San Francisco Bay Area. WIRED uses empirical data from Lyft and Uber trips and aims to minimize charger equipment cost, network installation size, driver use cost, travel time, and charging time. The model outputs the number of chargers needed statewide as well as at the aggregated census tract level for the three regions mentioned above. Compared to the WIRED analysis included in the first AB 2127 assessment, this analysis has been expanded to cover the entire state, extended to cover EVs driving for TNCs through 2035, and rescaled based on the substantial decline in ride hailing post-COVID.

Ensuring that sufficient charging is available for these vehicles is necessary to ensure that TNCs can comply with the Clean Miles Standard, enacted by SB 1014, which requires TNCs to electrify 50 percent of vehicle miles traveled by 2027 and 90 percent starting in 2030.<sup>72</sup> Electrifying TNC vehicles is particularly important because these vehicles are generally driven

71 CARB staff. November 19, 2020. Clean Miles Standard Workshop. "[Proposed Regulation Targets.](https://ww2.arb.ca.gov/sites/default/files/2020-11/CMS%20Workshop%206_public%20%28002%29.pdf)" [https://ww2.arb.ca.gov/sites/default/files/2020-11/CMS%20Workshop%206\\_public%20%28002%29.pdf](https://ww2.arb.ca.gov/sites/default/files/2020-11/CMS%20Workshop%206_public%20%28002%29.pdf).

72 CARB staff. 2020. "[Clean Miles Standard Regulation: Passengers and Communities to Benefit From Lower Emissions With Actions by Transportation Network Companies.](https://ww2.arb.ca.gov/resources/fact-sheets/clean-miles-standard-regulation-passengers-and-communities-benefit-lower)" <https://ww2.arb.ca.gov/resources/fact-sheets/clean-miles-standard-regulation-passengers-and-communities-benefit-lower>.

significantly more and generate substantially more GHG emissions than privately owned vehicles.<sup>73</sup>

## **Modeling Results**

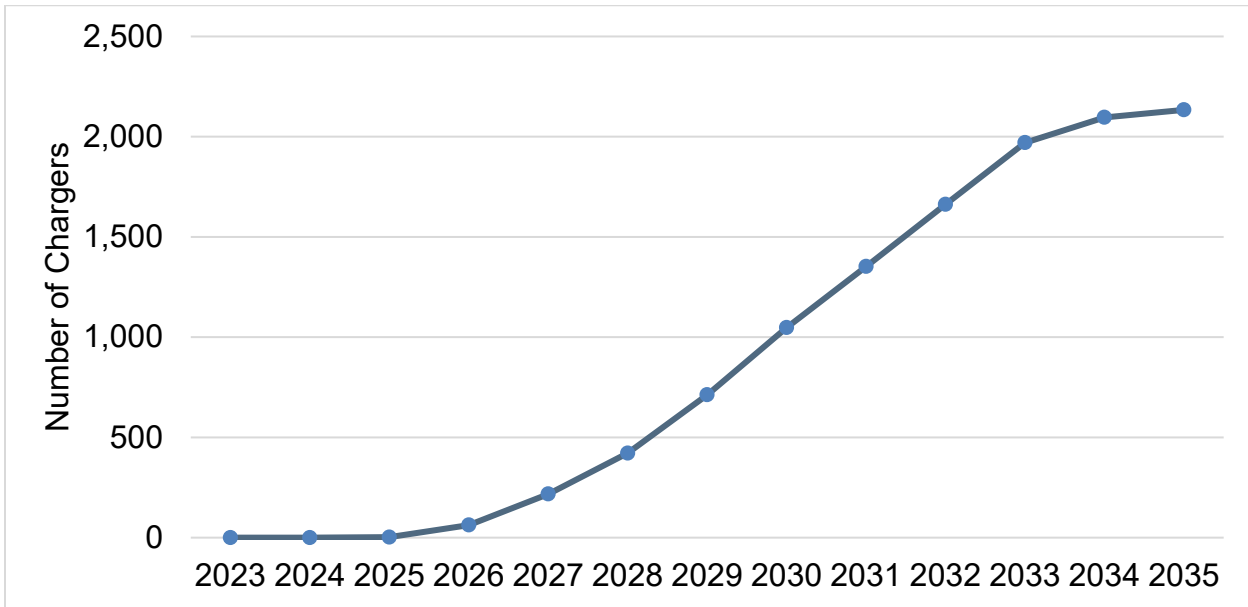
WIRED projects a steady increase in the number of DC fast chargers required statewide as the Clean Miles Standard vehicle mile electrification requirement increases. The model assumes that 40 percent of TNC drivers will have access to charging at home and will start each day with a full battery, using DCFC only when needed. Other drivers will rely entirely on DCFC for their charging. Chargers installed to support TNC drivers could either be publicly accessible or made available only for TNC drivers, but the charger estimates for WIRED represent an additional number of chargers needed to support TNC vehicles beyond what is estimated in EVI-Pro and EVI-RoadTrip.

Figure 22 shows the number of chargers needed statewide, while Figure 23 shows the regional needs for charging infrastructure. By 2030, more than 1,000 DC fast chargers will be needed across the state to serve TNCs, and by 2035, more than 2,100 DC fast chargers will be needed. As Figure 23 shows, the need for these chargers will be highest in the Greater Los Angeles and San Francisco Bay Area regions, each of which will require roughly 800 chargers to support TNC vehicles by 2035. Even after expanding the analysis to cover the entire state, estimates for TNC charging infrastructure needs in 2030 are 50 percent lower than those shown in the first AB 2127 assessment because the model has been updated to account for the general decline in TNC usage since the start of the COVID pandemic. Appendix F provides annual results from WIRED, as well as maps of charging needs in each region.

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73 Jenn, Alan. 2019. *National Center for Sustainable Transportation*. "[Emissions Benefits of Electric Vehicles in Uber and Lyft Services](https://escholarship.org/uc/item/15s1h1kn)." UC Davis Institute of Transportation Studies, <https://escholarship.org/uc/item/15s1h1kn>.

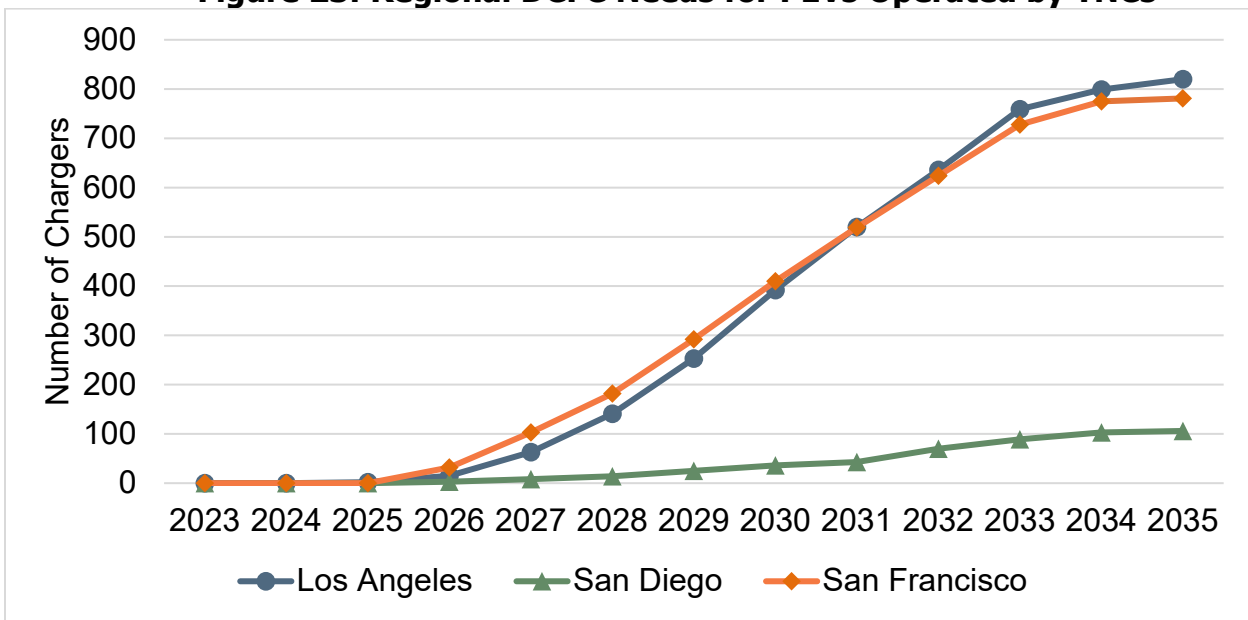
**Figure 22: Number of DCFC Chargers Needed to Support TNC Electrification Under the Clean Miles Standard**



**Aggregated DC fast charging needs modeled by WIRED**

Source: UC Davis

**Figure 23: Regional DCFC Needs for PEVs Operated by TNCs**



**Regional DC fast charging needs modeled by WIRED in the Greater Los Angeles region, San Diego County, and the San Francisco Bay Area**

Source: UC Davis

The results highlight the reliance of PEVs used for TNC service on DC fast chargers.<sup>74</sup> TNC charging needs are highest in areas where these services make the most trips like airports and downtown areas. The need for high-speed charging at these locations is particularly important because drivers are not paid for time spent charging.

## **Combined DC Fast Charging Needs for Light-Duty Vehicles**

The three models for light-duty EV charging infrastructure presented in this chapter provide estimates for how many DC fast chargers are needed to serve three use cases:

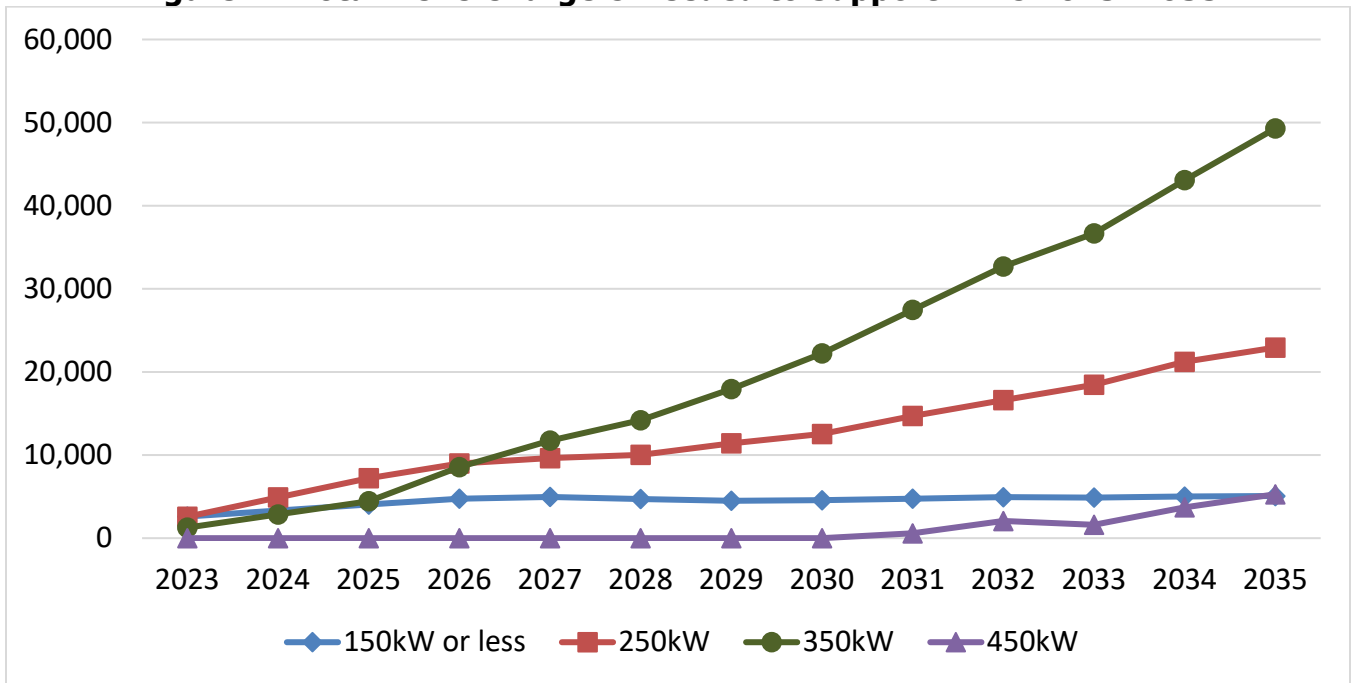
- EVI-Pro 3 includes DC fast chargers used by BEV drivers during their daily routine travel, typically because they do not have access to charging at home and do not make any stops long enough to receive enough charging with L2.
- EVI-RoadTrip includes DC fast chargers used by BEV drivers on long-distance trips. On these trips, high-speed charging is necessary to ensure that drivers can reach their destination in a reasonable amount of time.
- WIRED includes DC fast chargers used by TNC drivers of BEVs.

These models provide separate estimates for the number of chargers needed in California; the pool of DC fast chargers needed for light-duty EVs in California is the total number of chargers across all three models, although a DC fast charger may serve several purposes to some degree. Figure 24 shows the number light-duty EV DC fast chargers of each power level needed from 2025 to 2035 under the AATE3 scenario. As noted in the EVI-Pro section, the transition away from lower-powered (150 kW or less) DC fast chargers after 2025 is driven by improving vehicle technology. Demand for lower-powered chargers may persist if they offer less costly charging than higher-powered DC fast chargers and if some drivers do not require the extra charging speed.

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74 Jenn, Alan. 2021. [Charging Forward: Deploying Electric Vehicle Infrastructure for Uber and Lyft in California](https://escholarship.org/uc/item/6vk0h1mj). Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-20-63, <https://escholarship.org/uc/item/6vk0h1mj>.

**Figure 24 Total DCFC Chargers Needed to Support LDVs 2023–2035**



**Total DC fast charging needs by power level combined between EVI-Pro 3, EVI-RoadTrip, and WIRED, assuming TNC BEVs have similar charging capabilities as privately owned BEVs.**

Source: NREL and UC Davis

## HEVI-LOAD

The Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operations, and Deployment (HEVI-LOAD) model is designed to determine regional fueling infrastructure needs through 2030 for depot and on-route public charging and refueling for on-road and off-road medium- and heavy-duty (MDHD) electric and hydrogen fuel cell vehicles. The model determines the number, locations, and types of charging infrastructure and hydrogen refueling station deployments to support California’s zero-emission vehicle adoption targets. HEVI-LOAD studies charger power levels ranging from 20 kW to 1.5 MW, suitable for a range of vehicle applications. HEVI-LOAD began development in 2020 under a collaboration between Lawrence Berkeley National Laboratory and the CEC and consisted of two modeling phases with separate approaches: top-down and bottom-up.



## Changes to the HEVI-LOAD Model

The top-down approach of HEVI-LOAD, shown in the first AB 2127 assessment, used three steps: vehicle projection, trip disaggregation, and infrastructure assessment. Researchers derived electric vehicle adoption forecasts from a combination of a truck choice model within the CEC's *Transportation Energy Demand Forecast (TEDF)* and CARB's *Mobile Source Strategy*. Energy consumption profiles sourced from CARB's Emission Factor (EMFAC) model were disaggregated into individual trips using survey information and vehicle payload calculations. From this step, the top-down approach used a probabilistic process to determine whether a vehicle would need to recharge during a trip. The first assessment used this method to generate charger numbers and vehicle load profiles statewide and on a per-county basis.

For the second AB 2127 assessment, the HEVI-LOAD model employs a bottom-up, agent-based modeling framework. The model simulates individual vehicle trips and calculates aggregated energy demand, specific to each vehicle application category, for multiple regions. HEVI-LOAD determines the number and power level of depot and public chargers that can meet this energy demand. Depot chargers provide lower-speed charging at destinations and have power levels between 20 kW and 150 kW. Public chargers provide higher-speed charging to allow vehicles to complete longer routes and have power levels between 350 kW and 1.5 MW. Both depot and public chargers can provide charging at any time of day or night. The charger classification used in this assessment differs from the one used in the first AB 2127 assessment, which included 50 kW depot chargers used exclusively for overnight charging and 350 kW public chargers used exclusively for daytime charging. Because all daytime charging was assigned to 350kW public chargers, there were more public chargers and more energy delivered through public chargers in the first assessment.

HEVI-LOAD determines the amount of charging MDHD vehicles need by simulating the trips these vehicles make, using origin-destination pair data from the Caltrans California Statewide Travel Demand Model (CSTDM). The vehicles move along the transportation network and take the shortest possible path to reach the respective destinations. In this model, charging events occur either at public chargers on route, if the battery of a vehicle does not have enough energy to last the entire trip, or at depot chargers between trips. "Depots" in this model include destinations as well as a home base for vehicles. Vehicles do not necessarily charge every time they return to the depot, but most vehicles charge at a depot at least once every 1-3 days. Depot charging events can occur if the vehicle is parked overnight or if the battery state of charge is below 50%. Most vehicles utilize depot chargers for the majority of their charging.

HEVI-LOAD uses location data sourced from the California Statewide Truck Parking Study (CSTPS) conducted by Caltrans. The model then aggregates characteristics from the simulated vehicles up to the traffic analysis zone (TAZ) level. Since the CSTDM trips do not have detailed start, end, and duration information, HEVI-LOAD probabilistically assigns them a start time and end time to increase the temporal resolution of driving behavior by using real-world GPS location data provided by UC Riverside and West Virginia University. Appendix G provides details on the distribution of start and end times, overall trip duration, and the interval between two consecutive trips used to calibrate the CSTDM data. As the model simulates trips, it determines the energy need of each vehicle based on the specific road segments it travels

along and assumed energy needs of that vehicle (class-level energy needs in kWh / mile are listed in Appendix G). The model calculates the charging needs of vehicles that make stops at each parking location based on state of charge and time of day. Finally, the model determines the number of chargers at each power level suitable to support these vehicles.

The updated HEVI-LOAD model uses a range of charger power levels based on vehicle-specific charging capacity and the amount of time available for charging. For depot charging, most vehicles default to 50 kW but may charge at higher speeds to ensure that charging will be completed before the departs for its next trip. For public charging, 350 kW chargers are most common, but some vehicles will use higher powered chargers to minimize time spent charging. The speed of public charging is an area of uncertainty for MDHD electrification. This assessment assumes that 350 kW chargers will be the default for on-route public chargers because 350 kW charging systems have already begun to be deployed in large numbers. If the Megawatt Charging System (MCS) or other charging systems that permit higher charging speeds are adopted rapidly, the resulting charging system would likely include more high-powered public chargers but fewer total public chargers.

### **Medium- and Heavy-Duty PEV Adoption Scenarios**

In the first AB 2127 assessment, HEVI-LOAD incorporated four adoption scenarios for MDHD vehicles in 2030: Medium Charging Demand and High Charging Demand scenarios from the TEDF, a preliminary analysis conducted by CEC and LBNL, and CARB's Mobile Source Strategy. The MDHD ZEV populations in these scenarios were 75,000, 81,000, 130,000, and 180,000, respectively.

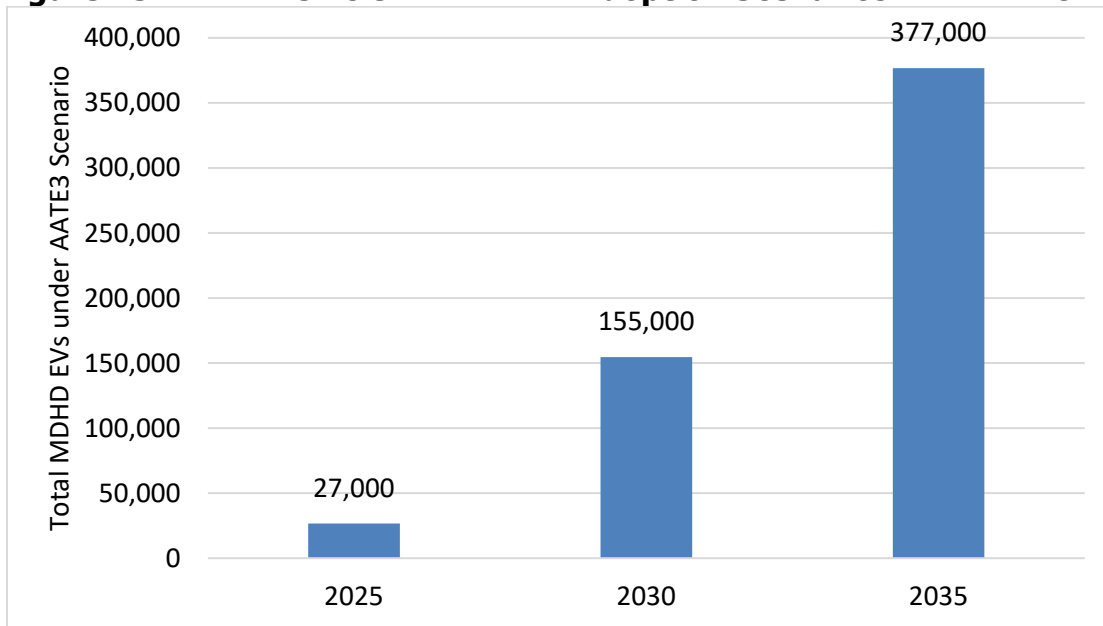
In this assessment, CEC staff uses the CEC's Additional Achievable Transportation Electrification 3 (AATE3) scenario developed for the IEPR as the primary scenario for medium- and heavy-duty ZEV adoption. The AATE3 scenario assumes compliance with the Advanced Clean Trucks (ACT)<sup>75</sup> and Advanced Clean Fleets (ACF)<sup>76</sup> regulations. This scenario has a population of nearly 155,000 MDHD PEVs in 2030 and 377,000 MDHD PEVs in 2035, as shown in Figure 25. The AATE3 scenario applies the maximum ZEV share from CARB's ACF scenario as the new vehicle ZEV sales share for each class included in the CEC's Truck Choice and Freight Model resulting in a slightly higher projection of medium- and heavy-duty ZEVs than CARB anticipates will be the minimum effect of the ACT and ACF regulations.

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75 California Air Resources Board. "[Advanced Clean Trucks Fact Sheet: Accelerating Zero-Emission Truck Markets.](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet)" <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet>.

76 California Air Resources Board. "[Advanced Clean Fleets Regulation Summary: Accelerating Zero-Emission Truck Markets.](https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary)" <https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary>.

**Figure 25 MDHD Vehicle MDHD PEV Adoption Scenarios in HEVI-LOAD**



**HEVI-LOAD uses the CEC’s Energy Assessment Division’s AATE3 scenario as its primary scenario for MDHD EV adoption in 2025, 2030, and 2035. This scenario applies a maximum ZEV PEV percentage share between CARB’s ACF fleet projections and the CEC’s Truck Choice and Freight Model.**

Source: CEC

Compared to the Mobile Source Strategy (MSS) scenario, used in the first assessment, the AATE3 scenario includes several differences in MDHD fleet size, fleet composition, and efficiency:

- AATE3 has 14.4 percent fewer zero-emission MDHD vehicles in 2030 compared to the MSS (155,000 compared to 180,000).
- AATE3 has a larger proportion of small and low-mileage classes among the zero-emission MDHD fleet in 2030, resulting in a 27.6 percent decrease in average per-vehicle daily energy use compared to the MSS. This change is partly due differences in the total number of vehicles (of all fuel types) in each class, and partly due to changes in expected ZEV sales shares because of the Advanced Clean Fleets regulation. The 2030 MDHD fleets in MSS and AATE3 are compared in Table 10.
- AATE3 assumes that MDHD vehicles use on average 37.8 percent less energy per mile than was used in the first AB 2127 assessment. The major cause of this change is that in the first AB 2127 assessment, vehicles were assumed to always have a full load, whereas this assessment assumes that vehicles sometimes are not carrying a full load.

These factors all contribute to lower expected MDHD energy needs in this assessment than in the first assessment. All told, these changes result in a roughly 60 percent decrease in total energy for MDHD vehicles, and a 55 percent decrease in per-vehicle energy use.

**Table 10 Number of MDHD ZEVs and average daily mileage in MSS and AATE3 scenarios for 2030, by weight class**

Gross Vehicle Weight Rating Class	Total ZEVs (MSS)	Average Daily Miles (MSS)	Total ZEVS (AATE3)	Average Daily Miles (AATE3)	ZEVs as a proportion of all vehicles in this class (AATE3)
Class 3	8,970	57.3	26,932	51.8	12.5%
Classes 4, 5, 6, and 7	72,421	51.6	76,200	53.3	24.8%
Class 8	99,245	96.5	51,441	88.1	16.2%
<b>Total MDHD</b>	<b>180,636</b>	<b>76.5</b>	<b>154,572</b>	<b>64.6</b>	<b>18.4%</b>

Source: CEC Staff

The first AB 2127 assessment included infrastructure needs analysis for on-road MDHD BEVs. CEC staff is incorporating additional use case analyses within HEVI-LOAD. In future versions of this assessment, the modeling framework will be updated to include an infrastructure analysis for off-road ZEVs using CARB’s OFFROAD2021 model for vehicle inventory, emissions, and duty cycles.

While not included in the AB 2127 report, hydrogen fuel cell vehicles will also be included in future modeling developments in HEVI-LOAD. The model will assess the hydrogen refueling infrastructure needs of on-road fuel cell MDHD vehicles in future assessments.

### **MDHD Infrastructure Needs**

HEVI-LOAD estimates that to support 155,000 MDHD PEVs in 2030, California will need about 109,000 depot and 5,500 public electric vehicle chargers. In 2035, HEVI-LOAD projects a need for roughly 256,000 depot and 8,500 public electric vehicle chargers. In each modeled year, charger power levels range from 20 kW to 150 kW for depot chargers and 350 kW to 1.5 MW for on-route public chargers. In 2030, about 82 percent of total MDHD charging load is estimated to be served by depot charging and 18 percent is served from public charging. In 2035, about 84 percent of total MDHD charging load is estimated to be from depot charging and 16 percent is from public charging. The CEC will continue to monitor the market and make modeling adjustments over time as the MDHD industry evolves as it could gravitate towards public chargers in greater numbers.

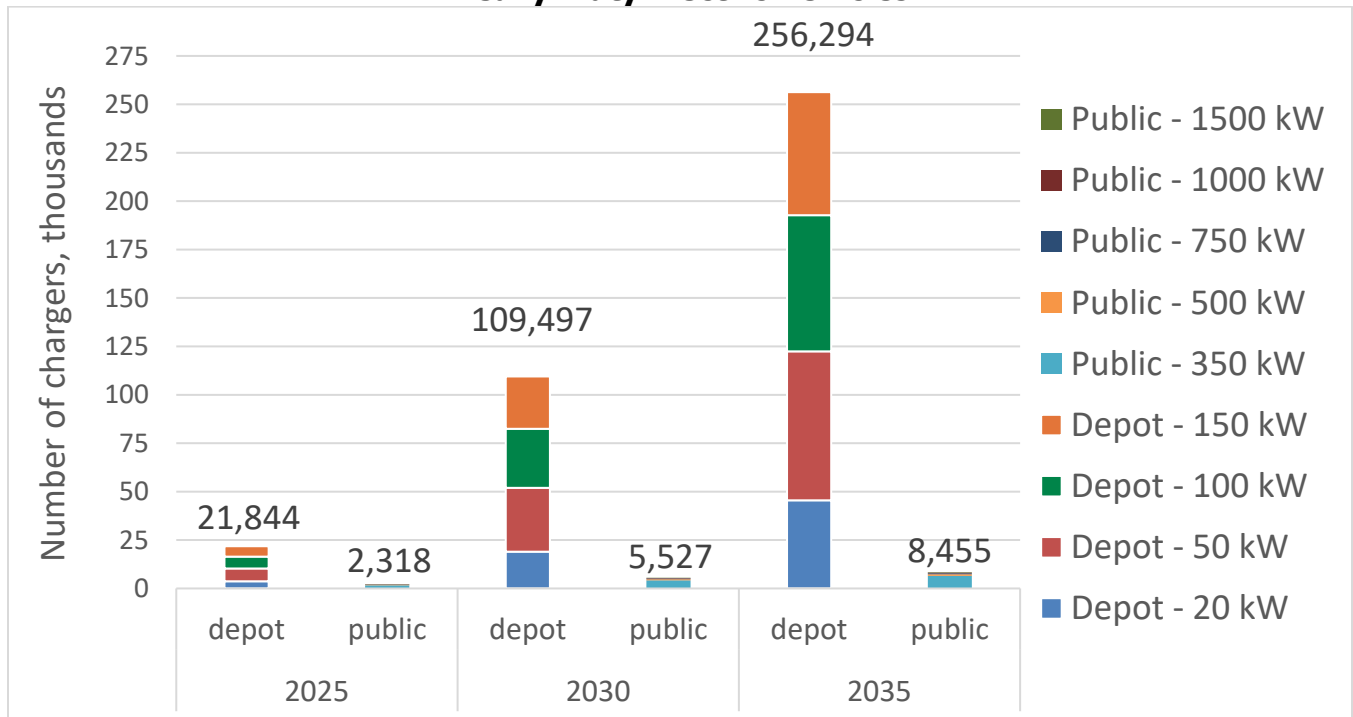
Figure 26 shows the growth in charging infrastructure need and corresponding power levels through time. In the first AB 2127 assessment, chargers were modeled as being either 50 kW or 350 kW, of which 141,000 and 16,000 were projected, respectively, to support 180,000 MDHD vehicles in 2030. Compared to the first assessment, this assessment estimates fewer chargers will be needed because there are fewer MDHD ZEVs; a larger proportion of MDHD

ZEVs are smaller and lower-mileage vehicles; vehicles are assumed to be more efficient; and some energy demand is satisfied by fewer, higher-powered chargers.

More depot chargers are needed than public chargers because depot charging allows vehicles to make the best use of vehicle idle time, avoid waiting for public charging during the trip, and avoid having to pay for high-powered public charging. The model assumes that most vehicles will rely on depot chargers for the bulk of their charging and will need to charge at a depot every 1–3 days, depending on driving patterns and vehicle range. Depot chargers can serve vehicles both in the daytime and at night, but each depot charger will serve at most one vehicle between the hours of 6 PM and 7 AM each night.

Charger utilization is a key uncertainty in charging infrastructure modeling, particularly for public chargers. This assessment assumes that public chargers for MDHD vehicles will average around 5 percent utilization per day in 2030, with utilization somewhat lower for 1.5 MW chargers. If actual utilization is higher than this, a smaller number of chargers would be able to serve the same charging demand. Actual utilization may also be affected by peak demand and drivers’ tolerance of queues, as well as station economics. As more MDHD stations are installed, monitoring utilization over time will provide more insight into this issue, and help determine the appropriate mix of depot charging versus public retail stations. Regardless, public charging will play an essential role for long-haul vehicles and smaller fleets that do not readily have access to depot charging.

**Figure 26: Projected Charging Infrastructure Needs for On-Road Medium- and Heavy-Duty Electric Vehicles**



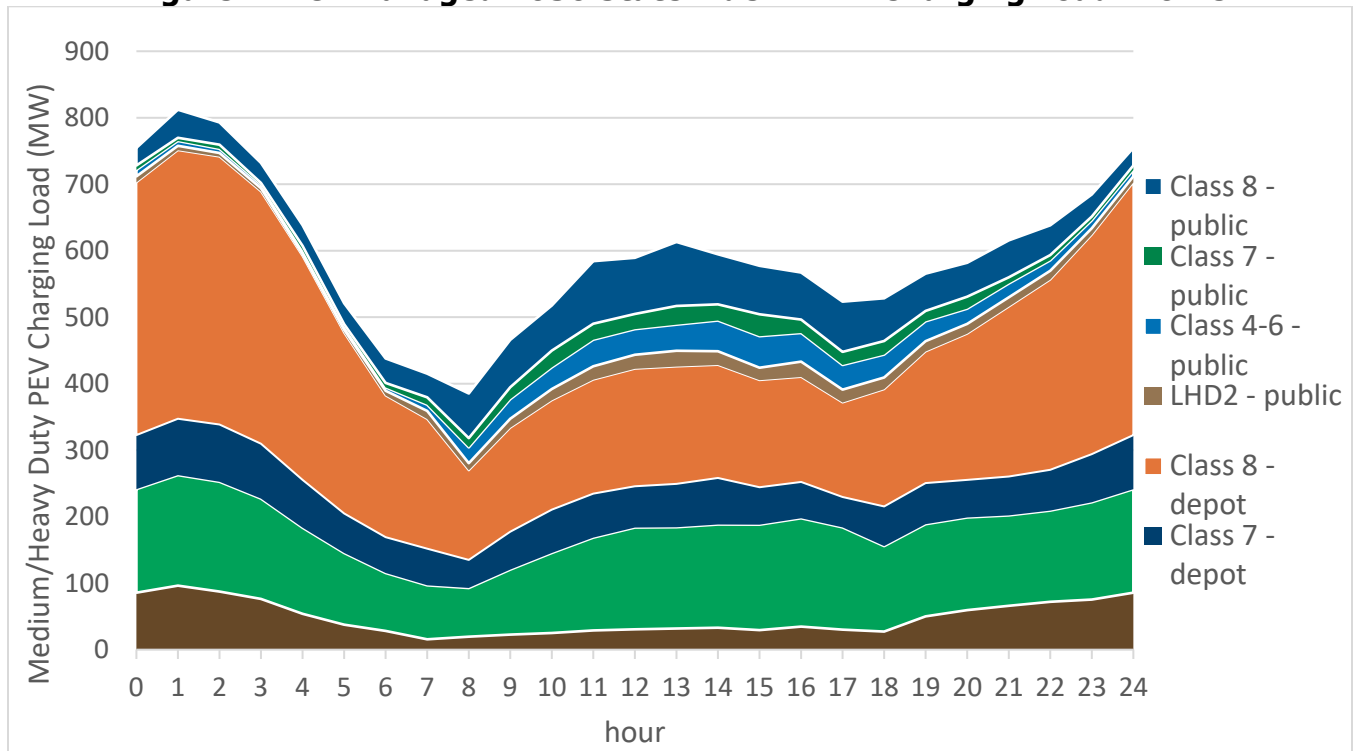
**HEVI-LOAD projects that about 109,000 depot-based chargers, ranging from 20 kW through 150 kW, and 5,500 public chargers, ranging from 350 kW through 1.5 MW, are needed to support about 155,000 MDHD vehicles in 2030. In 2035, the charging need grows to about 256,000 depot chargers and 8,500 public chargers.**

Source: CEC and LBNL

HEVI-LOAD analyzes charging load profiles for all vehicles simulated in the model for managed and unmanaged charging cases. In the unmanaged case, vehicles are assumed to charge immediately whenever a charging request is generated. However, in the managed charging case, the model incorporates several factors that affect the charging behavior of the simulated vehicles and the impact vehicle charging has on California’s electric grid. Vehicles in the managed case have more flexibility in the amount of time they can wait to charge, and the energy pricing schemes are more dynamic when compared to unmanaged charging.

Figure 27 and Figure 28 show the load profiles for both scenarios broken down into four vehicle categories: LHD (vehicles with a GVWR of 10,001–14,000 lbs.), Classes 4–6, Class 7, and Class 8, which are direct mappings from the CSTDM categories of light truck, medium truck, and heavy truck. Both figures reflect the AATE3 vehicle adoption scenario for 2030. Charging in the unmanaged scenario starts ramping up around 6 p.m. and peaks at about 800 MW around 1 a.m. In the managed scenario, the charging peak is instead shifted to the hours between 10 a.m. and 5 p.m., with another small peak of about 725 MW around 3 a.m. The model assumes that vehicles which return to base around high-demand periods will defer charging until after 11 p.m., and vehicles returning before 3 p.m. will start charging immediately until about 5 p.m. If the battery is still not fully charged, the vehicle waits until early the next morning to finish charging.

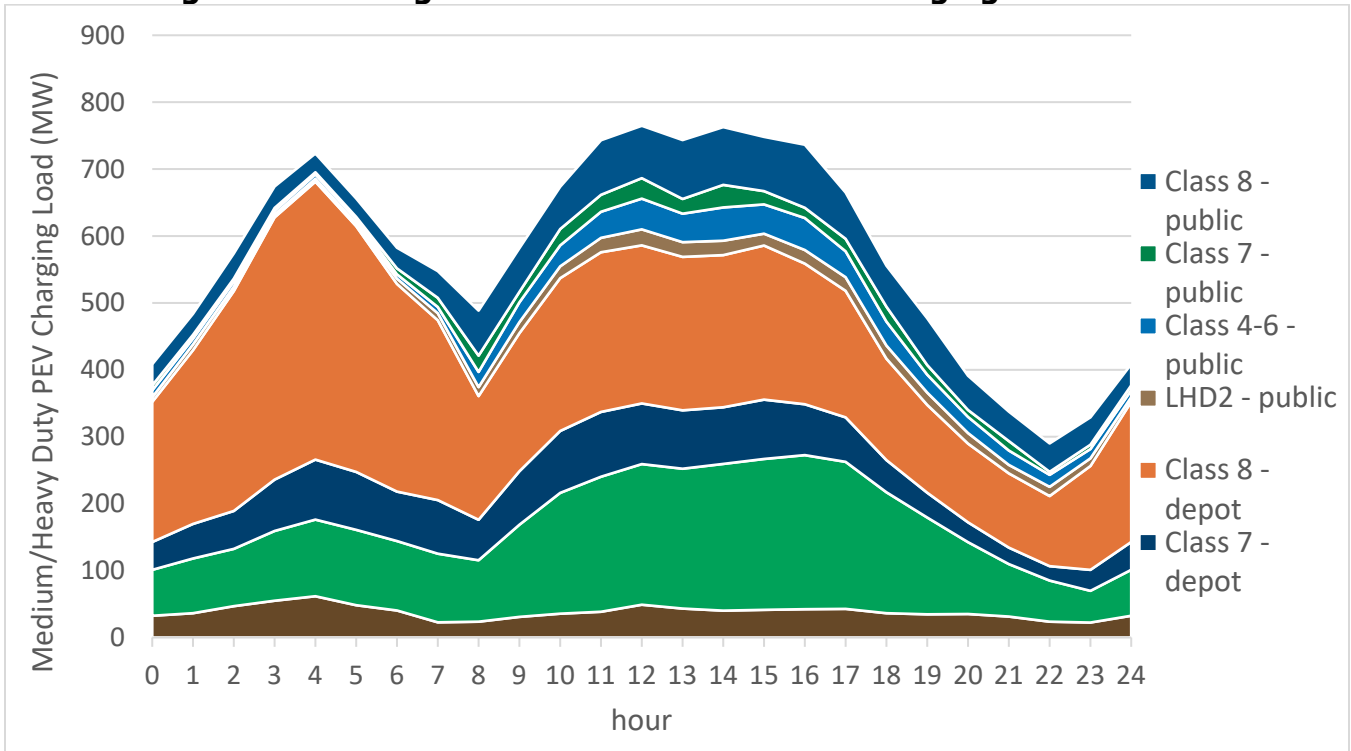
**Figure 27: Unmanaged 2030 Statewide MDHD Charging Load Profile**



**Unmanaged charging results in a large aggregate demand peak of about 800 MW at 1 a.m. during typical weekday conditions. Class 8 trucks contribute the largest portion of the demand because of the overall battery size, energy consumption, and tendency to use depot charging.**

Source: CEC and LBNL

**Figure 28: Managed 2030 Statewide MDHD Charging Load Profile**



**In the managed charging scenario, peak load is shifted from between 8 p.m. and 1 a.m. to between 10 a.m. and 5 p.m., with a similar overall magnitude. In this case, vehicles tend to avoid high electricity demand periods while maintaining normal duty cycle operations.**

Source: CEC and LBNL

Increased load from charging MDHD vehicles will require grid planning. As the number of chargers throughout the state grows, utilities will have to make upgrades to the physical components of the distribution system such as transformers, primary and secondary circuits, and substations. As a result, HEVI-LOAD, via integration with functionality from the CEC's EVSE Deployment and Grid Evaluation (EDGE) tool analysis, conducted a site-specific capacity mapping study to estimate the impact that the energy demanded by the simulated vehicles of the model could have on specific locations throughout the state. This study is discussed in the following section on the EDGE tool analysis.

### **EVSE Deployment and Grid Evaluation (EDGE)**

The ability to address local grid constraints related to EV charging is an area of focus and is vital to enabling widespread transportation electrification in all sectors. This is especially true in the MDHD context, since these vehicles rely on high-powered chargers at depots and when recharging on route. Properly distributing the large number of chargers detailed in earlier sections in this report will require identifying locations that can sufficiently and economically host them.

Depending on the overall power level and other factors, EV charging may impact areas of the electrical grid distribution system in different ways.<sup>77</sup> In cases where a small amount of relatively low-powered chargers are deployed, such as a small group of Level 2 chargers, there likely will not be a need to upgrade grid equipment beyond the transformer level. However, deploying many high-powered fast chargers at a site may trigger an upgrade for several components up to the primary distribution circuit and possibly even the substation.

In the first AB 2127 assessment, analysis of California’s electric grid system appeared to indicate that many of the primary distribution circuits that serve customers in PG&E, SCE, and SDG&E territories have limited capacity to serve new load. However, the analysis relied on the utilities’ Load Integration Capacity Analysis (ICA) maps which only reflect past load profile data rather than current or future load and lack the granularity that project developers need. To address localized grid capacity concerns, the CEC developed the EDGE visualization tool which is designed to help users identify candidate locations to deploy electric vehicle charging infrastructure and plan associated behind-the-meter equipment investments. EDGE is designed to highlight areas where new EV charging load is expected to grow through time. The tool identifies specific areas of the state where expected EV load growth could exceed grid capacity limitations. This information could be used to identify “low hanging fruit” opportunities where charging infrastructure could potentially be deployed without overloading existing local electric grid equipment. Utility planners could also use this information to identify similar opportunities in the form of least-regrets grid upgrade projects. Highlighting regions where modeled load exceeds the grid hosting capacity could inform proactive utility planning conversations and potentially help address regional grid constraints before project developers submit infrastructure project applications. This has the potential to help mitigate long lead times for distribution system upgrades, especially if initially targeting those areas with the highest likelihood of needing grid upgrades based on current circuit capacity and projected EV load.

EDGE inputs and processes both regional grid condition data and information from CEC’s charging infrastructure projection models. EVI-Pro provides data for light-duty infrastructure, and HEVI-LOAD provides data for medium- and heavy-duty infrastructure. Both data are in the form of generated charging load profiles in 2025. For the electric grid system, EDGE sources information from the IOU Grid Needs Assessment (GNA) data portals instead of the ICA maps which were used in the first assessment. The GNA data provide information regarding the amount of “headroom” that primary circuits and substations have that can accommodate new load before requiring attention through 2025. The GNA data do not provide any information on the secondary distribution system. This is a data gap that the CEC hopes to resolve if sufficient data can be obtained from the utilities.

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<sup>77</sup> The distribution system covers the last stage of energy transmission, from substations down to end users. Substations change the voltage of transmission grid level electricity into a lower voltage range so that it can be safely delivered to buildings along distribution lines. Distribution lines that operate between substations and transformers are part of the primary distribution system. Transformers then further step this voltage down and, depending on local energy needs, service drop lines deliver electricity directly to end users in homes and businesses. Distribution lines operating between transformers and endpoints make up secondary distribution system.



On a TAZ basis, EDGE compares the load that EVs are expected to produce over time against the aggregated capability of existing circuits to take on new load. The result is the “capacity need indicator metric” for each TAZ throughout California. When a region shows a positive capacity need indicator metric value, it means that the modeled EV charging load there exceeds the local grid capacity and may require grid equipment upgrades or other solutions to support expected load growth. This calculation depends on the power levels of the chargers modeled in EVI-Pro and HEVI-LOAD, and any changes made to those assumptions will directly affect the capacity need indicator metric values produced by EDGE.

The vision for EDGE is to provide users with the capability to identify good candidate locations to install charging infrastructure, as well as hotspots where the grid may not suitably accommodate large EV charging load without upgrades via a publicly accessible tool hosted online. The CEC will work with utility planners and regulators by sharing information on regional capacity need indicator metrics to provide insight on where clustered EV charging load is projected to grow over time and could potentially constrain electric system infrastructure. This relationship could provide insight for the utilities to engage in proactive grid planning.

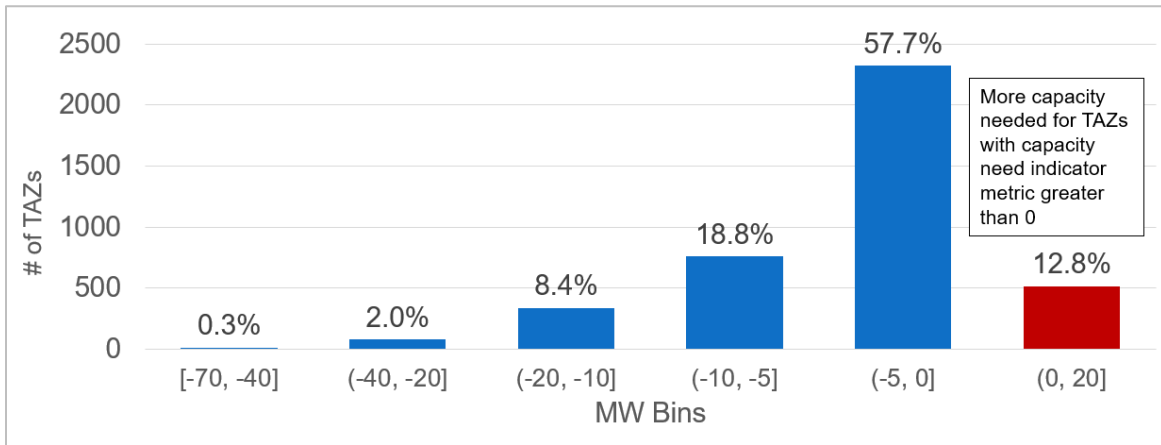
### **Modeling Results**

For this analysis, EDGE combines the TAZ load profiles from EVI-Pro and HEVI-LOAD and compares the resultant combined peak load for LD vehicles and MDHD vehicles in 2025 to the regional circuit capacity from the IOUs’ GNA data in 2025. EDGE highlights areas that may need grid equipment upgrades to accommodate for any capacity deficits. These results have not been peer reviewed by utilities and there could be additional factors impacting current and future grid capacity that are not captured in the current analysis. The CEC is in the process of refining the EDGE tool including an upcoming workshop and public release of the tool.

When looking at the capacity of individual circuits in 2025 throughout all IOU territories, nearly 64 percent have up to 5 MW of additional capacity to host new load, with another 3.4 percent having 0 MW or less. Analysis of the individual circuits is discussed in Appendix I.

When assessing grid conditions at the TAZ level, about 26 percent of the 5,454 TAZs in California do not have any grid capacity data associated with them. This lack of grid capacity data is because either the data are redacted in the IOU portals or the TAZs fall outside IOU service territories. About 13 percent, or 516 TAZs, have a positive capacity need indicator metric value, indicating that the overall modeled EV charging peak load may exceed the aggregated circuit capacity in those areas. Another 58 percent of TAZs have up to 5 MW available before capacity is exceeded. These data can be seen in Figure 29.

**Figure 29: Distribution of Capacity Need Indicator Metric Values in California TAZs in 2025**

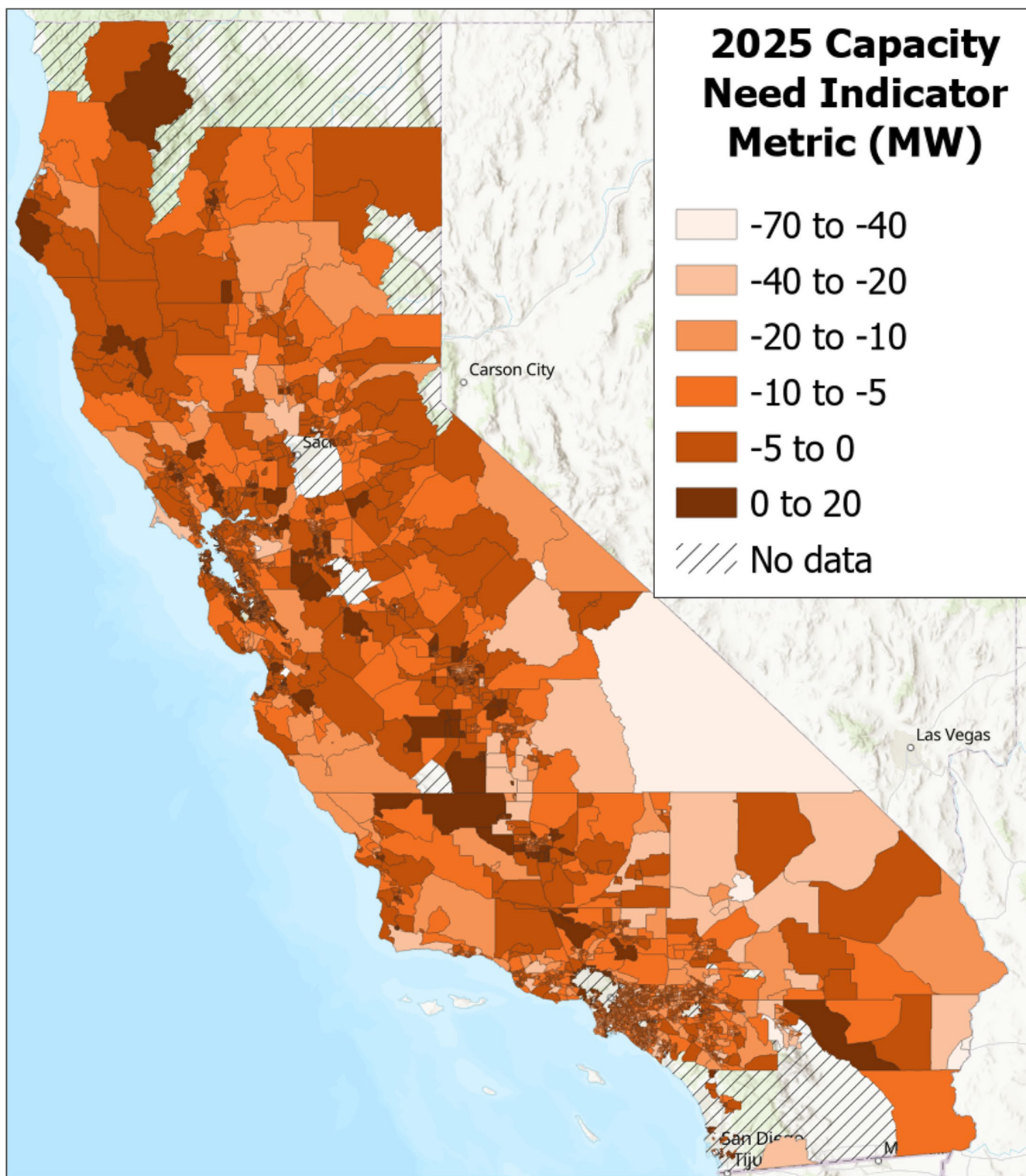


**Of the 3,802 TAZs in California with IOU grid data associated with them, nearly 13 percent potentially have EV charging peak loads that exceed the available circuit capacity in 2025. Another 58 percent have up to 5 MW of additional load beyond projected EV charging demand before needing attention. These are areas in which planners may want to focus their attention in the near term.**

Source: CEC staff

TAZs with a potential positive capacity need indicator metric value are scattered throughout the state with 370 in PG&E’s service territory, 122 in SCE’s service territory, and 24 in SDG&E’s service territory, but some areas have a high concentration of them. A map of the overall statewide view in EDGE can be seen in Figure 30, and zoomed-in views of the positive capacity need indicator metric value regions can be found in Appendix I at the end of this report. Many of these TAZs with positive capacity need indicator metric values are clustered around the I-5 corridor, especially in the San Joaquin Valley. Moreover, some locations near the San Pedro Bay ports as well as many regions in the counties making up the San Francisco Bay Area — such as in San Francisco, San Mateo, Santa Clara, and Alameda counties — also have clustered TAZs where the available capacity is exceeded by expected EV load growth in 2025. The large capacity deficit values in these regions are due to the combination of a high amount of projected EV load growth and lower-than-average grid capacity. There are some TAZs throughout the state that have higher EV load growth or less grid capacity than these, but the overlap of these two factors in the regions listed above identifies them as areas in which to prioritize and focus grid planning to address grid constraints early.

**Figure 30: Statewide EDGE Map of Capacity Need Indicator Metric Values in TAZs**



**A map from the CEC’s EDGE Visualization Tool showing TAZs in California and the associated capacity need indicator metric values using 2025 GNA circuit capacity forecasts and 2025 EV infrastructure load projections. Regions with positive capacity need indicator metric values potentially have larger EV charging load than available circuit capacity and are colored dark brown on the map. Areas with hashed lines have no utility grid data associated with them in EDGE.**

Source: CEC staff

## **Barriers and Future Refinements**

In the first assessment, the EDGE tool used grid data from the IOUs' ICA maps. However, after several discussions with the IOUs, CEC staff updated EDGE to use GNA data instead. There are several differences between these datasets that affect the functionality of EDGE. The ICA data provided a more geospatially granular look at the circuit nodes in each utility territory, whereas the GNA data show only information for the large overall primary circuits and substations. This distinction can lead to a different interpretation of grid readiness such that more capacity is apparent in GNA data, but the spatial resolution is decreased. Some flexibility in site location within a circuit is therefore implied in these results. In addition, the ICA data provide only a static snapshot of information at the time the values were updated and do not provide any time-dependent variability, whereas the GNA data provide annual forecasts for the five years after the dataset is updated.

EDGE is best situated to provide utility planners with information that affects system-level planning, such as primary circuit or substation upgrades. However, more geospatially granular information could be implemented in future iterations of the tool to give users the ability to assess particular sites where they may be interested in deploying charging infrastructure. However, this will require more data from the electric utilities. Furthermore, EDGE combines the capacity of different circuits within a TAZ, but the limits on the power available on any one site is best evaluated at a circuit level, as shown in Appendix I. There may be significant grid limitations for large sites even if TAZ-level results show capacity.

CEC staff held a closed beta testing period in May 2023 in which a small set of users tested early functionality and provided feedback and suggestions for improvement. In Q3 2023, the CEC plans to roll out the initial public version of the tool and hold a public workshop to gather feedback and announce the release of the tool. EDGE will be constantly monitored and updated when additional data and more information that are relevant to the analysis become available. The GNA datasets are updated annually to include additional forecast years and future load calculations with expected growth and deficiencies, so that information will be reflected in EDGE as well.

Moreover, CEC staff is exploring a project proposal with a national laboratory to develop a toolset for small to medium utilities to conduct their own analyses to produce results similar to the IOU GNA data. This toolset will allow the creation of an environment in which utilities — primarily publicly owned utilities — would, if the information does not already exist, create data reflecting the physical characteristics of the electric grid system in their service territories. These data would then be housed and managed by the utility and could be queried for integration within the EDGE tool. The project would give utilities the ability to perform power flow analyses on circuit components in their system using circuit-specific EV adoption forecasts and geospatially granular charging load growth projections as the foundation to identify and prioritize impact mitigation solutions. This work would help supplement the large data gaps existing in EDGE and create a more comprehensive understanding of the infrastructure hosting capabilities in specific regions throughout the state.

# CHAPTER 5:

## Meeting California's Charging Needs

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### Near-Term Charging Infrastructure Needs

California's charging infrastructure needs will grow rapidly once ACC II takes effect in 2026, but PEV ownership has already begun to increase, increasing the importance of the state's commitment to support the market as it matures. Charging infrastructure needs for 2030 and 2035 are large but are more subject to uncertainty than near-term needs. In contrast, charging infrastructure needs for 2025 are more predictable as they more directly reflect today's trends. The models in this report estimate that California will need 257,689 public and shared-private chargers, including 15,705 DCFC chargers to support 2.5 million light-duty PEVs by 2025. California has 91,943 public and shared private chargers, including 9,808 DCFC chargers,<sup>78</sup> indicating a shortfall of 165,746 chargers, including 5,897 DCFC chargers that will need to be installed over the next few years to support the vehicles that will be on the road soon. California requires a steady growth of charging infrastructure to ensure that the state can reach its ambitious ZEV targets in 2025 and beyond.

To determine progress toward achieving the state's goal of 250,000 public and shared private chargers by 2025, CEC staff estimates the number of projected charger installations that will occur through 2025 based on funding allocated through state/federal programs, ratepayer-funded programs, and settlement agreements. CEC staff projects that the 250,000 charger goal will be met in 2026. However, the state is well ahead of schedule to meet the 10,000 DCFC goal which is projected to occur by the end of 2023, two years ahead of schedule. Table 11 shows the progress toward meeting California's goal of 250,000 chargers in 2025 and toward the estimated charging needs for 2030 from the models presented in this report.

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<sup>78</sup> California Energy Commission (2022). "[Electric Vehicle Chargers in California.](https://www.energy.ca.gov/zevstats)" Data last updated August 22, 2023. August 23, 2023, from <https://www.energy.ca.gov/zevstats>.

**Table 11: Progress Toward 250,000 Chargers**

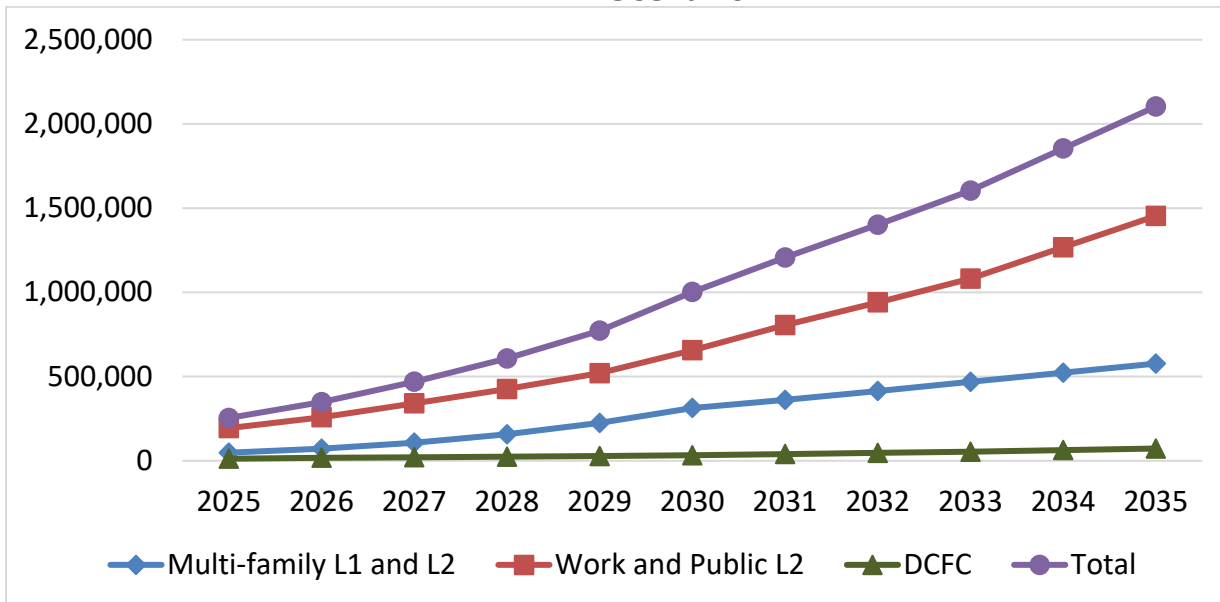
Category	Chargers
Existing Chargers (Estimated)*	91,943
Number of Chargers for Which Funding Has Been Allocated (includes anticipated funding from Clean Transportation Program)**	167,000
<b>Total</b>	<b>258,943</b>
2025 Goal (Executive Order B-48-18)	250,000
<b>Gap From 2025 Goal</b>	<b>0</b>
AB 2127 Report 2030 Estimate of Charging Needs	1,008,844
<b>Gap From 2030 Estimates</b>	<b>749,901</b>

\* Existing charging ports estimated based on available data from U.S. Department of Energy’s Alternative Fuels Data Center and surveys to electric vehicle network service providers, utilities, and public agencies in California. Not included in this table are an estimated 560 statewide public or shared-private Level 1 chargers.

\*\* Estimate of ports from other state programs derived from public presentations and statements by utilities, CPUC, CARB, other entities, and CEC. Includes funding from the State Budget Act of 2021 and State Budget Act of 2022 intended to close the gaps for Level 2 and DC fast chargers; the estimated number of chargers could change as solicitations are released.

Charger needs will increase steadily as more Californians adopt light-duty PEVs. Figure 31 shows annual charger needs from 2025 to 2035 under the primary AATE3 scenario. While California is on track to meet charger needs in 2025, the state will need nearly four times as many chargers in 2030 and more than eight times as many in 2035.

**Figure 31: Total Annual Charger Needs for Light-Duty PEVs Under the AATE3 Scenario**



**The number of chargers serving light-duty PEVs in California will increase steadily through 2035, when California PEVs will need 2.11 million public and shared private chargers, including more than 80,000 DC fast chargers.**

Source: CEC, NREL, and UC Davis

As discussed in Chapter 2, sales of light-duty PEVs (particularly BEVs) increased rapidly in 2021 and 2022, and PEVs made up nearly 19 percent of LDV sales in California in 2022. If sales continue to increase in 2023–2025, California will reach the AATE3 scenario 2025 fleet size assumption of 2.5 million PEVs. If sales increase more rapidly in 2023 and 2024, California may reach 2.5 million PEVs sooner than expected. Annual charger estimates for 2026 could be used to assess charger needs if California reaches a higher PEV fleet size in 2025.

## **Supporting Routine Charging**

An equitable transition to PEVs will require fairly priced and convenient ways for all drivers to meet their routine charging needs. Home charging access is a priority, but residents of multifamily housing, renters, and lower-income households may not be able to install conventional home charging without assistance. The modeling results in this report include a range of potential alternatives to conventional home charging, including expanding home charging access through programs like curbside charging, investment in charging at multifamily housing, and expanded DCFC charging, alongside L2 destination charging.

The expanded at- and near-home charging approach aligns most closely with providing grid-friendly and convenient access. The potential benefits of this approach are that expanding access to charging near home would provide many more households with a charging option that is as convenient as those who have home charging in single-family homes. Long dwell times at home also mean that this option could rely on less expensive charging equipment than a DCFC-heavy scenario while having the flexibility to adjust charging times to minimize cost and support the grid. The potential drawbacks of this approach are that home charging may be more difficult to shift to the daytime than other charging system designs, and that it may require installing more chargers overall than other approaches.

In contrast, the gas station model approach allows more vehicles to be served by a smaller number of chargers and might make it easier to shift charging loads to daytime hours, when more solar energy is available. As DCFC charging speeds increase, more drivers would opt to fit DCFC charging events as brief stops during their regular travel patterns rather than relying on lower-speed charging at longer dwell-time destinations. Because these charging events would be relatively brief, some drivers may be willing to time them to periods of lower demand to minimize charging cost. On the other hand, these charging events may concentrate in commute hours, leading to increased charging loads during times of day when heating and cooling loads are higher and solar generation is low. Because DCFC charging is potentially less convenient and more expensive than charging at home, this approach may be less equitable than increasing charging access at or near homes.

After home charging, L2 charging while at work is the second-most-used routine charging option among PEV drivers. As PEV adoption spreads through the general population, retail, dining, and entertainment work locations may become highly important charging locations for workers while serving many customers who may also want to charge. This availability may require striking a balance between providing shared private charging to ensure that workers who can't charge at home have access to charging at work and providing public charging to support all PEV users. Because home charging access is highly variable throughout California, this balance may vary across the state. EVI-Pro 3 takes an initial look at this issue by

separating work L2 charging by location and access based on the proportion of Californians working in various economic sectors.

Charging flexibility and timing are key considerations for ensuring that transportation electrification supports the grid. Home L2 charging is inherently the most flexible option, but it generally concentrates charging at night. Because L2 charging times are much shorter than the amount of time most people spend at home overnight or the energy needed for average daily driving, home charging events could be shifted substantially within this window without inconveniencing drivers. TOU rates could be one method of achieving this, but less rigid methods like charging management systems may be required to optimize charging loads for grid health and clean energy.

DC fast charging sessions are shorter than L2 charging sessions but are normally done as part of a trip rather than at a destination. Gas-station-style DCFC has the potential to concentrate charging during regular travel times, adding electrical load at times when other load may be increasing on the grid, like early morning in winter and late afternoon in summer and fall. Pricing by time of day may be one way to shift DCFC loads into the most desirable times of day for the grid and clean energy. Work charging may be less flexible than either home L2 or DCFC, but most people work during the day, when solar energy is most plentiful, meaning it may be unnecessary to shift this load.



# CHAPTER 6:

## Vehicle-Grid Integration

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Vehicle-grid integration (VGI) can play a powerful role preparing the electric system to accommodate new charging load reliably and cost-effectively. VGI describes technologies and strategies that allow users to alter the charging behavior of PEVs in a manner that benefits the grid while ensuring driver needs are met. By taking advantage of the flexibility of the charging schedule of a vehicle<sup>79</sup> or by intelligently integrating with local electric loads and generation, VGI can shift and adjust the charging load on the grid. VGI technologies and strategies can help maximize customer savings, minimize carbon emissions, and support reliable and economic power grid operation. VGI appears in various forms, including:

- **Smart charging**, also called managed charging or V1G, which adjusts charging time or power level in response to utility rates, demand response events, local site controllers, or other signals.
- **Bidirectional charging**, which enables a PEV to export energy from its onboard battery to buildings (vehicle-to-building [V2B]), homes (vehicle-to-home [V2H]), or to the grid (vehicle-to-grid [V2G]). When equipped with the appropriate power electronics and electrical switching,<sup>80</sup> bidirectional charging can provide power to a site during a grid outage.
- **Automated load management (ALM) systems**, which manage charging load with the objective of reducing or eliminating the need for electrical capacity upgrades on the utility or customer side of the meter or both.<sup>81</sup>
- **Distributed energy resource (DER) supported charging systems**, which integrate one or more chargers with DERs<sup>82</sup> to reduce or time-shift electric load on the grid without compromising the charging experience. Examples include individual chargers featuring both a grid connection and an integrated battery, and multiple chargers supported by on-site solar generation and storage.

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79 PEVs are often plugged in for several hours but typically only need to charge for a small portion of that time, resulting in a scheduling flexibility for when the charge occurs.

80 Bidirectional charging for backup power in particular may require other hardware such as transfer switches (to disconnect the site from the distribution system) and additional panels to isolate critical loads. Furthermore, power electronics used for backup power must be capable of independently generating voltages to support local loads. The number of additional “boxes” needed to enable bidirectional charging will depend on the features requested by the customer and the electrical architecture used by the automaker and charger manufacturer.

81 This definition is used by [CPUC](#). Importantly, ALM may enable a project to safely oversubscribe a breaker, panel, or other applicable point of electrical connection.

82 DERs are decentralized generation or storage devices connected to the distribution grid. DERs include rooftop solar photovoltaics, on-site batteries and other energy storage systems, and electric vehicles. As noted later in this chapter, the CPUC’s High DER Rulemaking (R.21-06-017) is exploring options to ensure the grid can support the growing number of DERs on the grid.

With broader consumer acceptance and thoughtfully designed products and programs, VGI could provide significant benefits to the electrical grid and customers, including drivers, ride-hail services, fleet managers, and so on. For example, smart charging can help drivers charge with cheaper and cleaner electricity by automatically shifting charging to times when electricity prices and emissions are lowest. Customers with bidirectional charging may enjoy greater energy resilience by using their vehicle as a zero-emission power source during times of high electricity prices, during a grid outage, or while visiting areas that are off-grid. VGI can even provide benefits during the charger deployment process itself. ALM can help a site owner maximize the number of chargers installed using the existing electrical capacity at a site, potentially yielding a less expensive and quicker deployment by reducing or eliminating the need for upgrades to the site electrical system or the existing connection to the grid.

In addition to customer benefits, VGI also strengthens grid operations and reliability. Using strategies such as electric rates that reflect electric system conditions, electric system operators can reward customers for charging during periods of abundant renewable generation with lower prices and, correspondingly, create an incentive for customers to avoid charging during periods of peak electricity demand with relatively higher prices.

With bidirectional charging, PEVs could export power to homes, facilities, or the grid to reduce electricity demand during peak hours or provide emergency electricity resources during a Flex Alert. Such benefits are not theoretical: SDG&E, Cajon Valley Union School District, and Nuvve launched a V2G project last year that enabled electric school buses to earn compensation for sending power back to the grid during peak grid conditions.<sup>83</sup> Building on Cajon Valley's success, several other school districts across California are already activating similar capabilities.

For VGI generally, the win-win aspects are not limited to improving customer benefits and addressing grid conditions. Widespread VGI (and load flexibility<sup>84</sup> generally) will help achieve California's climate and decarbonization goals. In the first edition of this report, the CEC wrote: "To fully realize the economic, air quality, and climate benefits of electrification, California must pursue greater vehicle-grid integration, the coordination of charging with grid needs, to ensure that charging is better aligned with clean, renewable electricity without sacrificing driver convenience." The need for load flexibility, which includes VGI, has been repeatedly

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83 Sempra. 2022. ["SDG&E and Cajon Valley Union School District Flip the Switch on Region's First Vehicle-to-Grid Project Featuring Local Electric School Buses Capable of Sending Power to the Grid,"](https://www.sempra.com/sdge-and-cajon-valley-union-school-district-flip-switch-regions-first-vehicle-grid-project) <https://www.sempra.com/sdge-and-cajon-valley-union-school-district-flip-switch-regions-first-vehicle-grid-project>.

84 *Load flexibility* refers to the ability of electric customers to shift the electricity consumption of devices, appliances, or other loads in response to electricity prices or other signals. VGI can be viewed as load flexibility applied to vehicle charging.

confirmed in subsequent reports from the CEC,<sup>85</sup> CPUC,<sup>86</sup> and others.<sup>87</sup> Accordingly, the remainder of this chapter describes a collaborative vision and framework for achieving widespread VGI in California.

## A Framework for Widespread VGI

To support full electrification of transportation, VGI products and programs should be widely available, be customer friendly, and serve as a reliable tool to aid grid operations. Given the immense potential and need for VGI, products and policies must continue to evolve to support a seamless, customer-friendly, and scalable VGI ecosystem. CEC has identified five broad areas in need of advancement to attain widespread VGI:

1. **Compensation structures.** To enable and reward widespread load flexibility, California must continue to improve rate design structures and other compensation programs to reflect true grid conditions. This improvement includes further developing dynamic tariffs that better reflect the benefits VGI can provide to the grid, as well as other nonrate compensation programs.
2. **Customer products and services.** Today, the array of incompatible connectors and communication protocols has resulted in customer and market confusion. Even when connectors and communications are aligned, many charging products and services do not support VGI features such as automated smart charging or bidirectional charging. Improved interoperability along with innovation in charging products and services from private industry will help ensure that customers have easy, affordable access to VGI capabilities.
3. **Site-level electrical readiness.** The ability to plug in a vehicle is a prerequisite to most forms of VGI, and it is not possible to optimize the charging behavior of a vehicle if the vehicle is unable to connect electrically for a charge. Investments in site-level electrical readiness will increase customer access to and participation in VGI.
4. **EV and grid planning processes.** VGI products and services are in an early commercialization stage and have seen limited deployment to date, and limited data exist. As such, CEC and other agencies have captured only load shifting from time-of-

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85 The joint agency SB 100 report found that “prioritizing ... load-flexibility measures remains critical as the state moves toward a 100 percent clean electricity future.” California Energy Commission. 2021. [SB 100 Joint Agency Report: Charging a path to a 100% Clean Energy Future](https://efiling.energy.ca.gov/EFiling/GetFile.aspx?tn=237167&DocumentContentId=70349), <https://efiling.energy.ca.gov/EFiling/GetFile.aspx?tn=237167&DocumentContentId=70349>

86 CPUC states that “going forward it is essential for California to leverage ... demand flexibility management as a critical resource in integrated resource planning (IRP) to meet the State’s aggressive GHG emissions reduction targets.” Madduri, Achintya, Masoud Foudeh, Paul Phillips. 2022. [“Advanced Strategies for Demand Flexibility Management and Customer DER Compensation,”](https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf) California Public Utilities Commission, <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf>.

87 An NREL report found that demand flexibility could significantly reduce costs associated with deep decarbonization. O’Shaughnessy, Eric, Monisha Shah. 2021. [“The Demand-Side Opportunity: The Roles of Distributed Solar and Building Energy Systems in a Decarbonized Grid,”](https://www.nrel.gov/docs/fy21osti/80527.pdf) National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy21osti/80527.pdf>

use rates in their demand forecasting and not fully considered other potential effects. Continued monitoring of the benefits of VGI can help improve forecasting and planning and eventually consider additional VGI options from the outset. This monitoring could mean more accurate assessments of the need and scale of charging infrastructure and grid upgrades.

5. **Customer ease, confidence, and enrollment.** Customers may not understand the potential bill savings, carbon emission reductions, and other benefits enabled by load flexibility and VGI. Even those who do may hesitate to enroll in unfamiliar VGI rates or programs. Customer-friendly utility enrollment processes, increased product choices, and education campaigns may improve customer confidence and willingness to participate in VGI.

The success of VGI relies on coordination across automakers, charging providers, utilities, automation service providers, regulators, and others; no single entity is entirely responsible for resolving any of the challenges described above. CEC actions can play a role in all five areas, and the remainder of this chapter describes current and planned CEC actions addressing each of these challenges, as well as those from other VGI stakeholders.

## **VGI Advancement 1: Compensation Structures**

A broad portfolio of compensation structures to reward customers for adjusting their charging behavior in response to grid conditions is foundational to VGI. Today's electricity rates do not always reflect real-time grid conditions and, therefore, do not consistently reward customers for consuming electricity in grid-friendly ways.<sup>88</sup> In other words, customers today are not provided with the information or incentives needed to consistently encourage grid-friendly charging, and stakeholders frequently cite the lack of these compensation structures as a primary reason why VGI has struggled to scale.<sup>89</sup>

To support VGI and decarbonization more broadly, CEC, CPUC, utilities, and community choice aggregators (CCAs)<sup>90</sup> are investigating rates and other programs that better reflect grid

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88 For example, as noted earlier, most time-of-use rates offer the lowest prices in the middle of the night even on days when grid operators are forced to curtail surplus solar generation during the day. Time-of-use rates are helpful for shifting consumption away from existing peaks but do not sufficiently encourage load shift in response to actual grid conditions. A CPUC paper found that "57% of the highest-priced intervals for wholesale energy prices fell outside the TOU on-peak period." Madduri, Achintya, Masoud Foudeh, Paul Phillips. 2022. ["Advanced Strategies for Demand Flexibility Management and Customer DER Compensation,"](https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf) California Public Utilities Commission, <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf>.

89 For example, in a broad assessment of barriers to VGI, the [final report](https://gridworks.org/wp-content/uploads/2020/07/VGI-Working-Group-Final-Report-6.30.20.pdf) of the California Joint Agencies VGI Working Group wrote, "Retail EV charging rates should reflect cost of generation, delivery, GHG, and other relevant value streams; all EV charging rates should be time-variant, starting with simple TOU rates and then enabling optional alternatives such as dynamic rates." California Public Utilities Commission. 2020. [Final Report of the California Joint Agencies Vehicle-Grid Integration Working Group](https://gridworks.org/wp-content/uploads/2020/07/VGI-Working-Group-Final-Report-6.30.20.pdf), <https://gridworks.org/wp-content/uploads/2020/07/VGI-Working-Group-Final-Report-6.30.20.pdf>.

90 Community choice aggregators procure energy for electricity users in a community or region. CCAs do not operate electric distribution infrastructure, and electricity procured by CCAs is delivered via existing distribution infrastructure typically operated by a utility.

conditions. Time-varying rates (including time-of-use rates and hourly or even subhourly dynamic rates), for example, typically encourage consumption during periods of grid abundance with lower prices and encourage load reductions or even export during periods of grid strain with higher prices. Earlier this year, CPUC staff outlined a rate design framework that could enable widespread load flexibility by providing customers with a unified electricity price capturing several electric system factors in real time, including wholesale energy cost, generation capacity, and distribution capacity.<sup>91</sup> This technology-agnostic rate design is distinct from the current and past approaches to rates, which have often emphasized EV-specific or other technology-specific rate structures. Similarly, in October 2022, the CEC approved revisions to its Load Management Standards, which would require California’s largest utilities to develop and propose dynamic rates that reflect actual grid conditions for all customer types. The updated Load Management Standards will spur the development and availability of innovative dynamic rates, and some utilities and CCAs across the state are already launching such rates to select customers, including PG&E,<sup>92</sup> SDG&E, SCE,<sup>93</sup> Valley Clean Energy,<sup>94</sup> and others.

Importantly, the revised Load Management Standards also direct utilities to upload their current and future electricity rates onto CEC’s Market Informed Demand Automation Server, or MIDAS. MIDAS is an internet-accessible database housing current electricity rates, carbon emissions data, and Flex Alert status in machine-readable formats.<sup>95</sup> In practice, MIDAS enables internet-connected devices such as smart EV chargers or thermostats to look up the customer’s electricity rate automatically and optimize electricity consumption around price. This automation afforded by MIDAS reduces or eliminates the need for customers to program their charger manually and makes it more practical and convenient for customers to enroll in rates that may update at hourly or even subhourly intervals.

While improved electricity rates may help support widespread VGI, other signaling structures such as virtual power plant programs and demand response could play significant roles as well. In 2021, the CPUC directed utilities to launch the Emergency Load Reduction Program (ELRP), which rewards customer load reductions during grid emergency events at \$2/kWh.<sup>96</sup> The CEC launched the complementary Demand Side Grid Support Program in 2022, which provides similar levels of incentives for load reductions by customers served by utilities not under CPUC jurisdiction. Both programs allow the participation of vehicle charging through “VGI aggregators.”

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91 CPUC termed this approach California Flexible Unified Signal for Energy, or [CalFUSE](#).

92 For example, PG&E’s upcoming [Day Ahead Hourly Real Time Pricing](#) EV rate.

93 [SCE is partnering with TeMix](#) to pilot a dynamic transactive energy rate.

94 [Valley Clean Energy](#) is partnering with TeMix and Polaris Energy Services to pilot a dynamic transactive energy rate for agricultural irrigation.

95 “Machine readable” means that data are stored in a standardized format across utilities. This storage ensures grid signals can be easily accessed and processed by devices, computers, software, and so on.

96 The ELRP received widespread media attention following the September 2022 heat storms. Aggregators such as OhmConnect and PowerFlex leveraged ELRP to compensate customers for emergency load reductions.

Customer value and compensation are not limited to bill savings or payments from utilities, and some customers may be more likely to respond to nonmonetary signals. For example, some customers may prefer to optimize charging around the availability of low-carbon or carbon-free electricity (instead of price signals), and others may rely on local signals from a site controller and eschew external signals entirely.<sup>97</sup> Alternatively, companies such as ev.energy and OhmConnect disburse point-based currencies for grid-friendly consumption, and customers can use these points to redeem merchandise, prizes, and other rewards. Similar gamification strategies may yield greater customer interest or more sustained participation than bill savings alone.

The various compensation structures described above provide customers — who ultimately make decisions about their charging behavior — with value and incentives for pursuing VGI and responding to grid conditions. Thoughtfully designed and widely available compensation structures will be the basis for why a typical customer will take an interest in VGI. California will benefit from a broad portfolio of VGI compensation and value structures to serve diverse customers effectively with diverse needs and priorities.

## **VGI Advancement 2: Customer Products and Services**

As grid- and customer-friendly compensation options become increasingly available, Californians will need access to a range of affordable, interoperable VGI products and services<sup>98</sup> to help them easily and confidently generate value from VGI. Most customers view their vehicles primarily as transportation tools, and broad VGI participation will require simple-to-use products and services that deliver clear benefits to the customer. While some power users may enjoy personally optimizing their charging around grid conditions, electricity prices, and expected departure time, most customers will rely on products and services from third parties to manage their relationship with the grid while maintaining an automated and straightforward charging experience. To support industry in developing these products and services, CEC has focused efforts on advancing VGI capabilities and interoperability.

### **VGI Capabilities**

Charging products can come in many forms, including chargers, charge management software, automation service providers<sup>99</sup> that connect to a charger or a vehicle, charging controllers, and so on. While charging products already exist on the market today, many make it cumbersome for the customer to participate in VGI, and some offer no VGI capabilities at all. For instance, many home chargers are “nonnetworked” and incapable of connecting to the

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97 For example, a site with rooftop solar may schedule charging around the availability of surplus solar generation and current demand from other site loads as indicated by a site energy management system.

98 “VGI products and services” is used to broadly capture anything that helps customers manage vehicle charging while considering grid conditions. These may include chargers, charge management software, automation services which connect to a charger or a vehicle, and so on. Such products are typically offered by “third party” companies — that is, entities that enable a more seamless relationship between the customer (the first party) and the utility or electric system (the second party).

99 Automation service providers and aggregators help customers manage, monitor, and control electricity usage on their devices such as EV chargers, smart light switches, smart thermostats, and so on. Automation service providers and aggregators typically manage many devices across many customers.



internet to retrieve electricity prices or other grid signals.<sup>100</sup> Product gaps are even greater with bidirectional charging; standards supporting bidirectional charging were only recently finalized (others are in the process of being finalized), few bidirectional charger models exist today, and those that do are offered only through select purveyors.<sup>101</sup>

To help remedy existing gaps, CEC is directing funds to support the development of products with customer-friendly<sup>102</sup> and intelligent VGI capabilities. The Response Easy Charging Products With Dynamic Signals (REDWDS) funding solicitation is intended to provide companies with resources to integrate products with real-time grid signals, improve algorithms to optimize charging around grid conditions and customer preferences, and develop strategies to ensure sustained customer participation, understanding, and value.<sup>103</sup> Importantly, the appropriate level of charging optimization in response to grid signals will vary by customer and use case. For example, to preserve a reliable customer experience, high-power public chargers may have limited or no opportunities to shift charging in response to price signals.

In addition to supporting product development, CEC will also direct funding toward helping markets create economies of scale. For example, as part of the REDWDS solicitation, awardees must also outline plans to deploy their developed product to a minimum number of customers across California and help customers enroll in dynamic rates. Similarly, CEC's draft Clean Energy Reliability Investment Plan calls for rapidly scaling flexible load resources and notes, "Funding could be used to support rapid scale up of VGI and V2B, particularly in collaboration with electric vehicle infrastructure buildout funded through separate programs."<sup>104</sup> CEC is also

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100 Similarly, most vehicles do not offer a way to look up electricity rates (even those with a telematics connection), forcing drivers to manually program a charging schedule — a user experience that is too involved for many customers and results in unrealized smart charging opportunities.

101 While CEC investments generally focus on charging and supporting infrastructure, implementation of VGI capabilities in vehicles is also necessary. Helpfully, a growing number of automakers have announced bidirectional capability in available or upcoming vehicle models, including [Ford](#), [GM](#), [Hyundai](#), [Lucid](#), [Nissan](#), and others.

102 "Customer friendly" is broadly defined and means any product that delivers perceived value for the customer in an understandable and frictionless way. Given that different customers have different needs and preferences, customer-friendly products can appear in different forms. For example, some customers may prefer a charging product that simply helps them maximize savings on their electricity bill through intelligent scheduling. Others respond better to a charging product that offers an attractively priced "subscription" for their charging needs in exchange for flexibility in their charging schedule, or a product that rewards grid-friendly charging with points, tiers, and other gamification. CEC funds, including through REDWDS, can help industry explore a variety of customer-friendly approaches and business models.

103 REDWDS funding could be used, for example, to develop algorithms that help minimize requests for customer input and automate charge scheduling by "learning" the customer's charging needs, similar to how smart thermostats "learn" the appropriate times to heat or cool a home. Funding could also be used to develop capabilities for a bidirectional charger to minimize charging cost while maximizing earnings from exports, potentially reducing charging costs to zero or even helping drivers earn money with their vehicles. This sort of product innovation and exploration will not only ensure that more products come equipped with VGI capabilities, but that these products provide benefits to customers by going beyond simply ensuring their vehicle is charged.

104 In September 2022, the passage of SB 846 tasked CEC with developing a [Clean Energy Reliability Investment Plan](#). SB 846 authorizes up to \$1 billion for the implementation of the Clean Energy Reliability Investment Plan.

exploring the potential for increased rebate amounts for bidirectional chargers in charger rebate block grants such as EnergiIZE.<sup>105</sup>

## **Interoperability**

A fundamental pillar of CEC’s approach to charging infrastructure deployment is a focus on interoperability. Interoperability, which enables different products to seamlessly work together without special effort by the user, yields critical customer experience benefits that will help ensure that charging is consistently accessible, simple, and grid-informed. Charging connector interoperability is the most visual and obvious example of interoperability, and much of the industry has made clear progress toward standardizing around the CCS connector for fast charging. Less obvious and equally important is interoperability of charging communication, which helps ensure that vehicles, chargers, and other actors supporting a particular charging session can exchange the necessary information to optimize charging around the grid and the driver. The CEC places particular emphasis on two key communication protocols to support interoperability in charger deployment activities: Open Charge Point Protocol (OCPP) and International Organization for Standardization (ISO) 15118.

OCPP is commonly used for communication between the charger and network software, and ISO 15118 is used for communication between the charger and the vehicle. Because a vehicle and charger are present in every charging session, standardizing communication at this “front” end with these protocols guarantees a consistent way to translate information from a wide variety of sources in the “back” end.<sup>106</sup> For example, as shown in Figure 32, OCPP and ISO 15118 ensure that the vehicle and charger can be informed of grid conditions. This information can come in the form of a price (using data provided by a utility or through MIDAS), a signal from the utility encouraging a load reduction (using a protocol such as IEEE 2030.5 or OpenADR), or a local load management signal (sent from an on-site controller). Going the other direction, standardized front-end protocols enable a vehicle to communicate needs, such as the total energy needed during a charge session, to a home charger, a charging network that manages many chargers, or a transactive energy platform. In short, interoperable charger communication provides a consistent and scalable platform for VGI innovation by unlocking the flexibility to accommodate diverse compensation frameworks, business models, and product types.<sup>107</sup>

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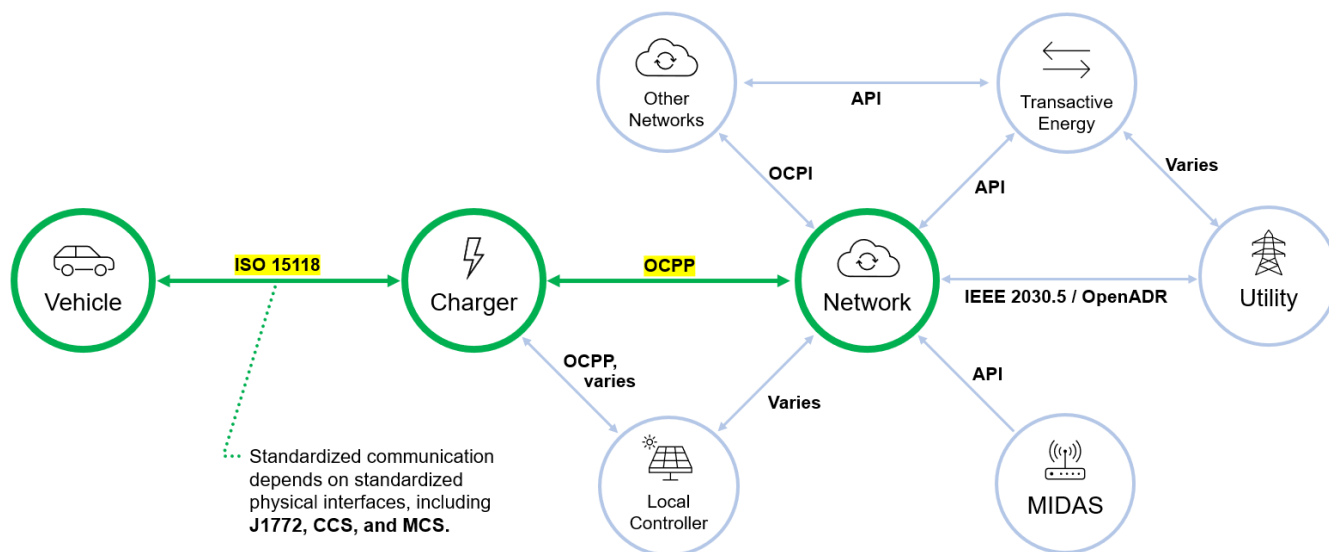
105 During a July 2022 [workshop](#) on VGI funding concepts, CEC staff sought feedback on expanded rebates for bidirectional chargers.

106 While OCPP and ISO 15118 are not the only communication protocols available, they are the most widely adopted among industry globally and thus the most appropriate baseline for interoperable and standardized communication. Other protocols exist for some portions of the communication link, such as Controller Area Network communication, IEEE 2030.5, proprietary telematics links, proprietary charger communication, custom application programming interfaces, and so forth. However, these do not provide the feature set, scalability, and global market adoption afforded by OCPP and ISO 15118.

107 Both OCPP and ISO 15118 present interoperability benefits beyond VGI. The charger-network interoperability afforded by OCPP enables a site host to manage a variety of different OCPP-compliant charger brands and models under any OCPP-compliant management software product, expanding choice and preventing vendor lock in. Likewise, a driver with an OCPP-compliant home charger can switch between different management software products based on cost, features, or other factors – much like how an unlocked cell phone can switch among



**Figure 32: Key Interfaces and Communication Protocols to Enable Flexible VGI**



**Given that the vehicle and charger are present in every charging event, standardizing communication at this front end around globally aligned protocols (ISO 15118 and OCPP, highlighted) will support economies of scale and market certainty. In concert, ISO 15118 and OCPP provide a consistent and flexible platform to accommodate diverse VGI business models and backend signaling schemes.**

Source: CEC staff

Implementation of ISO 15118 — the protocol for digital communication between a charger and a vehicle — is especially important for bidirectional charging. The latest version, ISO 15118-20, includes provisions for standardized and cybersecure bidirectional charging controls.<sup>108</sup> These provisions pave the way for a future where any electric vehicle that supports bidirectional charging could supply power to a home, a neighbor’s home, a local library, or community center, or a microgrid. Following publication in mid-2022, stakeholders have indicated plans to begin implementing ISO 15118-20 to enable bidirectional charging.<sup>109</sup>

While the ISO 15118-20 standard provides a technical basis for interoperable bidirectional charging, unresolved utility policy challenges remain. Bidirectional chargers that export to or operate in parallel with the grid must undergo a utility process called *interconnection* before

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different networks. ISO 15118 enables “plug and charge,” which enables a driver to start and pay for a charging session simply by plugging in. These customer benefits are additional non-VGI reasons why CEC maintains a strong emphasis on charger communication interoperability.

108 International Organization for Standardization. 2022. “[ISO 15118-20:2022 Road vehicles – Vehicle to grid communication interface – Part 20: 2nd generation network layer and application layer requirements,](https://www.iso.org/standard/77845.html)” <https://www.iso.org/standard/77845.html>

109 For example, [BMW](#), [In-Charge](#), [Shell](#), [Switch](#).

powering on.<sup>110</sup> DC bidirectional charging<sup>111</sup> using ISO 15118 for charger-vehicle communication complies with existing California utility interconnection requirements and is being implemented and offered by various companies. AC bidirectional charging may yield total cost advantages over the DC approach. While ISO 15118 also supports AC bidirectional charging, the current standard does not include provisions for communicating certain grid parameters required by many California utilities for interconnection.<sup>112</sup> To avoid the need for different communication standards in different parts of the world, industry workgroups are discussing the gaps that must be addressed in ISO 15118 and OCPP to support communication of grid parameters, such as those required in California.<sup>113</sup> Other groups are working on methods to enable AC bidirectional charging using standards besides ISO 15118, though it remains to be seen whether automakers and charging providers have appetite for implementing additional communication standards.<sup>114</sup>

To support the adoption and use of interoperable communication protocols, CEC will require that all chargers funded through its block grant rebate projects — CALeVIP, Communities In Charge, and EnergIIZE — be, at minimum, hardware-ready for ISO 15118 communication and certified for OCPP compliance beginning July 2023.<sup>115</sup> These technical requirements represent a floor and are the same as those used by the CPUC for ratepayer-funded charging investments, providing alignment and consistency across state agencies.<sup>116</sup> Incorporating ISO 15118-ready requirements in CEC block grants and other solicitations ensures that publicly funded chargers can receive software updates to activate various VGI use cases, even if that software is not available when the equipment is initially installed. The July 2023 phase-in date for these requirements is supported by industry trends. CEC is not aware of any CCS DC

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110 “Interconnection” specifically refers to the utility process for connecting a generating source (such as a vehicle, a battery, or solar photovoltaics) onto the utility distribution system, and requirements for interconnection with California utilities are often described in a document called “Rule 21.” Interconnection is distinct from “energization,” which is used when discussing non-generating loads such as a one-way charger. Bidirectional chargers that never interact with the grid are not subject to utility interconnection.

111 Bidirectional charging is typically divided into two types, AC and DC.

112 Notably, Rule 21 requires that generating sources be capable of receiving information describing how the source should respond to electric system abnormalities. Examples include volt-watt and frequency-watt response curves.

113 CharIN and other industry groups have begun discussing gaps among ISO 15118, Institute of Electrical and Electronics Engineers (IEEE) 1547, and Rule 21. Rule 21 requirements are based on IEEE 1547. Separately, the Open Charge Alliance is developing updates to OCPP to include communication of grid codes, including those required by Rule 21.

114 SAE and UL are defining an approach for AC bidirectional charging that relies on SAE J3072 and UL 1741 Supplement C. This architecture would use IEEE 2030.5 for communication between grid operators, the charger, and the vehicle. To date, CEC is not aware of any commercially available PEVs that have implemented IEEE 2030.5 for charging communication.

115 CEC developed a definition for “ISO 15118-ready” through an expansive effort in 2021–2022, which included dozens of stakeholder conversations, a public workshop, and many docketed comments.

116 In its August 2022 [submetering decision](#), CPUC required all ratepayer funded EVSE to be ISO 15118 Ready and OCPP compliant and certified beginning July 2023. The CPUC reaffirmed these requirements in November 2022 as part of its [decision on transportation electrification funding](#).

chargers that are not already ISO 15118-ready, and staff tallied more than 30 ISO 15118-ready AC charger models as of late 2022.<sup>117</sup>

While the standards discussed above are applicable to the charger, various methods for VGI not involving the charger also exist. Some stakeholders raise the possibility for vehicles to retrieve electricity rates and other grid signals using telematics,<sup>118</sup> thus enabling managed charging even without a smart charger. Telematics-based managed charging may be an appropriate and lightweight solution for customers whose vehicles support the feature, particularly for home charging where the customer location and rate are consistent and known. The telematics approach may be less useful for enabling VGI away from home, as telematics systems lack the ability to coordinate with local site controllers (for example, automated load management systems) and likely do not have access to relevant grid signals at every location visited by the vehicle. Further, there are ongoing efforts at utilities and the CPUC to determine whether telematics-based submetering is appropriate. (Submetering is distinct from managed charging control.)<sup>119</sup> Telematics-based managed charging can complement smart chargers as part of a multifaceted strategy to maximize opportunities for VGI in California.

### **VGI Advancement 3: Site-Level Electrical Readiness**

A prerequisite to widespread VGI is site-level electrical readiness to support installation of charging infrastructure. Drivers must be able to plug in for a charge before they can even consider opportunities for VGI. Failure to adequately prepare homes and other sites with sufficient electrical infrastructure for charging will impede VGI. Parties from across the VGI ecosystem must pursue a variety of strategies to maximize site electrical readiness in preparation for widespread VGI, including building codes for new construction, site electrical upgrades for existing buildings, and various load management strategies.

New construction in California is subject to the California Green Building Standards Code, or CALGreen, which already requires a minimum level of electrical capacity to support EV charging based on the building type, number of parking spaces on site, and, in some

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117 To further aid the industry's implementation of these standards, CEC funded DEKRA to open the Vehicle Grid Innovation Lab (ViGIL), which provides a la carte conformance testing and certification services for chargers. Furthermore, the CEC funded Innos to host a Vehicle Interoperability Testing Symposium (VOLTS) in 2023 which will provide a collaborative environment for automakers and charging providers to participate in round robin interoperability testing and discuss current engineering challenges.

118 Vehicle telematics systems enable vehicles to communicate information with the automaker's back office. Telematics is often used to transmit basic vehicle commands (such as unlocking doors via an app) and may require a monthly subscription fee. Vehicle telematics implementations are not standardized and are often unique to each automaker, presenting challenges for interoperability and scale.

119 Importantly, this section describes telematics-based charging control. CEC and other state agencies only recently began to evaluate the possibility and usefulness of telematics-based metering for billing purposes. On metering, the CPUC, through D.22-08-024, determined it is "... premature to move forward with telematics at this time." CPUC and the IOUs will host a public workshop in 2023 to explore telematics related issues, with modifications or amendments to the PEV Submetering Protocol to include telematics a possible consideration if parties can justify the need for the CPUC to continue pursuing the issue.

instances, the full installation of a minimum number of chargers.<sup>120</sup> Importantly, CALGreen includes provisions permitting the use of ALM to reduce the total electrical capacity needed for code compliance.

Unlike new construction, many existing sites in California — including homes, apartments, churches, commercial sites — are not well-equipped to host vehicle charging due to limited electrical capacity. Legacy electrical panels used at older buildings typically have lower current ratings and few breaker slots, and often cannot easily accommodate an EV charger or other additional loads. In some cases, it may be appropriate to replace the existing panel with an upgraded one, particularly if the site is also planning to electrify other loads or install new DERs. Panel upgrades can be expensive and cost several thousand dollars for a residential site. However, many utilities are already offering or developing programs to offset the cost of the retrofit.<sup>121</sup> With bidirectional charging, additional electrical equipment may be required at the site such as inverters, subpanels, and transfer switches (which disconnect a site from the distribution system before activating backup power).

Given the cost of panel upgrades, some companies are exploring alternative pathways that rely on sharing circuits among different appliances or tapping into the utility meter socket to add an additional circuit (or multiple additional circuits) without modifying the existing panel.<sup>122</sup> These solutions may present lower-cost options to homeowners, renters, or other building managers who want to defer or potentially avoid a full panel upgrade.

Beyond simply ensuring sufficient wires and other physical electrical infrastructure, “nonwire” load management solutions can help maximize the use of existing electrical infrastructure at a site. ALM, for example, can intelligently coordinate power among several chargers as needed, taking advantage of the fact that chargers at a site are not typically all used at the same time.<sup>123</sup> ALM can enable a site host to share a single circuit or panel among multiple chargers, netting more total connectors and serving more drivers than would have been possible without ALM. In some cases, ALM may defer the need for customer- or utility-side upgrades, yielding lower cost per connector and shorter deployment times. ALM is especially important for charging deployments featuring many chargers, and numerous California companies are already deploying ALM at sites across the state.

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120 For example, the 2022 CALGreen revision (effective January 2023) requires a newly constructed site with 30 parking spots to include at least 8 parking spots with electrical capacity to support charging, and at least 2 of these spots to also include full installation of a Level 2 charger. For sites with more than 200 parking spots, at least 20 percent of the parking spots must be equipped with electrical capacity to support charging, and at least 25 percent of these must be further equipped with a Level 2 charger.

121 For example, SCE will provide [up to \\$3,600](#), and SMUD will provide [up to \\$2,500](#) in rebates for residential panel upgrades.

122 For example, [NeoCharge](#) offers an adapter that manages power from a single NEMA outlet among several 240 V loads (such as dryers and EV chargers). [ConnectDER is working with Siemens](#) to develop a device that can add a circuit for charging through the meter socket.

123 For instance, a 50 amp circuit could normally accommodate a 9.6 kilowatt charger at 40 amps. With ALMS, multiple chargers could be connected to the 50 amp circuit, with each charger adjusting the power delivered to a plugged-in vehicle up or down as needed to stay below the circuit limit. ALMS may enable a single circuit to serve more electricity across more vehicles than would have been possible without ALMS.

Like ALM, pairing vehicle charging with battery storage, local generation, and other DERs can also maximize the use of existing electrical infrastructure and create a buffer to soften the charging load seen by the grid. On-site stationary storage or generation (such as a solar canopy) can supplement electricity delivered by the grid, help reduce peak usage electricity fees,<sup>124</sup> and minimize or eliminate the need for electrical upgrades.<sup>125</sup> Likewise, battery swapping and chargers with built-in batteries<sup>126</sup> achieve similar grid benefits by leveraging batteries as a buffer against surges in customer charging demand. Such solutions may be cost-effective when considering costs beyond the charging hardware itself, such as expenses and wait times for site and utility upgrades. To simplify the integration of DERs with charging, many charging providers have begun offering “charging as a service” packages, which include site design and deployment in addition to charger installation and operation. Both ALM and DER-integrated charging will be crucial in the near term as California faces grid component supply shortages and may support an accelerated energization timelines for sites that would otherwise need capacity upgrades.<sup>127</sup>

As charging technologies move toward megawatt-level power to support electrification of tractors and other large vehicles, on-site storage and generation may be necessary in some cases to supplement existing and available utility power. For example, WattEV’s planned electric truck stop in Bakersfield will initially feature 5 MW of solar generation and 4.5 MWh of storage capacity in addition to a 4 MW grid connection.<sup>128</sup>

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124 “Demand charges” are billed by the utility based on the peak power usage at a site. Batteries and other generation can help a site “flatten the curve” to reduce peak power usage and therefore demand charges.

125 For example, Electrify America recently [expanded the use](#) of on-site storage and solar to support additional DC fast chargers. Electrify America notes that some sites already exceed 1 MW of electrical load during times of higher customer demand.

126 For example, Freewire’s Boost DC fast charger uses a 27 kW grid connection and a 160 kWh built-in battery to provide 150 kW of charge power to a vehicle. Such products offer customers a prepackaged solution that avoids the need for additional site integration design and construction.

127 The ability of ALMS and DER integration to reduce or eliminate utility upgrades is especially important, given concerns about utility energization timelines (see “16. Service Energization Timing Expectation” in [E-5167](#)) and nationwide grid component [supply shortages](#). The federal government reports that lead times for transformers — equipment needed for electrical capacity upgrades — have increased to more than two years for larger transformers. In response to these challenges, the CPUC [established](#) a 125-day target for average energization time, and the federal government is [exploring the use of the Defense Production Act](#) to expand domestic grid component manufacturing capacity. Additional state and federal assistance may be appropriate to help utilities prepare for accelerated electrification.

128 WattEV [plans](#) up to 40 MW of solar generation on site to support several MW-level truck chargers.

## VGI Advancement 4: EV and Grid Planning Processes

The CEC and CPUC have supported the maturation of the VGI ecosystem through various proceedings,<sup>129</sup> rates,<sup>130</sup> and technology investments.<sup>131</sup> In addition to these efforts, there are opportunities to better incorporate VGI into EV and grid planning at both state agencies. Providing assurance on the state's direction within planning can increase stakeholder buy-in and decrease uncertainty. Conversely, there must be some degree of assurance that VGI benefits and claims can be verified and relied upon when conducting grid planning.

Specifically, the CEC and CPUC are embarking on an effort to better align various internal modeling efforts and ensure that results from CEC models are appropriately transmitted to the CPUC to inform utility planning efforts. There are two key VGI-related modeling efforts at CEC:

- EV modeling: The Fuels and Transportation Division maintains models such as EVI-Pro 3 and HEVI-LOAD to support its AB 2127 analysis. These models are designed to project needed charging infrastructure counts and associated load curves, and results are reported in the AB 2127 assessment (this publication).
- Grid modeling: The Energy Assessments Division maintains models to forecast future electricity demand, including for electric transportation. These models also include load curves, and results are reported in the *Integrated Energy Policy Report (IEPR)*. Forecasts published in the *IEPR* are used by CPUC and utilities for grid planning.

To ensure consistency, the Fuels and Transportation Division and the Energy Assessments Division are collaborating to ensure harmonization between the two modeling tracks. Further, both modeling tracks are exploring new VGI scenarios that will begin to quantify the effects of VGI that can be incorporated into planning processes at the CEC and CPUC. The CPUC independently conducts VGI-related modeling for its grid planning activities as well.<sup>132</sup>

The CEC's IEPR forecasts are particularly important in planning grid upgrades because they are used by the CPUC for Integrated Resource Planning and the Distribution Planning Processes. The Integrated Resource Planning process relies on IEPR forecasts to identify portfolios of electricity resources to reliably and cost-effectively meet the load forecasted by the CEC while meeting the state's decarbonization goals. In addition, the CPUC transmits the resource portfolios developed within the IRP process to the California ISO for its annual

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129 For example, the CPUC recently [approved](#) a transportation electrification program as part of the R-18-12-006 proceeding.

130 For example, PG&E's upcoming [Day Ahead Hourly Real Time Pricing](#) EV rate. Importantly, time-of-use rates are already widely offered and used by electric customers across California. CPUC ordered investor-owned utilities begin offering time-of-use rates by default in [2019](#).

131 For example, [GFO-21-303](#) funded deployments of V2B for backup power through the Electric Program Investment Charge.

132 For example, CPUC hosted a [workshop](#) in September 2022 to discuss inputs and assumptions for VGI to be used in integrated resource planning. <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/integrated-resource-plan-and-long-term-procurement-plan-irp-ltpp/2022-irp-cycle-events-and-materials/iamag09222022.pdf>.



transmission planning process (TPP). The ISO uses these portfolios as part of its TPP analysis to identify system-level transmission solutions and upgrades.<sup>133</sup>

The CPUC's Distribution Planning Process uses IEPR forecasts to help identify areas of the distribution system needing upgrades to serve future electrical demand. Potential upgrades are detailed as part of the Distribution Planning Process Grid Needs Assessment and Distribution Deferral Opportunity Report. Notably, the CPUC's High DER Rulemaking (R.21-06-017) is investigating updates to the Distribution Planning Process to incorporate improved data sharing, EV adoption, dynamic rate development, and load-flexibility utilization.

Relatedly, SB 846 requires the CEC, in consultation with the CPUC and ISO, to "adopt a goal for load shifting to reduce net peak electrical demand" and publish this target in the *IEPR*. This will be the first time CEC quantifies a load-shift target.<sup>134</sup>

## **VGI Advancement 5: Customer Ease, Confidence, and Enrollment**

Even though VGI can yield a wide range of customer benefits, Californians may not be accustomed to viewing their vehicle as anything other than a tool exclusively for transportation or adjusting their charging patterns in response to grid signals. For VGI to scale, customers must be confident that participating in VGI rates and programs is beneficial, is easy, does not compromise their mobility needs, and has low barriers for enrollment. In particular, customer-friendly utility processes, increased product choices, and education campaigns can strengthen customer confidence and interest in VGI.

The CEC and CPUC have taken steps to simplify utility processes and lower barriers to customer participation in VGI. In September 2020, the CPUC directed utilities to begin interconnecting DC bidirectional chargers using existing Rule 21 requirements, thus confirming that DC bidirectional chargers do not necessitate special utility policies and should be treated like solar inverters and other generating devices.<sup>135</sup> In August 2022, the CPUC directed utilities to allow nonutility meters (referred to as "submeters") to measure electricity consumption of vehicle charging for customer billing purposes.<sup>136</sup> Importantly, submetering will make it easier and cheaper for customers to enroll in EV-specific electricity rates, which offer strong off-peak discounts, and will enable V2B and V2H use cases by allowing the vehicle load to be comingled with the facility load.

In early 2023, CEC launched a V2G Equipment List tracking bidirectional charging equipment certified to national safety standards (namely, Underwriters Laboratories 1741). The V2G Equipment List may help streamline utility interconnection of bidirectional chargers and was

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133 The annual Transmission Plan then goes before the California ISO Board of Governors for approval. The transmission planning process culminates in a procurement phase which includes a competitive solicitation process.

134 The CEC hosted a [workshop](https://www.energy.ca.gov/event/workshop/2023-04/lead-commissioner-workshop-sb-846-preliminary-load-shift-goal) on a preliminary SB 846 load shift goal in April 2023 <https://www.energy.ca.gov/event/workshop/2023-04/lead-commissioner-workshop-sb-846-preliminary-load-shift-goal>.

135 See Ordering Paragraph 39 in [Decision 20-09-035](#)

136 The CPUC's [submetering decision](#) would require submeters used for billing to meet a 1 percent accuracy standard.

created in response to repeated industry requests. These agency actions help provide certainty and will simplify the deployment of VGI products and programs.

Beyond state actions, industry plays a crucial role in helping translate these various policy underpinnings into realized customer participation through easy-to-use products and services. The submetering decision is potentially important as it allows industry to offer products that enable customers to enroll in a different electricity rate for charging (separate from the rest of the home or site) and help them automate charging around the lowest-priced hours of that rate.<sup>137</sup> As submetering is likely a novel concept for many drivers, charging providers and other third parties will be important ambassadors for helping customers understand the benefits of and options for submetered vehicle charging. For bidirectional charging, market actors such as Sunrun are already helping customers understand, install, and interconnect bidirectional charging setups that can provide backup power during grid outages. Moving forward, utilities and third-party market actors such as aggregators and charging providers have an essential role in helping customers through utility enrollment and interconnection processes and ensuring customers receive a range of benefits from VGI.

Finally, awareness and education campaigns can also promote customer understanding and interest in VGI. For example, CPUC already directs funding toward statewide Flex Alert media campaigns.<sup>138</sup> Similar efforts can help inform customers about the benefits of smart charging and bidirectional charging (including V2H for backup power during grid outages). As regulations, technology, and products continue to evolve and mature, customer education will be an important component to ensure Californians receive all the benefits electrified transport can offer.

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137 Submetering permits customers to bill electricity consumed for vehicle charging separately from electricity consumed by the rest of the home. Submetering opens opportunities for customers to consider rates that, without submetering, would require installation of a separate costly utility meter at the site (such as an hourly rate with deep discounts during hours with abundant clean electricity). Because vehicle charging is flexible and can be shifted or paused, submeters enable customers to charge up on deeply discounted off-peak electricity through a grid-friendly rate, while keeping the rest of the home on the existing rate. This gives customers peace of mind and saves them from worrying about higher peak prices or frequent price changes for less flexible home loads such as cooking, space conditioning, and so on.

138 In a December 2021 [decision](#), CPUC directed utilities to continue a statewide Flex Alert media campaign during the summers of 2022 and 2023.



# CHAPTER 7:

## Labor and Workforce

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### Introduction

Labor<sup>139</sup> and workforce training and development<sup>140</sup> support for electric vehicle charging infrastructure (EVCI) deployment is critical for ZEVs to be 100 percent of sales in California. Current and projected investments for charger deployments, public and private alike, require the state to consider thoughtfully the range of labor and workforce issues involved in providing this infrastructure to meet the state's ZEV goals and realize other cobenefits.

EVCI career pathways must be intentionally cultivated with collaboration among the state's workforce entities, employers, training partners, trades, and workers. Furthermore, the state takes an inclusive<sup>141</sup> and high-road approach<sup>142</sup> for businesses and workers and expands workforce opportunities for priority communities and populations that can participate in the EVCI industry.

Senate Bill 589 (Hueso, Chapter 372, Statutes of 2021) requires the CEC to identify workforce training and development resources needed to meet the state's ZEV and climate goals and include this information as part of the AB 2127 assessment starting with this second assessment. This chapter identifies these resources and two other requirements related to the expansion of project eligibility for the manufacturing workforce and expansion of entities the CEC should collaborate with on workforce development.

This chapter also provides a framework to understand the elements of EV chargers and the workforce for each market segment, and a brief overview of key reports and papers about EVCI labor and workforce. These studies provide a useful backdrop and a foundation in understanding analysis of the various roles and occupations needed to install chargers. Estimating the number and types of jobs that will be required is a key step in understanding the EVCI job space. Finally, this chapter will address current state investments and approaches to ensure skills and workforce development prepare workers in all areas of California for the significant investment that lies ahead.

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139 *Labor* refers to the labor required for the projects such as the construction, installation, operations and maintenance, and end-of-life/replacement of EV chargers.

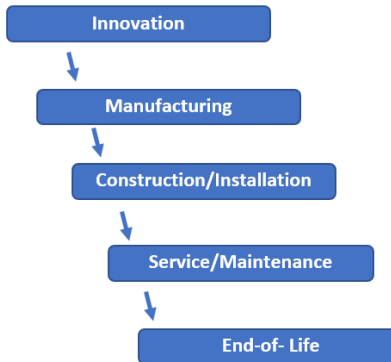
140 *Workforce training and development* refers to the ongoing support structures, institutions, and resources needed to develop the workforce needed to EVSE deployment.

141 Rillera, Larry, Samantha Houston. 2022. [Electric Vehicle Charging in Communities Equity Workgroup Report](https://etcommunity.org/assets/files/03-StrikeForceEquityWorkgroupReport-ElectricVehicleCharginginCommunities.pdf). Electric Vehicle Charging Infrastructure Strike Force (ET Community). <https://etcommunity.org/assets/files/03-StrikeForceEquityWorkgroupReport-ElectricVehicleCharginginCommunities.pdf>.

142 California Workforce Development Board. ["High road Training Partnerships,"](https://cwdb.ca.gov/initiatives/high-road-training-partnerships) <https://cwdb.ca.gov/initiatives/high-road-training-partnerships>.

The *ZEV Market Development Strategy*<sup>143</sup> (ZEV Strategy) provides a framework in understanding the role of the EVCI workforce.<sup>144</sup> The ZEV Strategy describes the role of the CEC with respect to ZEV infrastructure investment and analysis, ZEV-related manufacturing, and workforce training and development. Figure 33 illustrates the EVCI segments needed to support state goals.

**Figure 33: EVCI Industry and Workforce Segments**



Source: CEC staff

- **Innovation** — The workforce devoted to innovation, research, development, and deployment (RD&D) of EVCI products and services is vast and includes California’s higher education systems, community colleges, and private entities. Continuous development and improvements to EVCI technologies are needed to meet market demands and drive down product costs.
- **Manufacturing** — California is home to 55 ZEV-related manufacturers, including ZEV infrastructure companies that commercially manufacture, produce, and assemble hardware. Investment by private capital and state support continues to scale up the ZEV supply chain, creating demand for California workers. Occupations that support manufacturing include engineers, technicians, line manufacturers, materials handlers, assemblers, and supporting roles.
- **Construction and installation** — EVCI labor in the construction and installation segment was presented in the first AB 2127 assessment. This sector includes roles in planning, designing, permitting, construction, installation, inspection, and commissioning technicians.
- **Service and maintenance** — EVCI service, maintenance, and repair were explicitly addressed and discussed in two workshops held on the second AB 2127 assessment. Ensuring high charger reliability relies on a combination of deliberate efforts for uptime standards, enforcement, and a reliable workforce. Whether EVCI service is on-demand

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143 California Governor’s Office of Business and Economic Development. 2021. [“California Zero-Emission Vehicle Market Development Strategy.”](https://static.business.ca.gov/wp-content/uploads/2021/02/ZEV_Strategy_Feb2021.pdf) [https://static.business.ca.gov/wp-content/uploads/2021/02/ZEV\\_Strategy\\_Feb2021.pdf](https://static.business.ca.gov/wp-content/uploads/2021/02/ZEV_Strategy_Feb2021.pdf).

144 The human workforce, including supply chains, needed to design, manufacture, sell, construct, install, service, and maintain ZEV infrastructure.

or scheduled, a trained and skilled workforce is critical to this early stage of charger deployment as EV drivers seek a reliable charging experience.

- **End of life** — EVCI assets reach the end of life (EOL) for various reasons (for example, end of product line, asset degradation or age, technological obsolescence, vandalism) and eventually require replacement. The EVCI workforce plays a significant role in the total asset life cycle of a charger. The same workforce skilled in the construction and installation of EVCI's may find a "second cycle" of employment and jobs in this segment and can help manage the EOL transition per manufacturer milestones and directives.

## **Senate Bill 589**

Senate Bill (SB) 589 requires as part of the CEC's AB 2127 assessment starting in 2023, to identify workforce development and training resources needed to meet EV adoption goals. SB 589:

- Specifies that a project, including a workforce development or training project, that develops in-state production of raw materials and the manufacturing supply chain for zero-emission vehicle components shall be eligible to receive funding under the Clean Transportation Program.
- Specifies that CEC shall collaborate with the California Community Colleges, the certified community conservation corps, the California Conservation Corps, and the California Mobility Center to implement the workforce development components of the Clean Transportation Program.
- Requires, as part of the AB 2127 EV charger assessment, the identification of workforce development and training resources needed to meet the ZEV and GHG emission reduction goals. These resources shall include qualified apprenticeships, on-the-job training programs, and other training opportunities that build career pipelines in the zero-emission transportation sector and provide long-term employment in disadvantaged communities.

With respect to provision (1) above, the CEC issued Grant Funding Opportunity (GFO)-21-605 titled "Zero-Emission Transportation Manufacturing" in March 2022 and GFO-21-606 titled "Zero-Emission Vehicle Battery Manufacturing Block Grant" in August 2022. Moreover, the Electric Program Investment Charge (EPIC) in the CEC's Energy Research, Development, and Deployment (ERDD) has a geothermal project that is in the RD&D stage for in-state production of raw materials that may have application for transportation electrification.

The Clean Transportation Program (CTP) has a workforce training and development investment portfolio of nearly \$50 million. As noted in provision (2) above, the CTP has recently included new and expanded workforce development partners such as the California Conservation Corps through a \$1 million agreement for the Transportation Electrification Training Project focused on classroom and on-the-job training for EV charger construction, installation, and maintenance. In 2022, the CEC issued GFO-21-604 IDEAL ZEV Workforce

Pilot,<sup>145</sup> which provided project funding through a new partnership with the California Mobility Center focused on ZEV manufacturing and service.

On October 18, 2022, the CEC held a workshop titled “Workshop on Labor and Workforce for the Second Assembly Bill 2127 Assessment” to discuss the provisions of SB 589 with respect to workforce training and development resources. Panelists were composed of workforce subject matter experts including the California Labor Federation, International Brotherhood of Electrical Workers (IBEW) Local 569, California Employment Training Panel, SoCal Pre-Apprenticeship, and the California Community Colleges. During the workshop, the information in Table was provided, and panelists and stakeholders commented on the occupations and the volume of approved apprenticeships that can support the ZEV industry.

**Table 1012: Registered Apprenticeships for Potential ZEV Occupations**

Occupation	Number of Apprenticeships
Sheet Metal	14
Manufacturing	41
Electrical and Electronics	41
Laborers	12
<b>TOTAL</b>	<b>108</b>

Source: California Department of Industrial Relations, Division of Apprenticeships Standards

The CEC will continue to collaborate with workforce stakeholders to ensure support needed to meet ZEV and EVCI deployment goals.

## Estimating Labor for EVCI Installation

Over the past 10 years, various entities have studied labor costs associated with EVCI deployment:

- In 2013, the Electric Power Research Institute (EPRI)<sup>146</sup> published the *Electric Vehicle Supply Equipment Installed Cost Analysis* technical report, which analyzed the cost of EVSE installation and excluded EVSE costs at 637 installation sites from 2009 to 2013.
- In 2019, the Rocky Mountain Institute (RMI)<sup>147</sup> published the *Reducing EV Charging Infrastructure Costs* report, which provided information on EVCI component costs, directed at utility buyers and utility regulators to understand “the best opportunities to

145 California Energy Commission. 2021. [“GFO-21-602 – IDEAL ZEV Workforce Pilot,”](https://www.energy.ca.gov/solicitations/2021-10/gfo-21-602-ideal-zev-workforce-pilot) <https://www.energy.ca.gov/solicitations/2021-10/gfo-21-602-ideal-zev-workforce-pilot>.

146 Electric Power Research Institute. 2013. [Electric Vehicle Supply Equipment Installed Cost Analysis](https://www.epri.com/research/products/000000003002000577), <https://www.epri.com/research/products/000000003002000577>.

147 Nelder, Chris, Emily Rogers. [“Reducing EV Charging Infrastructure Costs.”](https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf) Rocky Mountain Institute. <https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf>

reduce the total cost of deploying EV charging infrastructure.” While labor was identified as a cost in the report, it was not the subject of analysis or key findings.

- In 2019, the International Council on Clean Transportation published *Estimating Electric Vehicle Charging Infrastructure Costs across Major U.S. Metropolitan Areas*.<sup>148</sup> The study projected estimated capital costs, including installation and hardware, of EVCI in residential and nonresidential markets for the most populous 100 metropolitan areas in the United States from 2019 through 2025. The report found that labor costs represented 50 percent of total EVCI installation costs.
- In 2019, the Avista Corporation<sup>149</sup> published the *Electric Vehicle Supply Equipment Pilot Final Report* that resulted from investments and study of a three-year EVSE pilot launched in 2016. The report identified construction labor and materials as significant cost factors, noting that “installation costs could be expected to gradually rise with labor and material cost inflation.”
- In 2021, the Electric Transportation Community Development Corporation published *Workforce Projections to Support Battery Electric Vehicle Charging Infrastructure Installation* (ET Community Jobs Report).<sup>150</sup> The report explored the workforce needs associated with LDV and MDHD EVCI build-out. The report was derived from a “bottom-up” survey designed to elicit information from industry and provides a framework and analysis for EVCI labor and workforce in terms of jobs and skills needed for the installation of chargers in California. Based on survey results, assignment of work phases,<sup>151</sup> job roles,<sup>152</sup> and time requirements, a workforce estimation model was developed, and an estimate of effort needed (multiplier factors) for L2 and DCFC installations was determined. The report shows “that California’s statewide light-duty electric vehicle program goals,<sup>153</sup> and the associated charging infrastructure would generate workforce needs of approximately 38,200 to 62,400 job-years<sup>154</sup> over the

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148 Nicholas, Michael. 2019. [“Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas.”](https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf) The International Council on Clean Transportation.

[https://theicct.org/sites/default/files/publications/ICCT\\_EV\\_Charging\\_Cost\\_20190813.pdf](https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf)

149 Farley, Rendall, Mike Vervair, Jon Czerniak. 2019. [Electric Vehicle Supply Equipment Pilot Final Report](https://www.myavista.com/-/media/myavista/content-documents/energy-savings/electricvehiclesupplyequipmentpilotfinalreport.pdf). Avista Corp. <https://www.myavista.com/-/media/myavista/content-documents/energy-savings/electricvehiclesupplyequipmentpilotfinalreport.pdf>.

150 Carr, Edward, James Winebrake, Samuel Winebrake. [“Workforce Projections to Support Battery Electric Vehicle Charging Infrastructure Installation.”](https://etcommunity.org/assets/files/Workforce-ProjectionstoSupportBatteryElectricVehicleChargingInfrastructureInstallation-Final202106082.pdf) Energy and Environmental Research Associates.

<https://etcommunity.org/assets/files/Workforce-ProjectionstoSupportBatteryElectricVehicleChargingInfrastructureInstallation-Final202106082.pdf>.

151 Work phases are 1) knowledge and skills training, 2) planning, 3) construction and installation, and 4) operations and maintenance.

152 Job-roles refers to the typical tasks performed on a project as identified by survey respondents with direct experience in EVCI installation.

153 The goal was based on the estimates provide in the First AB 2127 Assessment.

154 Workforce needs are estimated based on analysis of survey responses, provided in person-days, and converted to job-years assuming a full time equivalent (FTE) of 2080 hours and 8-hour workdays. Note that job-years cannot always be directly translated into a number of jobs created, but instead help to describe the

period from 2021 to 2031 in California, based on the baseline and high electric vehicle adoption scenarios. The greatest workforce needs for light-duty infrastructure would be for electricians (21.3% of job-years), general contractors (21% of job-years), planning and design (20% of job-years), and electrical contractors (15% of job-years).” The report further shows that “[f]rom estimates of projected medium and heavy-duty electric vehicle growth, this work estimates that the associated charging infrastructure in California would generate approximately 9,100 additional job-years from 2021–2031, in addition to the light-duty charging infrastructure workforce needs.”

## **Electric Vehicle Infrastructure Training Program**

Assembly Bill 841 (Ting, Chapter 372, Statutes of 2020) requires Electric Vehicle Infrastructure Training Program (EVITP) training and certification to install EV charging infrastructure and equipment that is on the customer side of the electrical meter that is funded or authorized, in whole or in part, by certain state entities. There are certain exceptions.<sup>155</sup> The law requires that certain state agency-funded EV charger installation projects shall be installed by a contractor with the appropriate license classification,<sup>156</sup> and at least one electrician on each crew, at any given time, must hold an EVITP certification. For projects that include installation of a charging port supplying 25 kW or more to a vehicle, at least 25 percent of the total electricians working on the crew, at any given time, must hold EVITP certification. One member of each crew can be both the contractor and an EVITP-certified electrician.

EVITP is a nonprofit organization that provides 20 hours of proprietary training and certification to eligible electricians for a \$275 fee in the EV infrastructure installation segment in the United States and Canada.

In August 2022, the EVITP training and certification exam went fully on-demand and online. After successful completion of the online training course, an applicant schedules a live proctored online examination with applicants notified via email of the examination results. It is important that EVITP training and certification continue to be online and on-demand. Before testing/certification being online and on-demand, there were only two locations in California.

The EVITP website provides a list of electrical contractors where contractors must be currently licensed electrical contractors<sup>157</sup> in good standing and execute an EVITP Approved Contractor

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demand for work. One job-year is equivalent to one person performing a job for one year, or two people performing the same job for half a year, etc.

155 These requirements do not apply to the following:

- EVCI installed by employees of an electrical corporation or local publicly owned electric utility.
- EVCI funded by moneys derived from credits generated from the Low Carbon Fuel Standard Program. (see <https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard>)
- Single-family home residential chargers that can use an existing 208/240-volt outlet.

156 As determined by the Contractors’ State License Board (CSLB).

157 California Department of Consumer Affairs Contractors State License Board. [“C-10 – Electrical Contractor,”](https://www.cslb.ca.gov/about_us/library/licensing_classifications/c-10_-_electrical.aspx) [https://www.cslb.ca.gov/about\\_us/library/licensing\\_classifications/c-10\\_-\\_electrical.aspx](https://www.cslb.ca.gov/about_us/library/licensing_classifications/c-10_-_electrical.aspx).

Agreement requiring them to use EVITP-certified electricians on jobs. EVITP does not train or certify contractors or employers, only eligible electricians.

As the EVCI industry continues to grow and technology advances, the EVITP curriculum should be updated in collaboration with industry and state agencies that are required to use EVITP-certified electricians. The current EVITP 4.0 curriculum includes DCFC, inductive charging equipment, liquid-cooled conductors, V2G applications, and other installation and maintenance best practices.

EVITP and the National Electrical Contractors Association (NECA) have publicly provided information on the number of electricians and the number of EVITP certified electricians in the nation and the state. In a June 28, 2022, letter from NECA — California Chapters to the CEC docket<sup>158</sup> for the California National Electric Vehicle Infrastructure (NEVI) Deployment Plan, NECA — California Chapters indicated that about 2,300 electricians were identified as EVITP-certified. During the Labor and Workforce Workshop for the Second AB 2127 Assessment on October 18, 2022,<sup>159</sup> a panelist referenced a 2021 NECA report and others<sup>160</sup> regarding the addition of roughly 7,000 electricians nationwide while experiencing the attrition of 10,000 electricians. During the workshop, a representative from EVITP commented there were more than 38,000 California-certified general electricians,<sup>161</sup> more than 7,000 registered electrical apprentices<sup>162</sup> in the state, and more than 2,300 California electricians<sup>163</sup> with EVITP-certified skills.

## **EVCI Service, Maintenance, and Repair**

Reliable and well-maintained chargers are critical to the transition to zero-emission vehicles. Charger availability is fundamental to functionality and reliability as chargers are increasingly subject to environmental, human-caused, technical, and end-of-life (EOL) issues. Ensuring accessible and operational chargers is paramount in this early adopter period, especially in underserved communities where charging coverage may be sparse and dependable mobility options may be limited.

Maintaining charger uptime requires performance standards and data collection. Restoring chargers to full operational status requires timely actions by skilled and trained personnel. EVCI companies provide a range of essential products in the service, maintenance, and repair

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158 National Electrical Contractors Association. ["NECA Comments on California's Draft Deployment Plan for the National Electric Vehicle Infrastructure Program,"](https://efiling.energy.ca.gov/GetDocument.aspx?tn=243754&DocumentContentId=77654)

<https://efiling.energy.ca.gov/GetDocument.aspx?tn=243754&DocumentContentId=77654>.

159 October 18, 2022, ["Labor and Workforce for the Second AB 2127 Assessment,"](https://www.energy.ca.gov/event/workshop/2022-10/workshop-labor-and-workforce-second-assembly-bill-2127-assessment) ChargePoint, Inc. representative. <https://www.energy.ca.gov/event/workshop/2022-10/workshop-labor-and-workforce-second-assembly-bill-2127-assessment>.

160 Border States. 2022. ["The State of the Electrician Shortage in 2022: New Data on the Impact of COVID-19,"](https://solutions.borderstates.com/the-electrician-shortage) <https://solutions.borderstates.com/the-electrician-shortage>.

161 California Contractors State Licensing Board as of February 3, 2020.

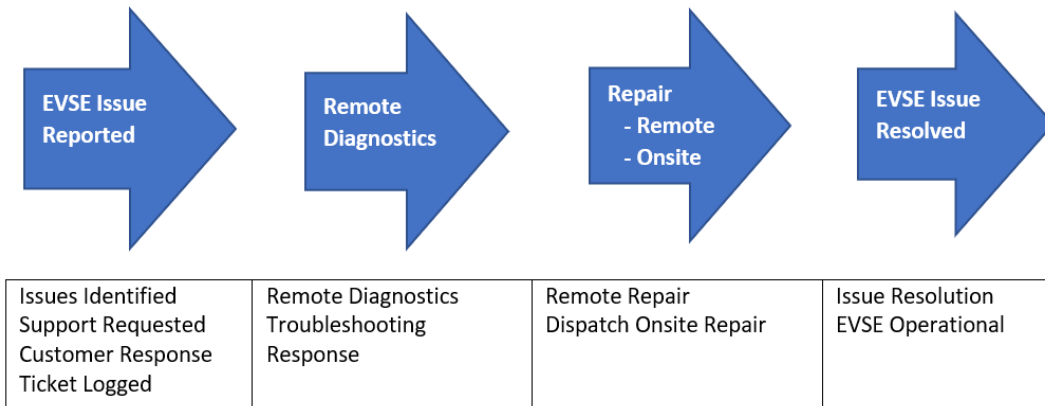
162 California Department of Industrial Relations, Division of Apprenticeship Standards as of February 21, 2020.

163 EVITP as of June 27, 2022.



of chargers to ensure chargers are available. Figure 34 illustrates how charger issues are identified and the workforce is engaged to resolve issues.

**Figure 34: EVSE Service, Maintenance, and Repair Pathway**



Source: CEC staff

Charger manufacturers provide service, maintenance, and repair products. In addition to certifying charger installers for their products, charger manufacturers also provide general and proprietary training and certification for service, maintenance, and repair. Nonmanufacturers or private companies also provide training and certification. Examples of products and services by companies include:

- ABB, Inc. "E-Mobility Service Offering;"<sup>164</sup>
- ChargePoint, Inc. "ChargePoint University;"
- ChargerHelp! "EVSE Technician Training;"<sup>165</sup>
- Electrify America internal training and certification program;<sup>166</sup>
- and EVITP 4.0 training content for "EVSE Troubleshooting, Maintenance and Repair."

## High-Road Principles in the EVCI Workforce

California strongly supports investments and projects that create good paying jobs, improve job quality, increase access to quality jobs, strengthen local and regional economies, sustain

164 ABB. "[E-mobility Service Offering,](https://new.abb.com/ev-charging/connected-services/emobility-service-offering-service-level-agreement)" <https://new.abb.com/ev-charging/connected-services/emobility-service-offering-service-level-agreement>.

165 Charger Help. "[Workforce Development,](https://www.chargerhelp.com/_files/ugd/30e128_0032898550534e609ce4188fa91bc926.pdf)" [https://www.chargerhelp.com/\\_files/ugd/30e128\\_0032898550534e609ce4188fa91bc926.pdf](https://www.chargerhelp.com/_files/ugd/30e128_0032898550534e609ce4188fa91bc926.pdf).

166 Electrify America. 2022. "[2922 Q2 Report to California Air Resources Board,](https://media.electrifyamerica.com/assets/documents/original/918-Q22022ElectrifyAmericaReporttoCARBPublic.pdf)" <https://media.electrifyamerica.com/assets/documents/original/918-Q22022ElectrifyAmericaReporttoCARBPublic.pdf>.



economic equity,<sup>167</sup> and generate opportunities for economic prosperity to develop an equitable and diverse workforce in building out the EVCI.

The High Road Training Partnerships (H RTP) initiative was developed by the California Workforce Development Board (CWDB) and started as a \$10 million demonstration project designed to model workforce partnership strategies for the state. The H RTP model embodies a sector approach through industry partnerships, with regional skills strategies designed to support economically and environmentally resilient communities. These partnerships support California’s “high road” employers — “companies that compete based on quality of product and service achieved through innovation and investment in human capital and can thus generate family-supporting jobs where workers have agency and voice.”<sup>168</sup> Moreover, the High Road Construction Careers (HRCC)<sup>169</sup> initiative partners construction trades councils with workforce boards, community colleges, and community-based organizations. These partnerships create structured career pathways with standard core curricula and supportive services to state-certified apprenticeships in a variety of crafts/trades, and focus on equity by expanding access to high-quality jobs to members of underrepresented populations, including women and persons of color.

The state has cultivated strong partnerships with crafts and trades associated with transportation electrification, specifically with EVCI installations. The state will continue to work with partners to establish a strong labor force of trained workers to support and enhance the EV industry. Specific partnerships with the EVCI-affected workforce and labor groups include those with the NECA, IBEW, Jobs to Move America, and others. State workforce agency partners that support labor, apprenticeships, and training, for EVCI installation, service, and maintenance include the CWDB, the Employment Training Panel (ETP), the Labor and Workforce Development Agency (LWDA), the California Community Colleges Chancellor’s Office, and the Department of Industrial Relations Division of Apprenticeship Standards.

Recent CEC solicitations for ZEV and EVCI funding opportunities have required applicants to include ZEV and EVCI Workforce Plans.<sup>170</sup> These workforce plans, submitted as part of competitive solicitation processes, were subject to evaluation and scoring criteria that included job creation and recruitment, training and upward mobility, safe workplace conditions, workforce engagement, workforce accessibility to jobs, prevailing wage pay, supplier diversity, benefits, and other job quality elements. As EVCI funding and incentive programs are developed, a high-road approach should be embedded in solicitation requirements, as well as in workforce training and development programs.

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167 Rillera, Larry, Samantha Houston. 2022. *Electric Vehicle Charging in Communities Equity Workgroup Report*. Electric Vehicle Charging Infrastructure Strike Force (ET Community). <https://etcommunity.org/assets/files/03-StrikeForceEquityWorkgroupReport-ElectricVehicleCharginginCommunities.pdf>.

168 California Workforce Development Board. [“High road Training Partnerships,”](https://cwdb.ca.gov/initiatives/high-road-training-partnerships) <https://cwdb.ca.gov/initiatives/high-road-training-partnerships>.

169 California Workforce Development Board. [“High Road Construction Careers,”](https://cwdb.ca.gov/initiatives/hrcc) <https://cwdb.ca.gov/initiatives/hrcc>.

170 California Energy Commission. [“GFO-21-605 – Zero-Emission Transportation Manufacturing,”](https://www.energy.ca.gov/solicitations/2022-03/gfo-21-605-zero-emission-transportation-manufacturing) <https://www.energy.ca.gov/solicitations/2022-03/gfo-21-605-zero-emission-transportation-manufacturing>.

The California Department of Transportation notes in the “California NEVI Deployment Plan” that HRTPs exist in ZEV manufacturing and other transportation fields and could be a model for EVSE manufacturing in California. The California Fiscal Year 2022–2023 budget includes \$15 million in HRCC and H RTP per year for the next three years, which could be used to advance economic equity in California's growing EVSE industry.<sup>171</sup>

## **EVSE Workforce Training and Development**

The labor and workforce needed to support the entire EV charger ecosystem (Figure 33), as noted in the tens of thousands of workers, will require ongoing training for new skills development, as well as upskilling and reskilling of the existing workforce. Continuous investment and advocacy for apprenticeship programs are critical given the duration of such programs and the clear need for these workers to safely install and maintain this infrastructure. New companies and workers will enter this ecosystem via adjacent<sup>172</sup> clean energy industries and existing technology sectors. The skill sets, training, and work experience acquired in adjacent sectors can be transferred to the EVCI sector workforce. The range of jobs, roles, and wages can also transfer.<sup>173</sup>

Jobs related to charging installations that include training through state-approved apprenticeship programs, payment of prevailing wages, and other labor standards create opportunities for middle-class careers with good wages and benefits through a pipeline for workers to learn specific crafts, skills, and knowledge.<sup>174</sup> From engineering and design jobs to administrative support jobs, EVCI is positioned to create many jobs in all areas of California via billions of dollars in public and private EVCI investments. New partnerships will be formed as businesses develop their company workforces to align and acquire new business opportunities or in developing new business-to-business (B2B) relationships.

As noted above, California has a rich culture of strong workforce development institutions among state agencies, training entities, and employers. Identifying workforce trends, challenges, and training needs will be important going forward. It will also require careful analysis and awareness of the net migration of jobs between industries and sectors adjacent to EVCI markets.

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171 Fauble, Brian, *et al.* 2022. [California's Deployment Plan for the National Electric Vehicle Infrastructure Program](https://dot.ca.gov/-/media/dot-media/programs/sustainability/documents/nevi/2022-ca-nevi-deployment-plan-a11y.pdf). California Department of Transportation, California Energy Commission <https://dot.ca.gov/-/media/dot-media/programs/sustainability/documents/nevi/2022-ca-nevi-deployment-plan-a11y.pdf>.

172 At the October 18, 2022, workshop, EVITP stated that there are “differences in industries such as solar where contractors hold C-10 licensed electrical contractor licenses and C-46 licenses. C-10 licensed contractors can do EV charger work, while C-46 licensed contractors cannot but pathways are available to get workers the certifications needed.”

173 For example, companies that provide EVCI construction and installation services will also find work in EVCI service, maintenance, and EOL replacement.

174 Carr, Edward, James Winebrake, Samuel Winebrake. [“Workforce Projections to Support Battery Electric Vehicle Charging Infrastructure Installation.”](https://etcommunity.org/assets/files/Workforce-ProjectionstoSupportBatteryElectricVehicleChargingInfrastructureInstallation-Final202106082.pdf) Energy and Environmental Research Associates. <https://etcommunity.org/assets/files/Workforce-ProjectionstoSupportBatteryElectricVehicleChargingInfrastructureInstallation-Final202106082.pdf>.

In addition to supporting apprenticeship programs and H RTP, state and local agencies are also moving forward with innovative projects that accelerate new skills development, on-the-job training, and career acquisition across the state. The CEC's Clean Transportation Program has funded several projects including:

- The "South Valley San Joaquin Valley ZEV Talent Pipeline Project" (Kern Community College District (KCCD) with the Kern County Electrical Apprenticeship Program).
- The "EVITP In-Person Certification Examinations" (EVITP and the KCCD).
- The "EV and EVCI Training Program" (The Latino Equity and Policy Institute (LEAP), ChargerHelp!).
- The "Los Angeles County Clean Transportation Program" (Los Angeles County, Cerritos College, California Clean Cities Coalitions).
- The "Transportation Electrification Training Project" (California Conservation Corp).

# CHAPTER 8:

## Conclusions

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Transportation electrification is key to meeting California’s climate change and air pollution reduction goals. Regulations like Advanced Clean Cars II, Advanced Clean Fleets, and Advanced Clean Trucks have set out the path for transitioning to light-, medium-, and heavy-duty ZEVs, but California cannot meet its transportation electrification goals without ensuring there is a sufficient supply of reliable charging infrastructure. To meet the needs of the 7.1 million light-duty PEVs on California’s roads in 2030, the state will need 1.01 million public and shared private chargers, including 39,000 public DCFC chargers. By 2035, charger needs will rise to 2.11 million public and shared-private chargers, including 83,000 public DCFC chargers to supporting 15.2 million light-duty PEVs. Medium- and heavy-duty PEVs will require 109,000 depot chargers and 5,500 public chargers in 2030 and 256,000 depot chargers and 8,500 public chargers in 2035.

This report assesses the amount of charging infrastructure needed to reach the state’s transportation electrification targets and identifies key areas for emphasis:

1. Providing access to home charging is a priority. Home charging is often the most convenient and least expensive charging option, and expansion of home charging reduces the need for public charging. In addition, home charging provides the flexibility to shift charging loads to support the grid.
2. Installing fast and convenient charging at other locations will be necessary to meet the transition from early adopters to a market that’s inclusive of all Californians. High-powered DCFC will be particularly important to support an increasing number of long-range BEVs. L2 charging deployment should focus on locations of long dwell-time activities, and charging must be available at all workplaces, not just offices.
3. Drivers must be able to reliably charge their electric vehicles. Factors affecting charging reliability include the operative state of the charger and related components, the ability for the electric vehicle to communicate successfully with the make and model of the charger, and whether peripheral payment systems can successfully authorize payment. CEC is taking steps to ensure the reliability of chargers that it funds and will work to harmonize existing reliability requirements with those required by AB 2061.
4. Leverage VGI technologies to manage charging in ways that benefit consumers and move charging to times when there’s excess capacity on the grid and the cleanest possible energy. While vehicle charging makes up a small fraction of California energy usage today, the rapid increase in ZEV adoption required by new regulations will increase the amount of grid capacity needed.
5. Panel upgrades and site improvements will be necessary to install chargers in many existing locations. The addition of automated load management systems at sites with many chargers could provide benefits and help increase installation speeds.
6. Prepare for the expansion of high-powered charging required by medium- and heavy-duty vehicles. While the overall charging need may be lower than light-duty vehicles,

vehicles will need to draw more power potentially creating bottlenecks to infrastructure deployment at the local grid level.

7. Analyze charging need and grid capacity to prioritize infrastructure upgrades throughout the state. The energy demand from vehicle charging will require upgrades to the physical components of the distribution system such as transformers, primary and secondary circuits, and substations. For the state to meet its GHG emissions goals, vehicle charging must be powered by clean energy when possible.
8. Prioritize labor and workforce training and development in vehicle charging infrastructure construction, installation, and maintenance. The rapid rollout of charging infrastructure through 2035 will require training of tens and thousands of existing and new workers across a range of occupations and geographies.

# GLOSSARY

**ADDITIONAL ACHIEVABLE TRANSPORTATION ELECTRIFICATION 3 (AATE3) SCENARIO** – A planning scenario from the 2022 Integrated Energy Policy Report Update that incorporates the expected impact of the ACC2, ACT, and ACF regulations on ZEV ownership and use. The AATE3 scenario

**ADVANCED CLEAN CARS II (ACCII)** – A regulation on light-duty vehicles adopted by CARB in 2022. ACCII requires an increasing proportion of new passenger vehicle sales to be ZEVs each year, reaching 100 percent in 2035.

**ADVANCED CLEAN FLEETS (ACF)** – A regulation on commercial vehicle fleet operators adopted by CARB in 2023. ACF requires fleet operators in certain segments to reach 100 percent ZEVs by 2035 or 2040.

**ADVANCED CLEAN TRUCKS (ACT)** – A regulation on medium- and heavy-duty trucks adopted by CARB in 2021. ACT requires an increasing fraction of truck sales to be ZEVs through 2035, with specific targets for each vehicle class.

**ALTERNATING CURRENT (AC)** – The flow of electricity that constantly changes direction. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

**AUTOMATED LOAD MANAGEMENT (ALM) SYSTEM** – ALMs manage charging load with the objective of reducing or eliminating the need for electrical capacity upgrades on the utility and/or customer side of the meter.

**BATTERY-ELECTRIC VEHICLE (BEV)** – Also known as an “all-electric” vehicle, BEVs use energy that is stored in rechargeable battery packs. BEVs sustain power through the batteries and therefore must be plugged into an external electricity source to recharge.

**BIDIRECTIONAL CHARGING** – Bidirectional charging, which enables a PEV to export energy from its onboard battery to buildings (vehicle-to-building), homes (vehicle-to-home), or to the grid (vehicle-to-grid). When equipped with the appropriate power electronics and electrical switching, bidirectional charging can provide power to a site during a grid outage.

**CALIFORNIA AIR RESOURCES BOARD (CARB)** – The state's lead air quality agency consisting of an 11-member board appointed by the Governor and more than 1,000 employees. CARB is responsible for attainment and maintenance of the state and federal air quality standards, California climate change programs, and motor vehicle pollution control. It oversees county and regional air pollution management programs.

**CALIFORNIA ENERGY COMMISSION (CEC)** – The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are forecasting future statewide energy needs; licensing power plants sufficient to meet those needs; promoting energy conservation and efficiency measures; developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels and infrastructure; and planning for and directing state response to energy emergencies.

**CALIFORNIA PUBLIC UTILITIES COMMISSION (CPUC)** – A state agency created by a California constitutional amendment in 1911 to regulate the rates and services of more than 1,500 privately owned utilities and 20,000 transportation companies. The CPUC is an administrative agency that exercises legislative and judicial powers; its decisions and orders may be appealed only to the California Supreme Court. The major duties of the CPUC are to regulate privately owned utilities, securing adequate service to the public at rates that are just and reasonable to customers and shareholders of the utilities; and the oversight of electricity transmission lines and natural gas pipelines. The CPUC also provides electricity and natural gas forecasting, and analysis and planning of energy supply and resources. Its headquarters are in San Francisco.

**CHAdEMO** – A connector standard for fast charging of electric vehicles that can provide up to 62.5 kilowatts of power.

**CHARGER** – The system within an EVSE 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. Also referred to as a charging port.

**COMBINED CHARGING SYSTEM (CCS)** – A connector standard for fast charging of electric vehicles that can provide up to 350 kilowatts of power.

**COMMUNITY CHOICE AGGREGATOR (CCA)** – Community choice aggregators procure energy for electricity users in a community or region. CCAs do not operate electric distribution infrastructure, and electricity procured by CCAs is delivered via existing distribution infrastructure typically operated by a utility.

**CONNECTOR** – A physical socket with a specified pin configuration. A charger may have one or multiple connectors.

**DEPOT CHARGER** – A depot charger is provided by a MDHD fleet operator at the location where the vehicle returns overnight or between trips. The models in this report estimate depot charging needs at a range of power levels from 20 kW to 150 kW.

**DIRECT CURRENT (DC)** – A current of electricity that flows in one direction and is the type of power that comes from a battery.

**DISTRIBUTED ENERGY RESOURCE (DER)** – DERs are decentralized generation or storage devices connected to the distribution grid. DERs include rooftop solar photovoltaics, on-site batteries and other energy storage systems, and electric vehicles. As noted later in this chapter, the CPUC's High DER Rulemaking (R.21-06-017) is exploring options to ensure the grid can support the growing number of DERs on the grid.

**ELECTRIC VEHICLE (EV)** – A broad category that includes all vehicles that can be fully powered by electricity or an electric motor.

**ELECTRIC VEHICLE CHARGING INFRASTRUCTURE (EVCI)** – A broad term covering the design, manufacture, installation, and maintenance of EVSE.

**ELECTRIC VEHICLE CHARGING STATION** – A charging station is a physical address where one or more chargers are available for use. This is the same usage as for "gas station." A charging station can be public, shared private, or private.

**ELECTRIC VEHICLE INFRASTRUCTURE TRAINING PROGRAM (EVITP)** – AB 841 requires EVITP training and certification to install EV charging infrastructure and equipment that is on the customer side of the electrical meter that is funded or authorized, in whole or in part, by certain state entities. The EVITP program was designed to provide qualified electricians with the most comprehensive training available in the market today. All EVITP Certified Electricians must pass a certification exam for proof of knowledge and skill.

**ELECTRIC VEHICLE SERVICE PROVIDERS (EVSP)** – An entity responsible for operating one or more EVSE.

**ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)** – Equipment designed to supply power to EVs. Most EVSEs can charge BEVs and PHEVs.

**GREENHOUSE GAS (GHG)** – Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (NO<sub>x</sub>), halogenated fluorocarbons (HCFCs), ozone (O<sub>3</sub>), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

**GRID NEEDS ASSESSMENT (GNA)** – The grid needs assessment (GNA) presents forecasted load and distributed energy resource (DER) planning assumptions and identified distribution and subtransmission needs in IOU territories. The data include forecasted equipment deficiencies, incremental demand, and incremental DER growth for each circuit and substation with a grid need over a five-year forecasting period.

**HYDROGEN FUEL CELL ELECTRIC VEHICLE (FCEV)** – A vehicle that uses an electric motor for propulsion, much like a BEV, but powers the electric motor using hydrogen fuel cells rather than a large onboard battery. FCEVs are a subcategory of ZEVs.

**INTEGRATED RESOURCE PLAN (IRP)** – Large utilities are required by Senate Bill 350 to develop integrated resource plans (IRPs) which are reports that detail how they will meet their customers' resource needs, reduce GHG emissions, and ramp up the use of clean energy resources within their service territories.

**INTEGRATION CAPACITY ANALYSIS (ICA)** – The integration capacity analysis (ICA) is a complex modeling study that uses detailed information about the electric distribution system, which includes physical infrastructure, load performance, and existing and queued generation. The ICA simulates the ability of individual distribution line sections to accommodate additional DERs without causing issues that would affect customer reliability and power quality.

**KILOWATT (kW)** – One thousand watts, a measure of power. On a hot summer afternoon, a typical home - with central air conditioning and other equipment in use - might have a power demand of 4 kW.

**KILOWATT-HOUR (kWh)** – One kilowatt of electricity supplied for one hour, that is, a measure of energy. It is the most used unit of measure telling the amount of electricity consumed over time.

**LEVEL 1 (L1) CHARGING** – Electric vehicle charging at 120 volts.

**LEVEL 2 (L2) CHARGING** – Electric vehicle charging at 240 volts.



**LIGHT DUTY VEHICLE (LDV)** – A vehicle with a GVWR of 10,000 lbs. or less. Most LDVs are privately owned cars and trucks.

**LOAD** – The amount of energy delivered by the electrical grid at a given time, often measured in MW. The models used in this report estimate the load needed to support EV charging throughout the day.

**LOAD FLEXIBILITY** – Load flexibility refers to the ability of electric customers to shift the electricity consumption of devices, appliances, or other loads in response to electricity prices or other signals. VGI can be viewed as load flexibility applied to vehicle charging.

**MEDIUM-/HEAVY-DUTY VEHICLE** – A vehicle with a GVWR of over 10,000 lbs. Most MDHD vehicles are used for commercial purposes. The models in this report consider four categories of MDHD vehicles: LHDVs (vehicles with a GVWR of 10,001-14,000 lbs.), class 4-6, class 7, and class 8.

**MEGAWATT (MW)** – A unit of power equal to 1 million watts.

**MEGAWATT CHARGING SYSTEM (MCS)** – A connector standard for fast charging of electric vehicles that can provide up to 3.75 megawatts of power.

**NITROGEN OXIDES (OXIDES OF NITROGEN, NO<sub>x</sub>)** – A general term for compounds of nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion and are major contributors to smog formation and acid deposition. NO<sub>2</sub> is a criteria air pollutant and may result in numerous adverse health effects.

**ON ROUTE PUBLIC CHARGER** – An on route public charger is a high-powered charger operated by an EVSP that is used to charge MDHD vehicles making brief stops during trips. The models in this report estimate on route public charging needs at a range of power levels from 350 kW to 1.5 MW.

**PLUG-IN ELECTRIC VEHICLE (PEV)** – A general term for any car that runs at least partially on battery power and is recharged from the electricity grid. There are two types of PEVs: pure battery-electric and plug-in hybrid electric vehicles.

**PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)** – PHEVs are powered by an internal combustion engine and an electric motor that uses energy stored in a battery. The vehicle can be plugged in to an electric power source to charge the battery. Some can travel nearly 100 miles on electricity alone, and all can operate solely on gasoline (like a conventional hybrid).

**PRIVATE CHARGING STATION** – A private charging station has parking space(s) that are privately owned and operated, often dedicated for a specific driver or vehicle (for example, a charger installed in the garage of a single-family home).

**PUBLIC CHARGING STATION** – A public charging station has parking space(s) designated by a property owner or lessee to be available to and accessible by the public for any period.

**SHARED PRIVATE CHARGING STATION** – A shared private charging station has parking space(s) designated by a property owner or lessee to be available to and accessible by employees, tenants, visitors, and/or residents. Parking spaces are not dedicated to individual drivers or vehicles.

**SMART CHARGING** – Smart charging, also called managed charging or V1G, adjusts charging time or power level in response to utility rates, demand response events, local site controllers, or other signals.

**SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)** – A global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial vehicle industries. It is the leader in connecting and educating mobility professionals to enable safe, clean, and accessible mobility solutions.<sup>227</sup>

**TRAFFIC ANALYSIS ZONE (TAZ)** – A spatial unit used for the planning of transportation systems. In the models used in this report, charging events are located in TAZs derived from the California Statewide Travel Demand Model.

**TRANSPORTATION ELECTRIFICATION (TE)** – The conversion of transportation system from the use of internal combustion engines and liquid fuels to ZEVs, particularly PEVs.

**TRANSPORTATION NETWORK COMPANY (TNC)** – A company that provides prearranged transportation services for compensation using an online-enabled application or platform (such as smartphone apps) to connect drivers using their personal vehicles with passengers.

**VEHICLE-GRID INTEGRATION (VGI)** – Methods to align electric vehicle charging with the needs of the electric grid. To do this, electric vehicles must have capabilities to manage charging or support two-way communication between vehicles and the grid.

**ZERO-EMISSION VEHICLE (ZEV)** – Vehicles that produce no emissions from the onboard source of power (for example, hydrogen fuel cell vehicles and electric vehicles).

# APPENDIX A:

## List of Related Public Workshops

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July 8, 2021: The CEC conducted a workshop to solicit feedback on analysis of public light-duty electric vehicle charging infrastructure access by disadvantaged communities, low-income communities, and rural communities and to seek feedback on components of the Senate Bill 1000 report.<sup>175</sup>

October 21, 2021: The CEC, CPUC, and GO-Biz conducted a workshop on EV charging infrastructure deployment acceleration and grid integration.<sup>176</sup>

January 20, 2022: The CEC conducted a workshop to present and gather stakeholder feedback on the *Zero-Emission Vehicle (ZEV) Infrastructure Plan (ZIP)*.<sup>177</sup>

March 11, 2022: The CEC conducted a workshop to discuss and receive stakeholder feedback on how to define, measure, and publish reliability metrics for electric vehicle (EV) charging infrastructure and how to incorporate reliability metrics in EV charging infrastructure funding opportunities.<sup>178</sup>

March 16, 2022: The CEC conducted a workshop to present the Electric Vehicle Infrastructure Projections 3 (EVI-Pro 3) model and analysis. The workshop gathered information for the CEC's second AB 2127 assessment.<sup>179</sup>

May 17, 2022: The CEC conducted a workshop to discuss the design and implementation of a voluntary, CEC-housed Vehicle-to-Grid (V2G) Inverter List.<sup>180</sup>

June 14, 2022: The CEC and California Department of Transportation cohosted a workshop to introduce and discuss preliminary elements of the California State Electric Vehicle Infrastructure Deployment Plan as required by the National Electric Vehicle Infrastructure Formula Funding Program (NEVI).<sup>181</sup>

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175 <https://www.energy.ca.gov/event/workshop/2021-07/senate-bill-1000-staff-workshop>.

176 <https://www.energy.ca.gov/event/workshop/2021-10/joint-agency-workshop-accelerating-electric-vehicle-charging-infrastructure>.

177 <https://www.energy.ca.gov/event/workshop/2022-01/workshop-zero-emission-vehicle-infrastructure-plan>.

178 <https://www.energy.ca.gov/event/workshop/2022-03/electric-vehicle-charging-infrastructure-reliability-workshop>.

179 <https://www.energy.ca.gov/event/workshop/2022-03/electric-vehicle-infrastructure-projections-evi-pro-assembly-bill-ab-2127>.

180 <https://www.energy.ca.gov/event/2022-05/workshop-vehicle-grid-inverter-list>.

181 <https://www.energy.ca.gov/event/workshop/2022-06/joint-workshop-california-department-transportation-california-state>.

July 28, 2022: The CEC conducted a workshop to discuss the current status of vehicle-grid integration (VGI) in California and present several funding solicitation concepts designed to help advance and prepare for widespread VGI.<sup>182</sup>

September 19, 2022: The CEC conducted a workshop to initiate public discussion of the second biennial AB 2127 Report. Staff shared plans for developing the assessment, introduced scenarios and analysis, and presented the EVI-Pro 3 model.<sup>183</sup>

October 18, 2022: The CEC conducted a workshop to discuss labor and workforce topics and to gather information for the CEC's second Assembly Bill (AB) 2127 assessment.<sup>184</sup>

November 9, 2022: The CEC conducted a workshop to discuss updates to its Medium- and Heavy-duty Electric Vehicle Infrastructure Load, Operations, and Deployment (HEVI-LOAD) and Widespread Infrastructure for Ride-Hailing EV Deployment (WIRED) modeling analyses. The workshop presented inputs, assumptions, and key differences from earlier versions of the analyses and solicited stakeholder feedback on their development.<sup>185</sup>

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182 <https://www.energy.ca.gov/event/workshop/2022-07/workshop-vehicle-grid-integration-market-status-and-funding-concepts>.

183 <https://www.energy.ca.gov/event/workshop/2022-09/assembly-bill-ab-2127-assessment-workshop>.

184 <https://www.energy.ca.gov/event/workshop/2022-10/workshop-labor-and-workforce-second-assembly-bill-2127-assessment>.

185 <https://www.energy.ca.gov/event/workshop/2022-11/workshop-medium-and-heavy-duty-and-ride-hailing-electric-vehicle>.

# **APPENDIX B:**

## **Text of Assembly Bill 2127 and Senate Bill 589**

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The scope of this report is defined in part by two state laws and an executive order that require the CEC to assess the charging infrastructure and workforce development and training resources needed to meet the state's transportation electrification goals. Assembly Bill 2127 (Ting, Chapter 365, Statutes of 2018) requires the CEC to prepare a statewide assessment of the charging infrastructure needed to achieve the goal of 5 million ZEVs on the road by 2030 and reduce emissions of greenhouse gases to 40 percent below 1990 levels by 2030. Executive Order N-79-20 directed the CEC to expand this assessment to support higher targets of electric vehicle adoption through 2035. Senate Bill 589 (Hueso, Chapter 732, Statutes of 2021) requires as part of the CEC's AB 2127 assessment starting in 2023, to identify workforce development and training resources needed to meet PEV adoption goals.

The text of these laws is included here for reference.

### **Assembly Bill No. 2127**

An act to add Section 25229 to the Public Resources Code, relating to electric vehicles. Approved by Governor September 13, 2018. Filed with Secretary of State September 13, 2018.

### **LEGISLATIVE COUNSEL'S DIGEST**

Existing law requires the State Energy Resources Conservation and Development Commission (Energy Commission), on a biennial basis, to adopt an integrated energy policy report containing an overview of major energy trends and issues facing the state. Existing law requires the Energy Commission, as a part of the report, to conduct transportation forecasting and assessment activities that include, among other things, an assessment of trends in transportation fuels, technologies, and infrastructure supply and demand.

Existing law requires the Public Utilities Commission (PUC), in consultation with the State Air Resources Board and the Energy Commission, to direct the electrical corporations to file applications for programs and investments to accelerate widespread transportation electrification to achieve certain state goals.

This bill would require the Energy Commission, working with the State Air Resources Board and the PUC, to prepare and biennially update a statewide assessment of the electric vehicle charging infrastructure needed to support the levels of electric vehicle adoption required for the state to meet its goals of putting at least 5 million zero-emission vehicles on California roads by 2030 and of reducing emissions of greenhouse gases to 40% below 1990 levels by 2030. The bill would require the Energy Commission to regularly seek data and input from stakeholders relating to electric vehicle charging infrastructure.

### **BILL TEXT**

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

#### **SECTION 1.**

(a) The Legislature finds and declares all of the following:

(1) Advanced clean vehicles and fuels are needed to reduce petroleum use, to meet air quality standards, to improve public health, and to achieve greenhouse gas emissions reduction goals.

(2) Widespread transportation electrification requires increased access to the use of electricity as a transportation fuel.

(3) Electric vehicles and charging infrastructure with the ability to record consumption and connect by remote communication technology could assist in grid management and the integration of eligible renewable energy resources. Electric vehicles can also reduce fuel costs for vehicle owners, and time-of-use electric rates can encourage charging that is compatible with electrical grid conditions.

(4) Deploying electric vehicle charging infrastructure will facilitate increased adoption of electric vehicles.

(b) It is the policy of the state and the intent of the Legislature to encourage transportation electrification as a means to achieve ambient air quality standards and the state's climate goals.

## **SECTION 2.**

Section 25229 is added to the Public Resources Code, to read:

### **25229.**

(a) The commission, working with the State Air Resources Board and the Public Utilities Commission, shall prepare a statewide assessment of the electric vehicle charging infrastructure needed to support the levels of electric vehicle adoption required for the state to meet its goals of putting at least five million zero-emission vehicles on California roads by 2030, and of reducing emissions of greenhouse gases to 40 percent below 1990 levels by 2030.

(b) The assessment shall expand on the commission's electric vehicle infrastructure projections to consider all necessary charging infrastructure, including, but not limited to, the chargers, make-ready electrical equipment, and supporting hardware and software, all vehicle categories, road, highway, and offroad electrification, port and airport electrification, and other programs to accelerate the adoption of electric vehicles to meet the goals described in subdivision (a). The assessment shall examine existing and future infrastructure needs throughout California, including in low-income communities.

(c) The commission shall regularly seek data and input relating to electric vehicle charging infrastructure from stakeholders, including, but not limited to, the Public Utilities Commission, the State Air Resources Board, electrical corporations, local publicly owned electric utilities, state and local transportation and transit agencies, charging infrastructure companies, environmental groups, and automobile manufacturers.

(d) The commission shall update the assessment at least once every two years.

## **Senate Bill No. 589**

An act to add Section 44272.2 to the Health and Safety Code, and to amend Section 25229 of the Public Resources Code, relating to air pollution. Approved by Governor October 8, 2021. Filed with Secretary of State October 8, 2021.

### **LEGISLATIVE COUNSEL'S DIGEST**

Existing law requires the State Energy Resources Conservation and Development Commission, working with specified state entities, to prepare a statewide assessment of the electric vehicle charging infrastructure needed to support the levels of electric vehicle adoption required to meet the goals of putting at least 5 million zero-emission vehicles in service by 2030 and of reducing emissions of greenhouse gases to 40% below 1990 levels by 2030. Existing law requires the commission to update the assessment once every 2 years.

This bill would require the commission, as a part of the assessment, to identify workforce development and training resources needed to meet those goals.

Existing law establishes the Alternative and Renewable Fuel and Vehicle Technology Program, which is administered by the commission to provide financial assistance to certain entities to develop and deploy innovative technologies to transform California's fuel and vehicle types to help attain the state's climate change goals. Existing law requires the commission to collaborate with entities that have expertise in workforce development to implement the workforce development components of the program.

This bill would specify that projects that develop instate production of raw materials and the manufacturing supply chain for zero-emission vehicle components are eligible for funding under the program. The bill would require the commission to also collaborate with the California Community Colleges, the certified community conservation corps, the California Mobility Center, and the California Conservation Corps to implement the workforce development components of the program.

### **BILL TEXT**

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

#### **SECTION 1.**

Section 44272.2 is added to the Health and Safety Code, to read:

#### **44272.2.**

(a) A project, including a workforce development or training project, that develops instate production of raw materials and the manufacturing supply chain for zero-emission vehicle components shall be eligible to receive funding under the program established pursuant to Section 44272.

(b) In addition to the entities set forth in Section 44272, the commission shall also collaborate with the California Community Colleges, the certified community conservation corps as defined in Section 14507.5 of the Public Resources Code, the California Conservation Corps, and the California Mobility Center to implement the workforce development components of the program established pursuant to Section 44272.

## **SECTION 2.**

Section 25229 of the Public Resources Code is amended to read:

### **25229.**

(a) The commission, working with the State Air Resources Board and the Public Utilities Commission, shall prepare a statewide assessment of the electric vehicle charging infrastructure needed to support the levels of electric vehicle adoption required for the state to meet its goals of putting at least five million zero-emission vehicles on California roads by 2030, and of reducing emissions of greenhouse gases to 40 percent below 1990 levels by 2030.

(b) The assessment shall expand on the commission's electric vehicle infrastructure projections to consider all necessary charging infrastructure, including, but not limited to, the chargers, make-ready electrical equipment, and supporting hardware and software, all vehicle categories, road, highway, and offroad electrification, port and airport electrification, and other programs to accelerate the adoption of electric vehicles to meet the goals described in subdivision (a). The assessment shall examine existing and future infrastructure needs throughout California, including in low-income communities.

(c) As a part of the assessment, the commission, in consultation with stakeholders, shall identify workforce development and training resources needed to meet the goals described in subdivision (a). These resources shall include, but are not limited to, qualified apprenticeships, on-the-job training programs, and other training opportunities that build career pipelines in the zero-emission transportation sector and provide long-term employment in disadvantaged communities.

(d) The commission shall regularly seek data and input relating to electric vehicle charging infrastructure from stakeholders, including, but not limited to, the Public Utilities Commission, the State Air Resources Board, electrical corporations, local publicly owned electric utilities, state and local transportation and transit agencies, charging infrastructure companies, environmental groups, and automobile manufacturers.

(e) The commission shall update the assessment at least once every two years.



# APPENDIX C:

## EVI-Pro 3 Inputs and Parameters

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This appendix presents several key inputs and parameters used for the EVI-Pro 3 analysis discussed in this report. Table C-1 provides a summary of the major parameters under the baseline scenario. To generate alternative future scenarios, individual parameters of the baseline scenario for 2030 were modified.

**Table C-1: Summary of input parameters for the baseline scenario**

Input	2023	2025	<b>2030</b>	2035
ZEV Count	1,459,396	2,495,085	<b>7,063,541</b>	15,165,466
BEV Count	1,076,462	2,015,881	<b>6,228,970</b>	13,613,011
PHEV Count	382,934	479,204	<b>834,571</b>	1,552,455
Commuter Share	70%	70%	<b>50%</b>	50%
Share of PEVs in Multifamily Housing	5%	8%	<b>23%</b>	23%
Res Access	84%	78%	<b>66%</b>	60%
BEV "Rational" Cohort Size	80%	80%	<b>65%</b>	65%
BEV "Free Public L2" Cohort Size	10%	10%	<b>20%</b>	20%
BEV "DCFC dominant" Cohort Size	10%	10%	<b>15%</b>	15%
PHEV "Lazy" Cohort Size	60%	60%	<b>50%</b>	50%
PHEV "Rational" Cohort Size	30%	30%	<b>30%</b>	30%
PHEV "Free Public L2" Cohort Size	10%	10%	<b>20%</b>	20%
No TOU Cohort Size	50%	50%	<b>0%</b>	0%
TOU ASAP (on peak ends) Cohort Size	17%	17%	<b>33%</b>	33%
TOU ASAP (off peak starts) Cohort Size	17%	17%	<b>33%</b>	33%
TOU ALAP Cohort Size	17%	17%	<b>33%</b>	33%
Non-res L2 Utilization (events per day)	0.9-1.1	0.9-1.1	<b>0.9-1.1</b>	0.9-1.1

DC50 Utilization (events per day)	4.8-6.8	4.8-6.8	<b>4.8-6.8</b>	4.8-6.8
DC150 Utilization (events per day)	6.5-8.5	6.5-8.5	<b>6.5-8.5</b>	6.5-8.5
DC250 Utilization (events per day)	3.2-5.2	3.2-5.2	<b>6.1-8.1</b>	6.1-8.1
DC350 Utilization (events per day)	1.2-3.2	1.2-3.2	<b>5.1-7.1</b>	5.1-7.1
DC50 Utilization (percent)	11.5%	11.5%	<b>11.5%</b>	11.5%
DC150 Utilization (percent)	10.0%	10.0%	<b>10.0%</b>	10.0%
DC250 Utilization (percent)	5.0%	5.0%	<b>8.5%</b>	8.5%
DC350 Utilization (percent)	2.5%	2.5%	<b>7.0%</b>	7.0%

Source: CEC Staff and NREL

Charging behavior cohorts represent these behaviors:

- **BEV "rational"** is the fraction of BEV drivers that choose to charge where it is cheapest, with home charging being the first choice.
- **BEV "Free Public L2"** cohort drivers use free public L2 charging when it is available at an activity destination.
- **BEV "DCFC dominant"** cohort drivers prefer to use DCFC whenever possible.
- **PHEV "Lazy"** cohort drivers only charge their PHEVs at home and use the internal combustion engine for the rest of the day if they expend their electric range.
- **PHEV "Rational"** cohort drivers manage their charging to minimize their use of the internal combustion engine, even if this means charging briefly at every destination.
- **PHEV "Free Public L2"** cohort drivers use free public L2 charging when it is available at an activity destination.

The residential load cohorts behave as follows:

- **No TOU** drivers start charging their car as soon as they arrive home.
- **TOU ASAP (on peak ends)** drivers start charging as soon as the peak TOU rate ends.
- **TOU ASAP (off peak starts)** drivers start charging as soon as the lowest cost off-peak hour TOU rate starts.
- **TOU ALAP** drivers start charging as late as possible while ensuring that they will have sufficient charge for that day's travel.

For this report, CEC and NREL attempted to disaggregate work and public charging events to a more specific range of locations based on business type and charger access. Table C-2 shows the allocation of work charging events to each location type. Other non-home charging events (formerly labeled "public" charging events) are split equally between retail and other locations.



**Table C-2: Proportion of chargers from work activity charging events allocated to shared private and public charging locations.**

Occupation Type	Shared Private Office	Public Office	Shared Private Retail	Public Retail	Shared Private Other	Public Other
2021	80	20	0	0	0	0
2022	76	20	1	1	1	1
2023	73	20	2	1	2	2
2024	69	20	3	2	4	2
2025	65	20	4	3	5	3
2026	62	20	5	3	6	4
2027	58	20	6	4	7	5
2028	55	20	7	4	8	6
2029	51	20	8	5	10	6
2030	48	20	8	6	11	7
2031	45	20	9	6	12	8
2032	41	20	10	7	13	9
2033	37	20	11	8	14	10
2034	34	20	12	8	16	10
2035	30	20	13.2	8.8	16.8	11.2

Source: CEC Staff and NREL

EVI-Pro 3 models the LDV fleet based on a range of vehicle categories and generations, with vehicles in each category / generation sharing battery capacity, efficiency, and charging characteristics, as shown in Tables C-3. Generation 1 contains vehicles manufactured in 2011-2025. Generation 2 contains vehicles manufactured in 2026-2030. Generation 3 contains vehicles manufactured after 2030. This fleet model was originally designed for the IEPR AATE3 scenario. Table C-4 contains the number of vehicles in each category and generation in the fleet as of 2025, 2030, and 2035.

**Table C-3: Light duty vehicle fleet characteristics**

Vehicle Category	Generation	Battery Capacity (kWh)	Efficiency (Wh/mi)	Charging speed AC (kW)	Charging speed DC (kW)	Electric Range (mi)
Large Car	PHEV	15.0	277	6.5	0	54
Large SUV	PHEV	20.0	376	6.4	0	53
Pickup Truck	PHEV	19.0	378	6.1	0	50
Small Car	PHEV	12.0	275	5.2	0	44
Small SUV	PHEV	17.0	339	6.1	0	50
Sport Car	PHEV	13.0	273	5.7	0	48

Van	PHEV	19.0	353	6.4	0	54
Large Car	Gen 1	136.0	349	12.0	281	390
Large SUV	Gen 1	172.7	500	12.0	311	346
Pickup Truck	Gen 1	179.1	611	12.0	232	293
Small Car	Gen 1	69.9	308	10.9	118	227
Small SUV	Gen 1	139.1	488	12.0	220	285
Sport Car	Gen 1	119.0	389	12.0	224	306
Van	Gen 1	99.9	411	11.6	247	243
Large Car	Gen 2	128.1	349	12.0	410	367
Large SUV	Gen 2	193.4	504	12.0	494	384
Pickup Truck	Gen 2	199.5	582	12.0	397	343
Small Car	Gen 2	79.6	314	12.0	177	254
Small SUV	Gen 2	155.8	487	12.0	363	320
Sport Car	Gen 2	147.4	398	12.0	378	370
Van	Gen 2	118.9	411	11.6	438	289
Large Car	Gen 3	135.7	351	12.0	595	386
Large SUV	Gen 3	208.8	509	12.0	676	410
Pickup Truck	Gen 3	211.9	534	12.0	621	396
Small Car	Gen 3	88.5	319	12.0	245	278
Small SUV	Gen 3	170.9	483	12.0	534	354
Sport Car	Gen 3	155.1	404	12.0	504	384
Van	Gen 3	142.7	425	11.6	681	336

Source: CEC Staff and NREL

**Table C-4: Light duty vehicle fleet makeup 2025, 2030, 2035 AATE3 scenario**

<b>Vehicle Category</b>	<b>Generation</b>	<b>2025</b>	<b>2030</b>	<b>2035</b>
Large Car	PHEV	2,278	1,494	1,054
Large SUV	PHEV	1,289	6,844	17,695

Pickup Truck	PHEV	8,211	73,471	212,912
Small Car	PHEV	241,543	256,675	333,556
Small SUV	PHEV	212,443	479,317	962,883
Sport Car	PHEV	1,159	1,014	1,834
Van	PHEV	12,280	15,755	22,521
Large Car	Gen 1	520,205	520,205	520,205
Large SUV	Gen 1	7,245	7,245	7,245
Pickup Truck	Gen 1	43,584	43,584	43,584
Small Car	Gen 1	600,956	600,956	600,956
Small SUV	Gen 1	784,036	784,036	784,036
Sport Car	Gen 1	39,753	39,753	39,753
Van	Gen 1	20,101	20,101	20,101
Large Car	Gen 2	0	956,970	956,970
Large SUV	Gen 2	0	30,167	30,167
Pickup Truck	Gen 2	0	339,145	339,145
Small Car	Gen 2	0	967,314	967,314
Small SUV	Gen 2	0	1,632,105	1,632,105
Sport Car	Gen 2	0	218,502	218,502
Van	Gen 2	0	68,886	68,886
Large Car	Gen 3	0	0	1,361,454
Large SUV	Gen 3	0	0	50,479
Pickup Truck	Gen 3	0	0	683,723
Small Car	Gen 3	0	0	1,652,725
Small SUV	Gen 3	0	0	3,003,706
Sport Car	Gen 3	0	0	504,438
Van	Gen 3	0	0	127,516

Source: CEC Staff

# APPENDIX D:

## EVI-Pro 3 Detailed Results for Primary Scenarios

**Table D-1: Statewide totals with lower and upper bounds for 2023 and 2025 AATE3**

Charger and Location	2023 – Lower	2023 – Upper	2025 – Lower	2025 – Upper
Single-family housing L1	380,533	422,815	666,941	741,045
Single-family housing L2	687,437	763,819	1,021,453	1,134,948
Multi-family housing L1	10,165	11,295	20,594	22,882
Multi-family housing L2	10,202	20,404	17,522	35,045
Shared Private Office	54,389	66,475	91,882	112,301
Public Office	14,901	18,212	28,271	34,554
Shared Private Retail	1,490	1,821	5,654	6,911
Public Retail	12,256	14,980	20,845	25,478
Shared Private Other	1,490	1,821	7,068	8,639
Public Other	13,001	15,890	20,845	25,478
DCFC 150 or less	1,161	1,521	2,149	2,815
DCFC 250	1,965	3,192	4,136	6,721
DCFC 350	697	1,842	2,418	6,447

Source: NREL

**Table D-2: Statewide totals with lower and upper bounds for 2030 and 2035 AATE3**

Charger and Location	2030 – Lower	2030 – Upper	2035 – Lower	2035 – Upper
Single-family housing L1	1,300,797	1,445,330	2,206,323	2,451,470
Single-family housing L2	2,584,764	2,871,960	5,416,469	6,018,299
Multi-family housing L1	115,555	128,395	186,052	206,724
Multi-family housing L2	127,564	255,128	253,752	507,503
Shared Private Office	185,511	226,735	264,323	323,061
Public Office	77,296	94,473	176,215	215,374
Shared Private Retail	30,918	37,789	116,302	142,147
Public Retail	125,231	153,060	291,164	355,867
Shared Private Other	42,513	51,960	148,021	180,914
Public Other	129,096	157,784	312,310	381,712
DCFC 150 or less	3,688	4,847	4,237	5,583
DCFC 250	9,220	12,242	18,439	24,485
DCFC 350	14,909	20,756	38,790	54,002

Source: NREL

**Table D-3: Statewide totals with lower and upper bounds for 2030 and 2035 ACCII**

Charger and Location	2030 – Lower	2030 – Upper	2035 – Lower	2035 – Upper
Single-family housing L1	1,046,015	1,162,239	1,780,618	1,978,464
Single-family housing L2	2,078,496	2,309,440	4,371,374	4,857,082
Multi-family housing L1	92,825	103,138	150,075	166,750
Multi-family housing L2	102,471	204,942	204,684	409,367
Shared Private Office	152,234	186,063	215,071	262,865
Public Office	63,431	77,526	143,381	175,243
Shared Private Retail	25,372	31,011	94,631	115,661
Public Retail	108,637	132,778	244,713	299,094
Shared Private Other	34,887	42,640	120,440	147,204
Public Other	111,808	136,655	261,919	320,123
DCFC 150 or less	2,088	2,750	2,463	3,254
DCFC 250	6,707	8,906	14,044	18,648
DCFC 350	11,992	16,695	31,092	43,285

Source: NREL

**Table D-4: County-by-county results for total L1 and L2 chargers at MUDs**

County	2023	2025	2030	2035
Alameda	1,119	2,980	20,854	37,252
Alpine	0	0	2	4
Amador	3	4	52	105
Butte	7	8	239	431
Calaveras	3	3	44	87
Colusa	2	2	40	80
Contra Costa	237	311	10,130	18,269
Del Norte	1	1	10	18
El Dorado	18	19	361	719
Fresno	34	35	1,423	2,880
Glenn	1	1	19	35
Humboldt	18	18	618	1,295
Imperial	5	6	171	299
Inyo	3	4	54	114
Kern	38	41	1,223	2,427
Kings	6	7	228	444
Lake	12	12	285	594
Lassen	1	1	12	20
Los Angeles	13,602	23,273	115,526	211,318
Madera	5	6	97	198
Marin	47	180	2,550	5,198
Mariposa	1	1	16	33
Mendocino	13	13	311	657
Merced	26	30	740	1,414



Modoc	0	0	3	6
Mono	1	1	20	40
Monterey	34	46	1,662	3,391
Napa	28	29	889	1,819
Nevada	7	8	93	181
Orange	2,047	4,645	28,985	51,635
Placer	42	48	1,139	2,203
Plumas	0	1	6	11
Riverside	222	261	6,260	11,697
Sacramento	142	150	6,123	12,097
San Benito	22	26	657	1,259
San Bernardino	188	216	7,219	13,604
San Diego	2,493	5,002	31,066	57,433
San Francisco	3,075	4,466	15,123	27,000
San Joaquin	79	96	2,420	4,496
San Luis Obispo	22	22	847	1,757
San Mateo	689	1,695	11,261	20,171
Santa Barbara	79	284	3,208	6,779
Santa Clara	1,259	3,572	26,357	47,391
Santa Cruz	43	49	1,958	3,798
Shasta	7	9	169	285
Sierra	0	0	3	5
Siskiyou	2	2	24	41
Solano	62	67	2,200	4,318
Sonoma	76	76	2,806	5,830
Stanislaus	32	40	905	1,650
Sutter	5	6	136	262
Tehama	4	5	71	136
Trinity	1	1	11	21
Tulare	13	15	309	589
Tuolumne	4	4	59	118
Ventura	131	131	5,239	10,987
Yolo	17	86	973	1,899
Yuba	4	5	112	213

Source: NREL

**Table D-5: County-by-county results for total L2 chargers at work and public sites**

County	2023	2025	2030	2035
Alameda	6,323	10,928	36,817	86,082
Alpine	2	6	9	17
Amador	68	61	347	808
Butte	123	224	931	1,865
Calaveras	32	59	216	535
Colusa	38	57	151	233

Contra Costa	3,457	5,605	24,235	54,297
Del Norte	9	14	54	82
El Dorado	281	384	1,646	3,603
Fresno	762	1,037	4,984	11,725
Glenn	17	34	100	198
Humboldt	351	476	2,323	6,104
Imperial	76	157	295	784
Inyo	33	55	393	886
Kern	718	1,350	3,970	9,320
Kings	181	281	977	1,909
Lake	167	212	1,048	2,738
Lassen	13	28	76	113
Los Angeles	34,191	62,746	201,464	435,764
Madera	161	201	577	1,456
Marin	1,027	1,423	4,918	10,522
Mariposa	18	15	88	290
Mendocino	285	338	1,545	3,818
Merced	443	620	1,887	5,252
Modoc	5	1	7	26
Mono	13	21	187	383
Monterey	621	973	4,232	11,042
Napa	524	937	3,802	8,109
Nevada	68	136	577	1,507
Orange	10,457	20,788	66,026	143,044
Placer	713	1,111	4,557	10,314
Plumas	3	5	27	64
Riverside	3,681	7,158	22,944	51,171
Sacramento	3,067	4,498	17,111	40,327
San Benito	386	422	2,412	4,552
San Bernardino	3,706	6,987	21,076	51,913
San Diego	11,418	20,869	70,112	153,300
San Francisco	2,204	3,874	12,625	27,537
San Joaquin	1,397	2,491	8,154	18,790
San Luis Obispo	573	823	2,879	7,365
San Mateo	2,851	6,305	18,693	41,352
Santa Barbara	1,132	1,679	6,713	17,278
Santa Clara	9,338	17,822	59,680	126,726
Santa Cruz	476	933	4,230	9,359
Shasta	142	277	870	1,664
Sierra	1	3	3	22
Siskiyou	30	53	159	282
Solano	1,297	2,020	7,202	15,525
Sonoma	1,549	2,052	10,103	20,564
Stanislaus	506	819	3,038	6,914

Sutter	44	60	321	867
Tehama	40	50	298	538
Trinity	3	8	37	80
Tulare	283	414	1,689	3,162
Tuolumne	46	79	320	886
Ventura	2,618	3,338	15,012	35,956
Yolo	278	475	1,759	4,135
Yuba	118	173	276	553

Source: NREL

**Table D-6: County-by-county results for total DC fast chargers**

County	2023	2025	2030	2035
Alameda	355	893	2,059	4,196
Alpine	0	1	1	4
Amador	7	13	39	89
Butte	4	11	36	80
Calaveras	5	6	18	43
Colusa	5	11	28	76
Contra Costa	147	425	1,391	2,873
Del Norte	1	1	4	9
El Dorado	9	28	120	266
Fresno	28	52	203	516
Glenn	1	3	4	6
Humboldt	19	40	124	349
Imperial	7	17	37	78
Inyo	6	10	40	127
Kern	44	105	230	559
Kings	8	32	60	153
Lake	14	27	125	287
Lassen	1	3	6	16
Los Angeles	1,277	3,284	8,601	20,201
Madera	8	13	36	82
Marin	53	51	295	690
Mariposa	2	1	7	21
Mendocino	5	18	100	205
Merced	27	62	127	362
Modoc	0	0	0	1
Mono	0	0	4	10
Monterey	32	87	251	644
Napa	47	84	321	644
Nevada	6	11	43	78
Orange	407	1,204	3,331	6,401
Placer	38	91	236	664
Plumas	0	1	2	6

Riverside	252	597	1,258	2,669
Sacramento	125	290	817	1,904
San Benito	35	96	206	487
San Bernardino	164	367	1,116	2,516
San Diego	437	999	3,184	6,658
San Francisco	123	285	692	1,431
San Joaquin	114	273	556	1,153
San Luis Obispo	21	35	188	432
San Mateo	164	374	1,032	2,224
Santa Barbara	83	134	391	988
Santa Clara	543	1,284	2,490	5,609
Santa Cruz	47	88	260	593
Shasta	5	12	47	86
Sierra	0	0	1	2
Siskiyou	2	6	11	26
Solano	148	282	435	1,111
Sonoma	109	220	738	1,688
Stanislaus	53	93	255	536
Sutter	7	11	31	59
Tehama	3	6	18	49
Trinity	2	4	2	9
Tulare	16	23	79	166
Tuolumne	2	7	18	51
Ventura	149	202	1,012	2,286
Yolo	13	45	94	238
Yuba	1	25	22	59

Source: NREL

**Table D-7: Statewide annual charger totals 2025-2028 AATE3**

Charger and location	2025	2026	2027	2028
Single-family housing L1	703,993	706,874	848,494	1,011,034
Single-family housing L2	1,078,200	1,462,310	1,764,791	2,085,154
Multi-family housing L1	21,738	27,156	40,569	59,845
Multi-family housing L2	26,284	44,350	66,616	97,440
Shared Private Office	102,091	124,766	154,123	174,920
Public Office	31,413	40,247	53,146	63,607
Shared Private Retail	6,283	10,062	15,944	22,263
Public Retail	23,161	34,648	48,341	66,756
Shared Private Other	7,853	12,074	18,601	25,443
Public Other	23,161	36,661	50,998	73,117
DCFC 150 or less	2,482	3,105	3,319	3,304
DCFC 250	5,428	6,978	7,304	8,005
DCFC 350	4,432	8,201	10,417	12,965

Source: NREL

**Table D-8: Statewide annual charger totals 2029-2032 AATE3**

Charger and location	2029	2030	2031	2032
Single-family housing L1	1,189,007	1,373,064	1,396,499	1,619,066
Single-family housing L2	2,407,927	2,728,362	3,430,800	3,966,763
Multi-family housing L1	86,430	121,975	122,957	141,213
Multi-family housing L2	138,185	191,346	238,476	273,139
Shared Private Office	186,602	206,123	243,017	255,798
Public Office	73,177	85,885	108,008	124,780
Shared Private Retail	29,271	34,354	48,603	62,390
Public Retail	95,365	139,146	165,050	201,842
Shared Private Other	36,589	47,237	64,805	81,107
Public Other	99,024	143,440	175,851	214,320
DCFC 150 or less	3,498	4,268	4,442	4,629
DCFC 250	9,288	10,731	12,776	14,526
DCFC 350	15,059	17,832	22,853	27,842

Source: NREL

**Table D-9: Statewide annual charger totals 2033-2035 AATE3**

Charger and location	2033	2034	2035
Single-family housing L1	1,850,110	2,088,838	2,328,896
Single-family housing L2	4,531,599	5,116,389	5,717,384
Multi-family housing L1	159,717	178,328	196,388
Multi-family housing L2	308,847	344,838	380,628
Shared Private Office	269,260	285,847	293,692
Public Office	145,546	168,145	195,795
Shared Private Retail	80,050	100,887	129,225
Public Retail	235,210	280,771	323,516
Shared Private Other	101,882	134,516	164,468
Public Other	249,765	297,586	347,011
DCFC 150 or less	4,599	4,774	4,910
DCFC 250	16,622	19,434	21,462
DCFC 350	32,483	39,250	46,396

Source: NREL

# APPENDIX E:

## EVI-Pro 3 Alternative Futures

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**Table E-1: Summary of Alternative Future scenarios**

<b>Scenario Name</b>	<b>Modification from Baseline Scenario</b>
<b>Higher home access</b>	Home charging access increased to 76% (66% in baseline)
<b>Lower home access</b>	Home charging access decreased to 56% (66% in baseline)
<b>Gas station model</b>	Drivers without home charging use DCFC as first choice
<b>Low work access</b>	Work charging access decreased to 40% (50% in baseline)
<b>More free public L2</b>	Free public L2 increased to 40% (20% in baseline)
<b>Solar priority</b>	Daytime charging prioritized by all drivers
<b>Home grid: unmanaged</b>	All home charging events start immediately upon arrival at home
<b>Home grid: pure TOU</b>	All home charging events start at beginning of off-peak rate
<b>Home grid: as late as possible</b>	All home charging events start as late as possible

Source: CEC Staff and NREL

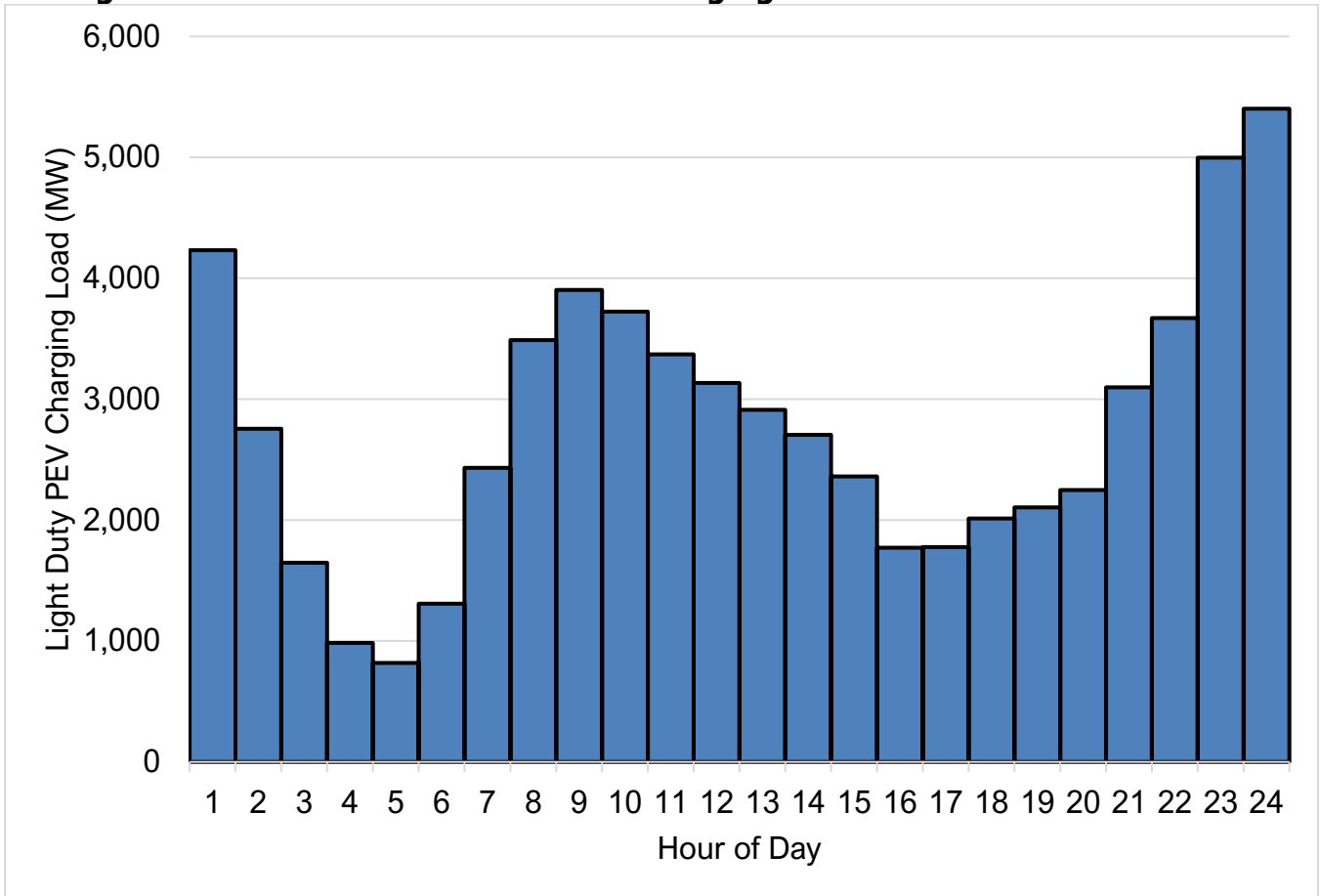
**Table E-2: Alternative Future results for 2030**

Location	Multi-Family Home L1 and L2	Public and Work L2	DCFC
Baseline	313,321	656,184	32,831
Higher home access	443,779	616,333	28,677
Lower home access	182,624	723,687	35,201
Gas station model	313,748	253,755	96,082
Low work access	313,322	578,357	36,883
More free public L2	312,442	899,381	30,511
Solar priority	310,000	1,052,338	59,581
Home grid: unmanaged	313,293	659,837	32,123
Home grid: pure TOU	313,321	656,184	32,831
Home grid: as late as possible	313,321	656,184	32,831

Source: CEC Staff and NREL

This appendix contains load curves for all alternative future scenarios. For reference, Figure E-1 shows the load shape on a typical summer day in 2030 for the CAISO planning area using the CEC’s Energy Demand Forecast’s Electric Vehicle Infrastructure Load Model. The EV Load Model distributes charging load over the course of a forecast year based on time-of-use rates and changes in the type of charging over time (e.g., home charging vs. away-from-home charging). These load shapes are used as part of the broader IEPR planning forecast to inform utility plans for resource procurement, distribution planning, and transmission planning.

**Figure E-1 EAD load curve from PEV charging in 2030 under AATE3 scenario**

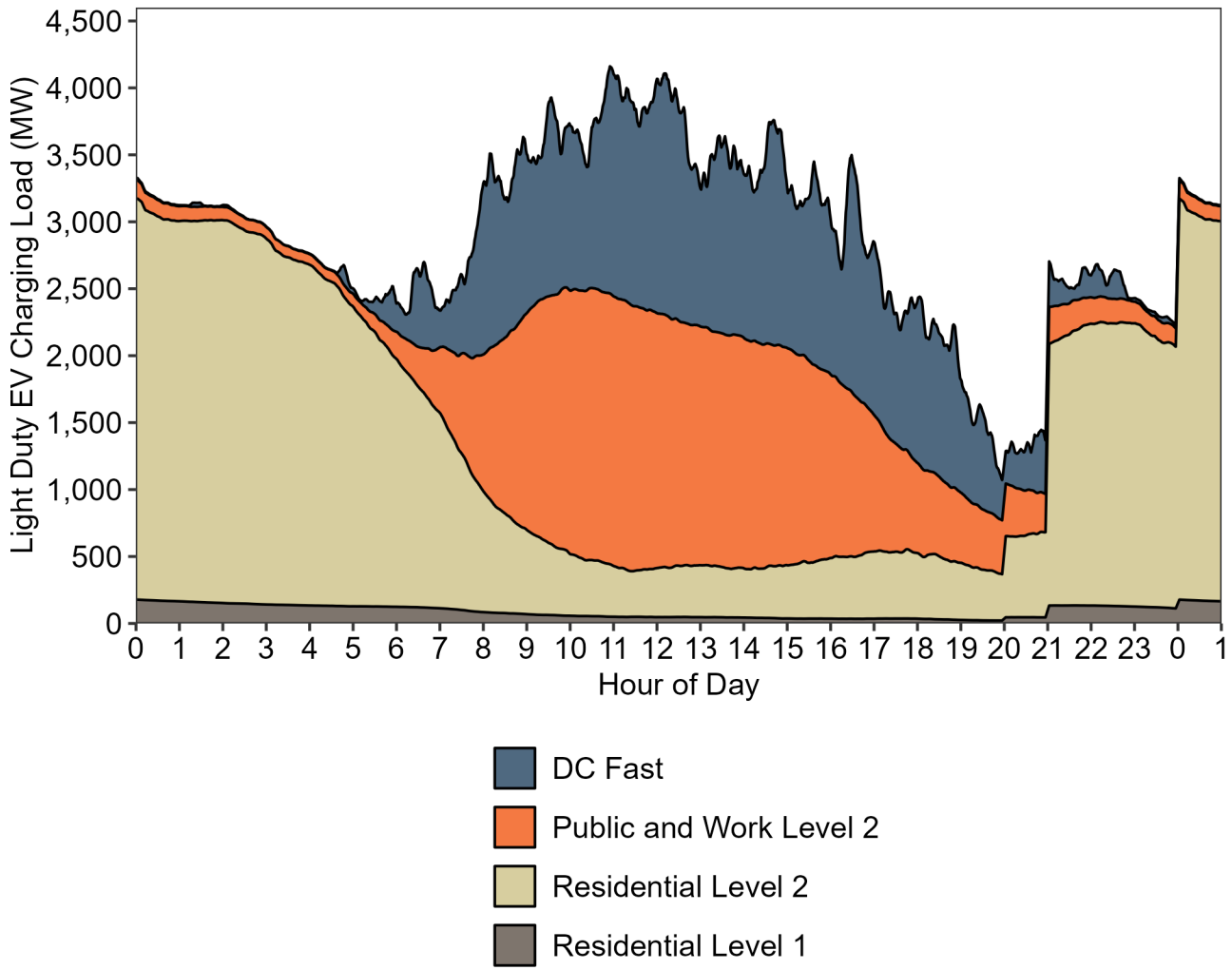


**LDV charging load modeled by the CEC’s Energy Assessment Division for the IEPR shows a large proportion of charging moved away from late afternoon and early evening to minimize strain on the grid and California’s energy supply.**

Source: CEC Staff

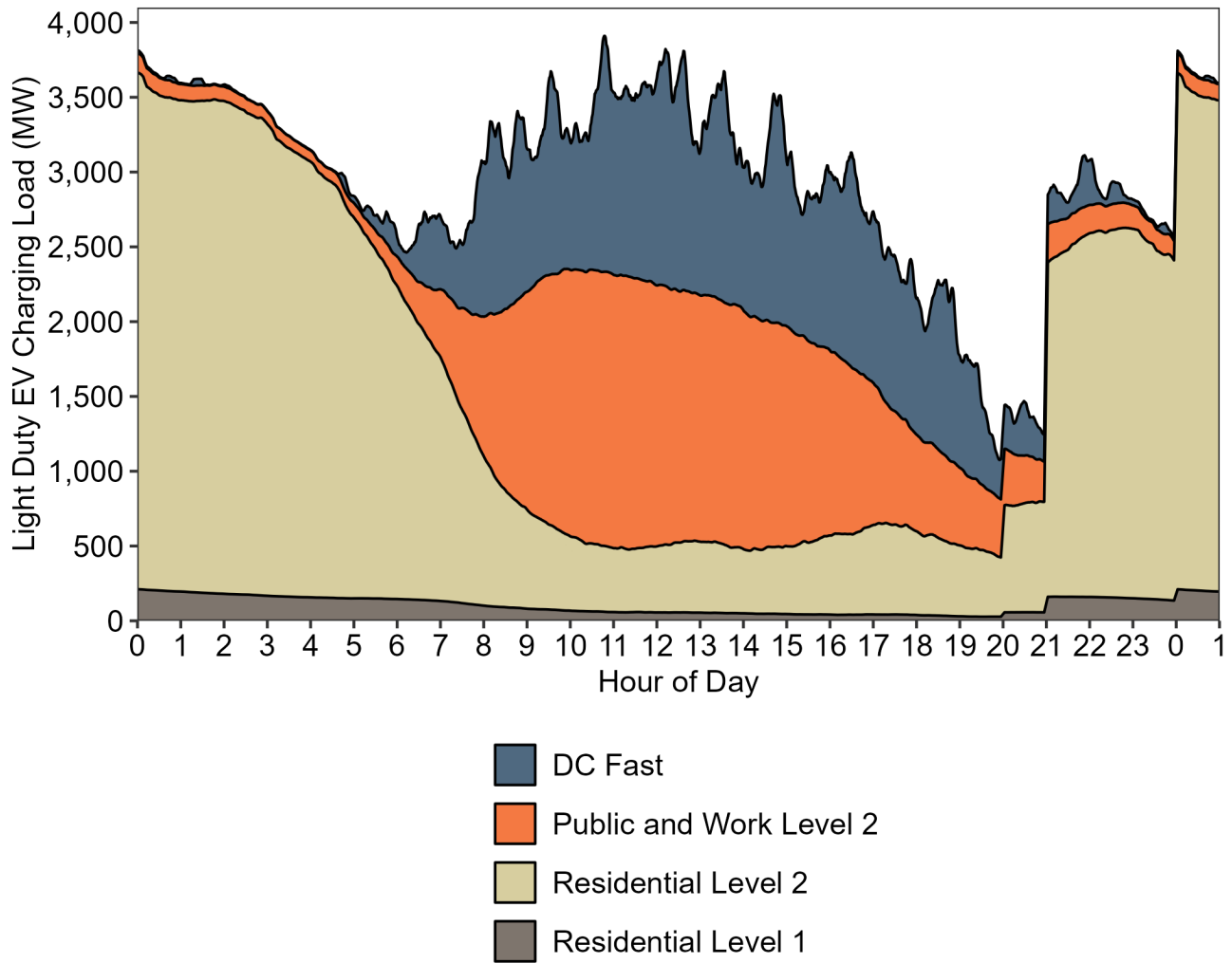


**Figure E-2: LDV charging load under the primary scenario**



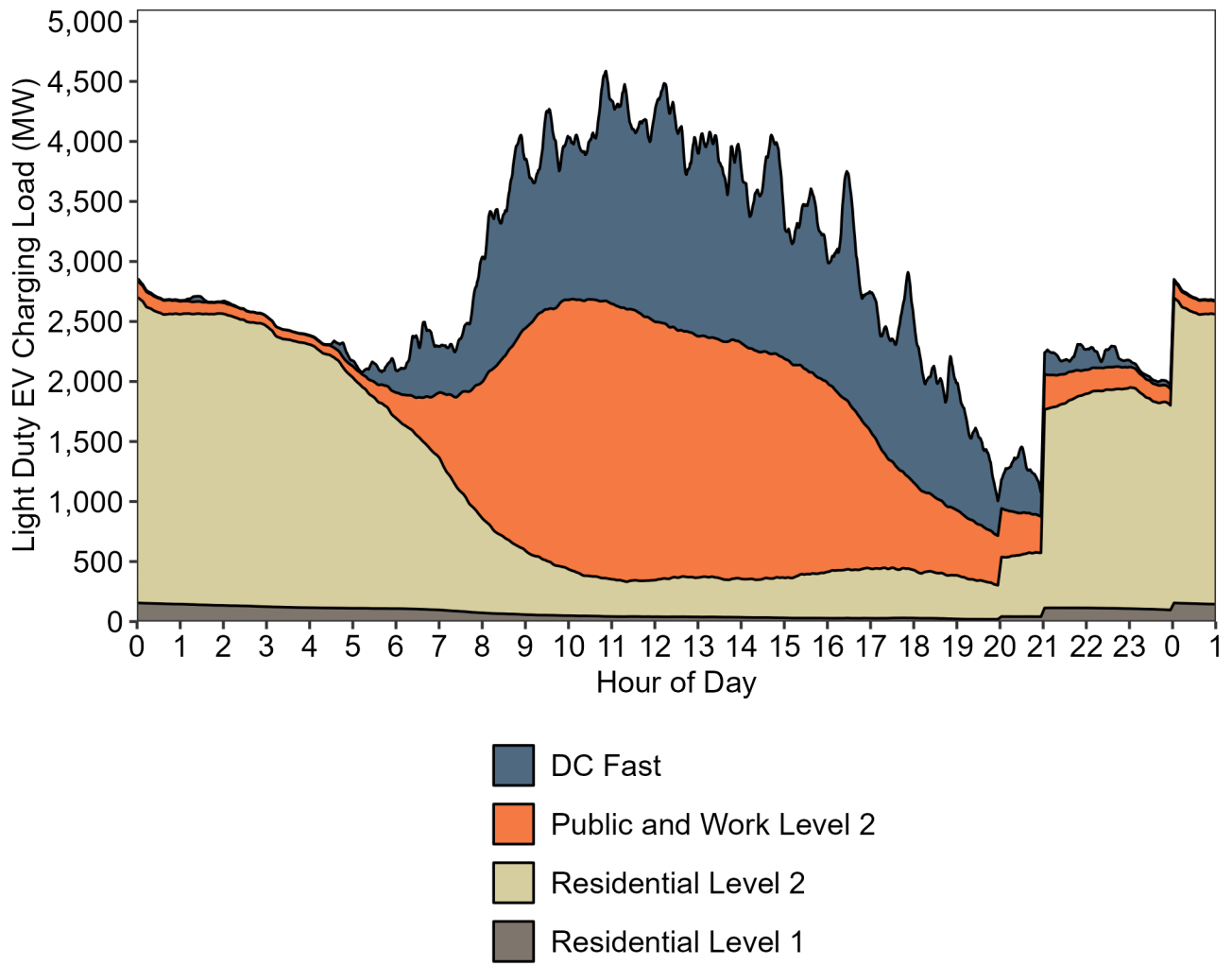
Source: CEC Staff and NREL

**Figure E-3: LDV charging load curve under high home access scenario**



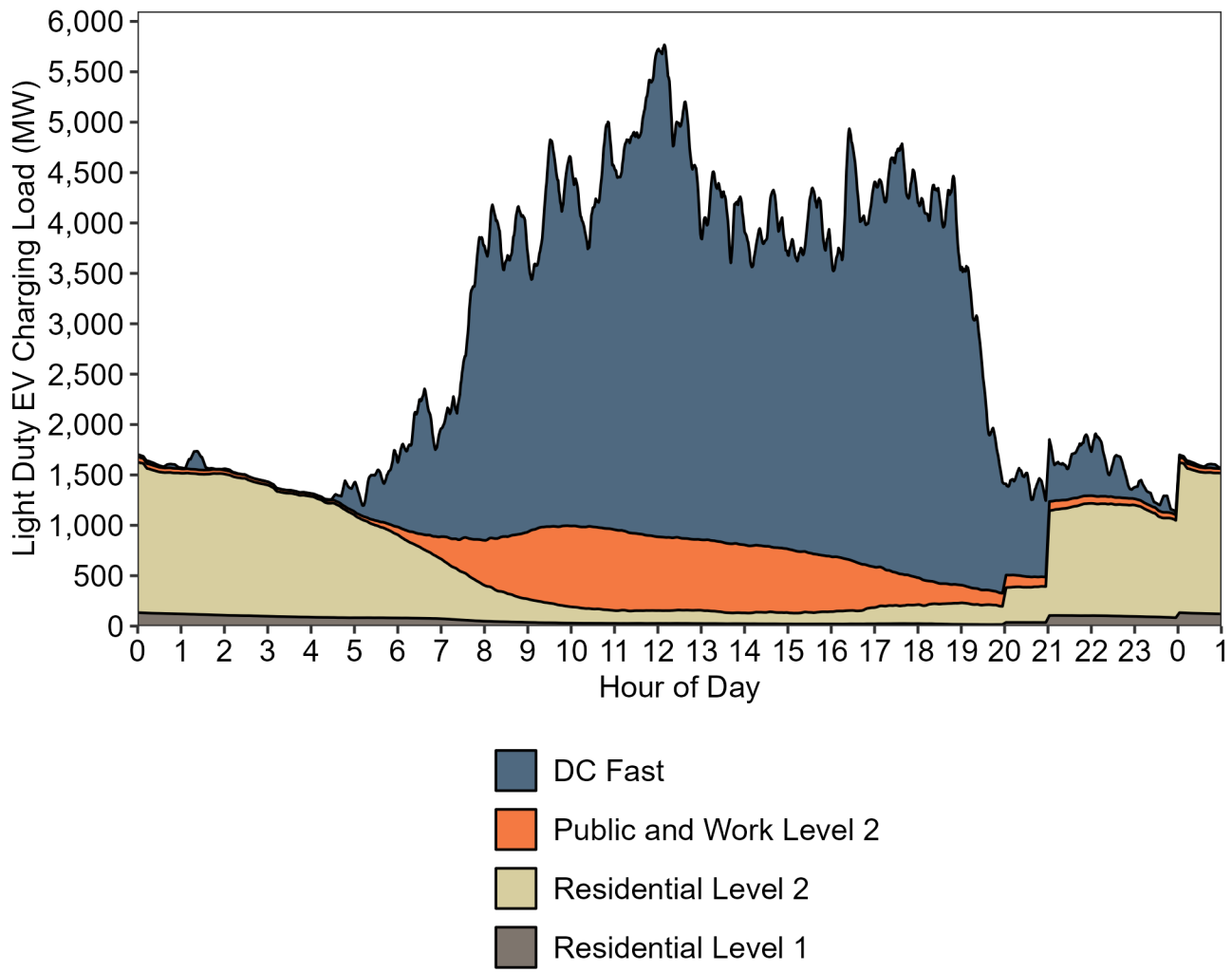
Source: CEC Staff and NREL

**Figure E-4: LDV charging load curve under low home access scenario**



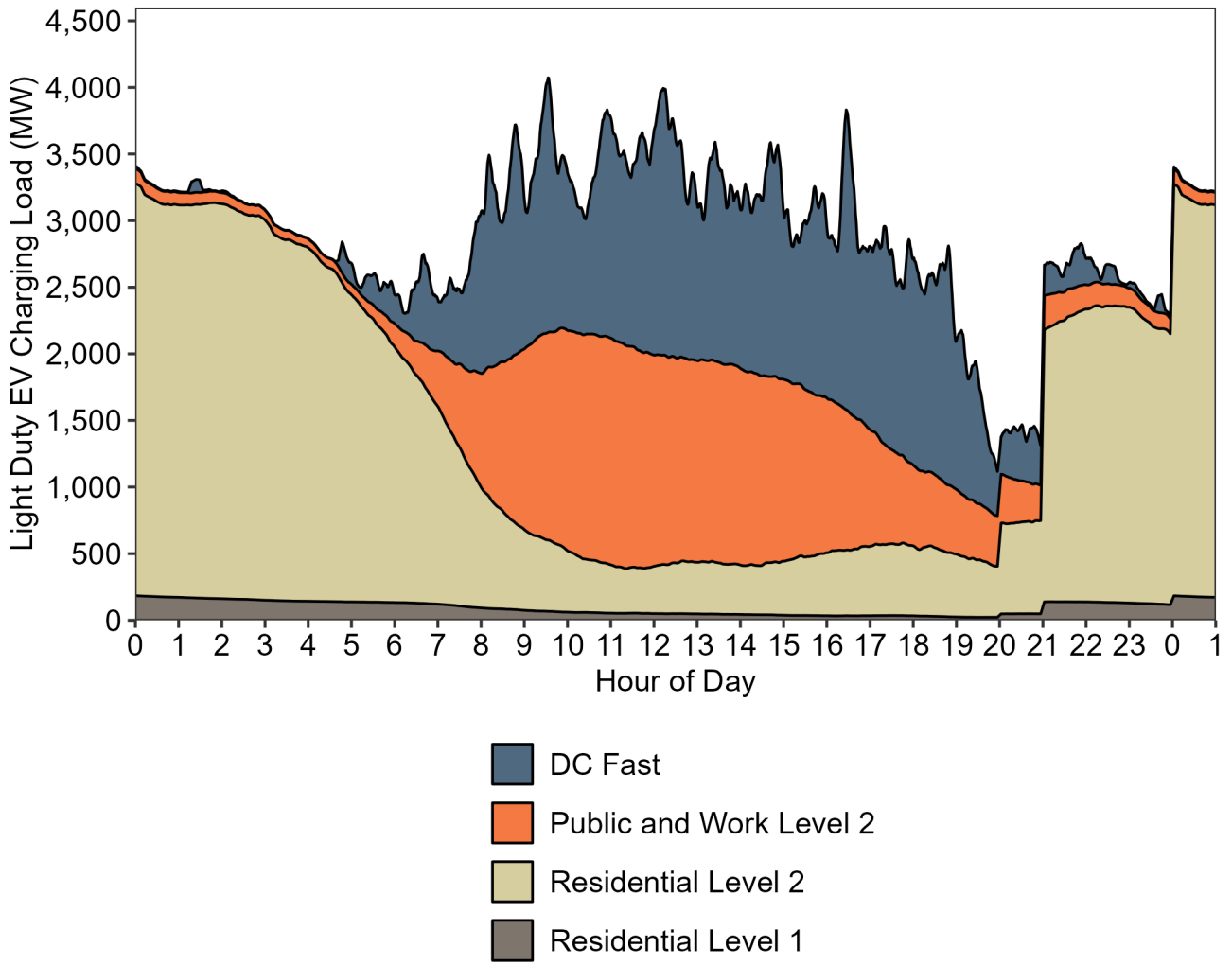
Source: CEC Staff and NREL

**Figure E-5: LDV charging load curve under gas station model scenario**



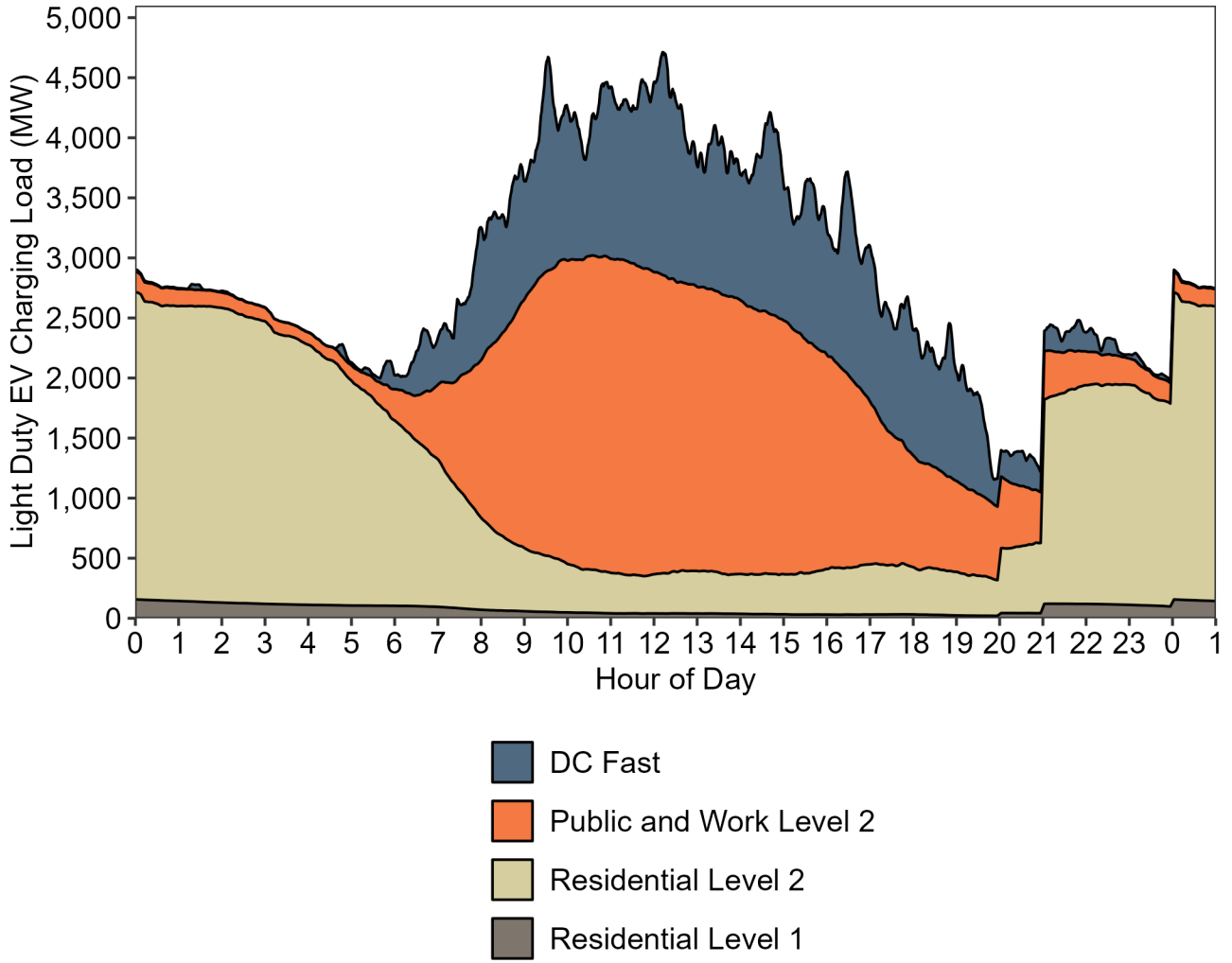
Source: CEC Staff and NREL

**Figure E-6: LDV charging load curve under low work access scenario**



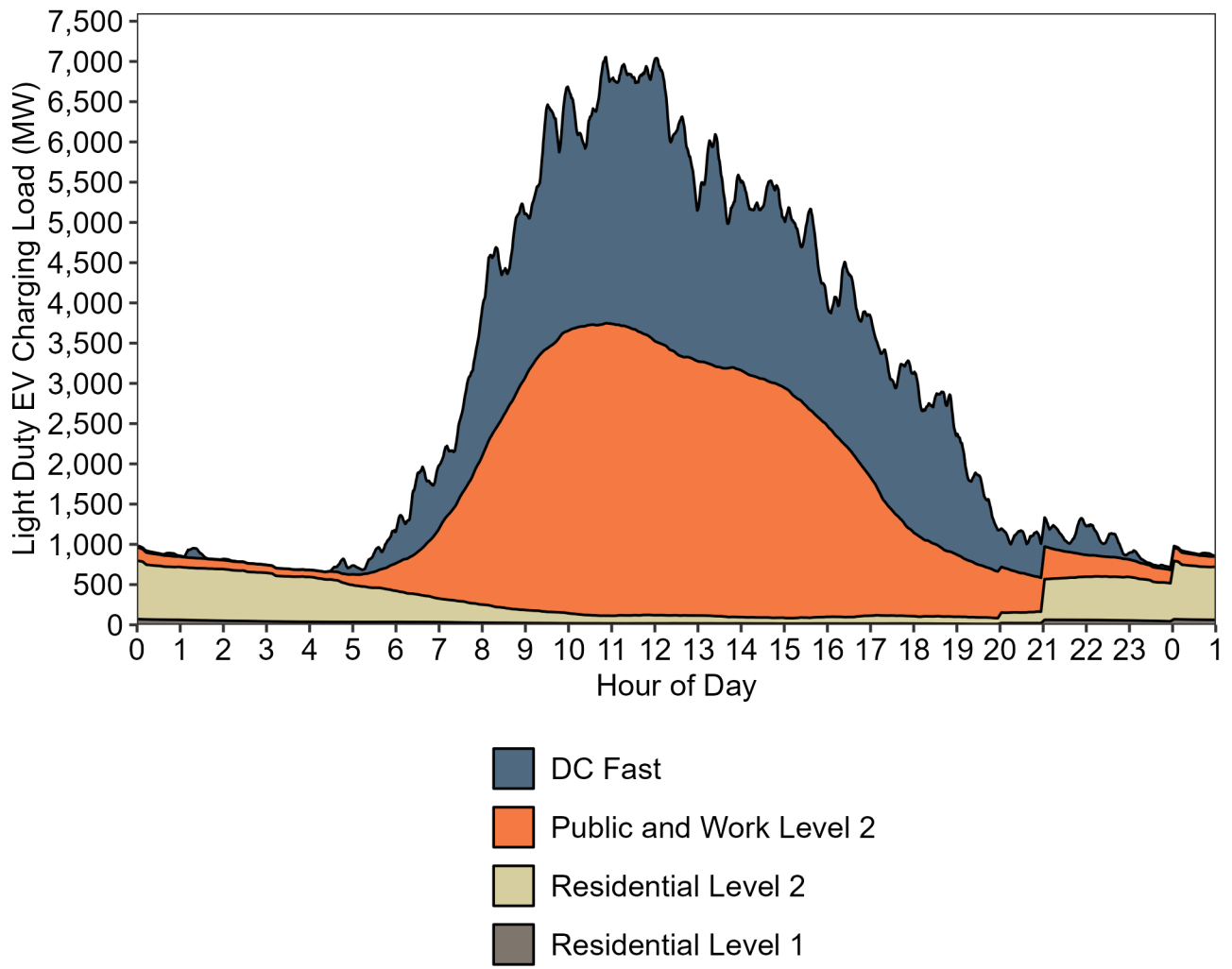
Source: CEC Staff and NREL

**Figure E-7: LDV charging load curve under more free public L2 scenario**



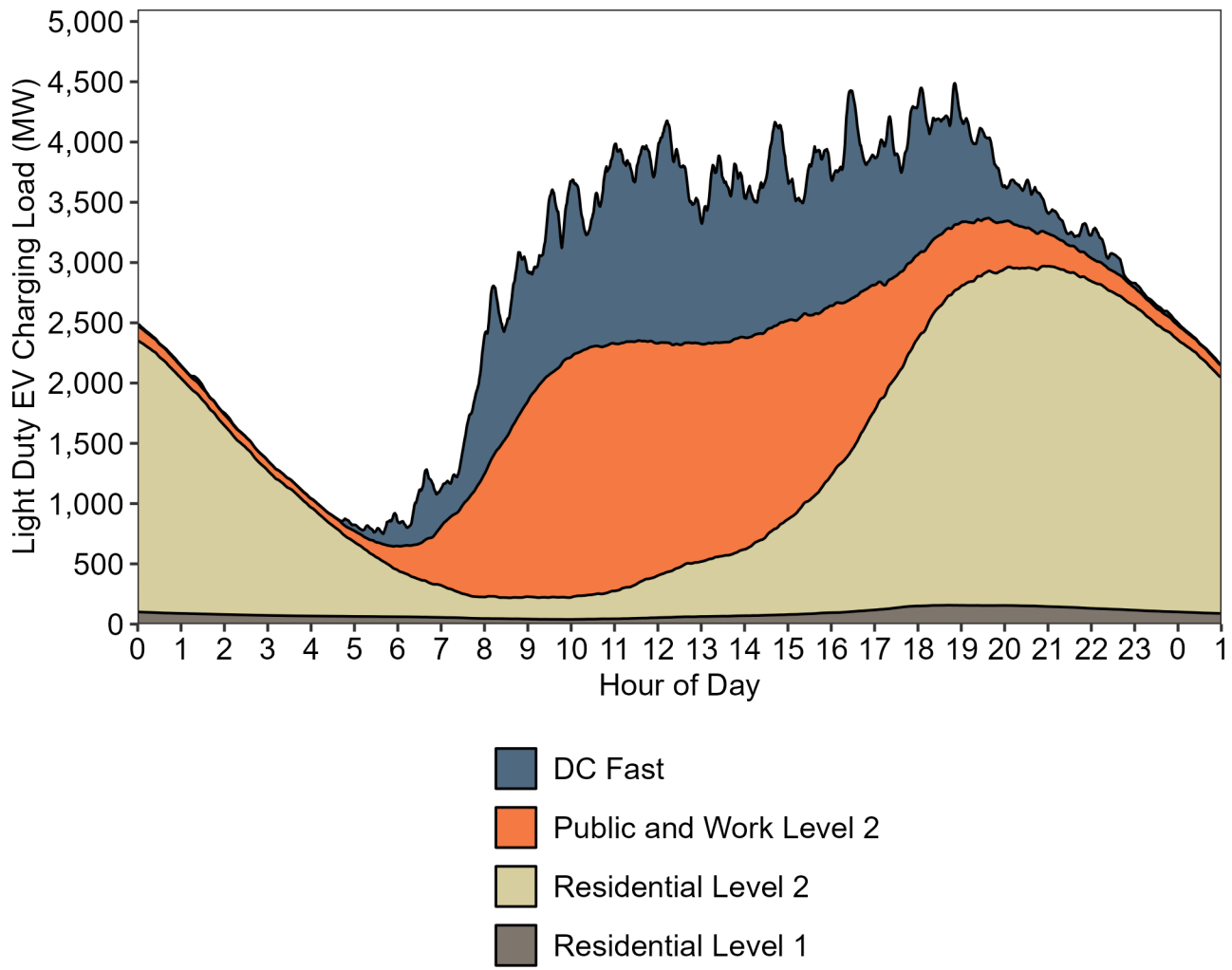
Source: CEC Staff and NREL

**Figure E-8: LDV charging load curve under solar priority scenario**



Source: CEC Staff and NREL

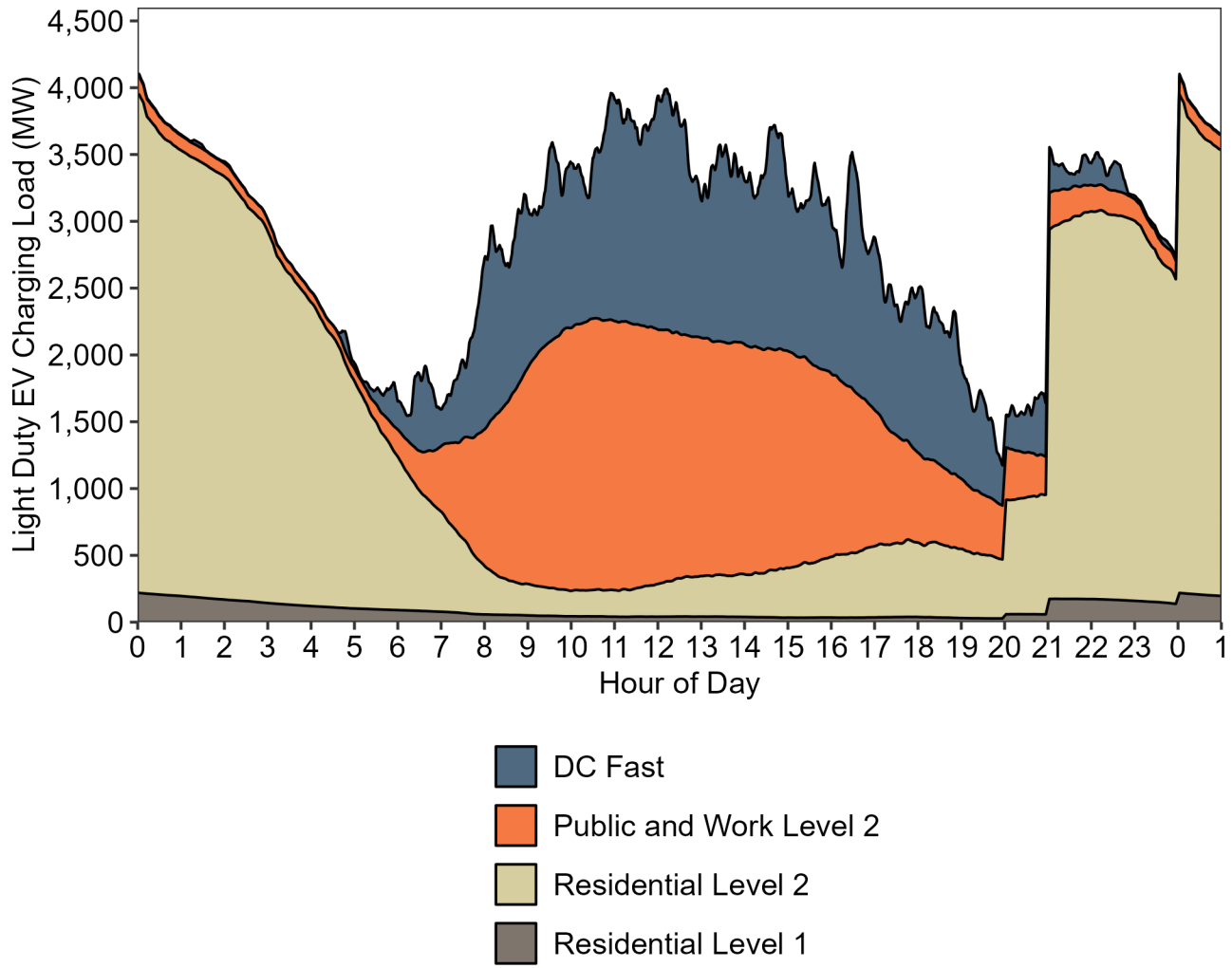
**Figure E-9: LDV charging load curve under home grid: unmanaged scenario**



Source: CEC Staff and NREL

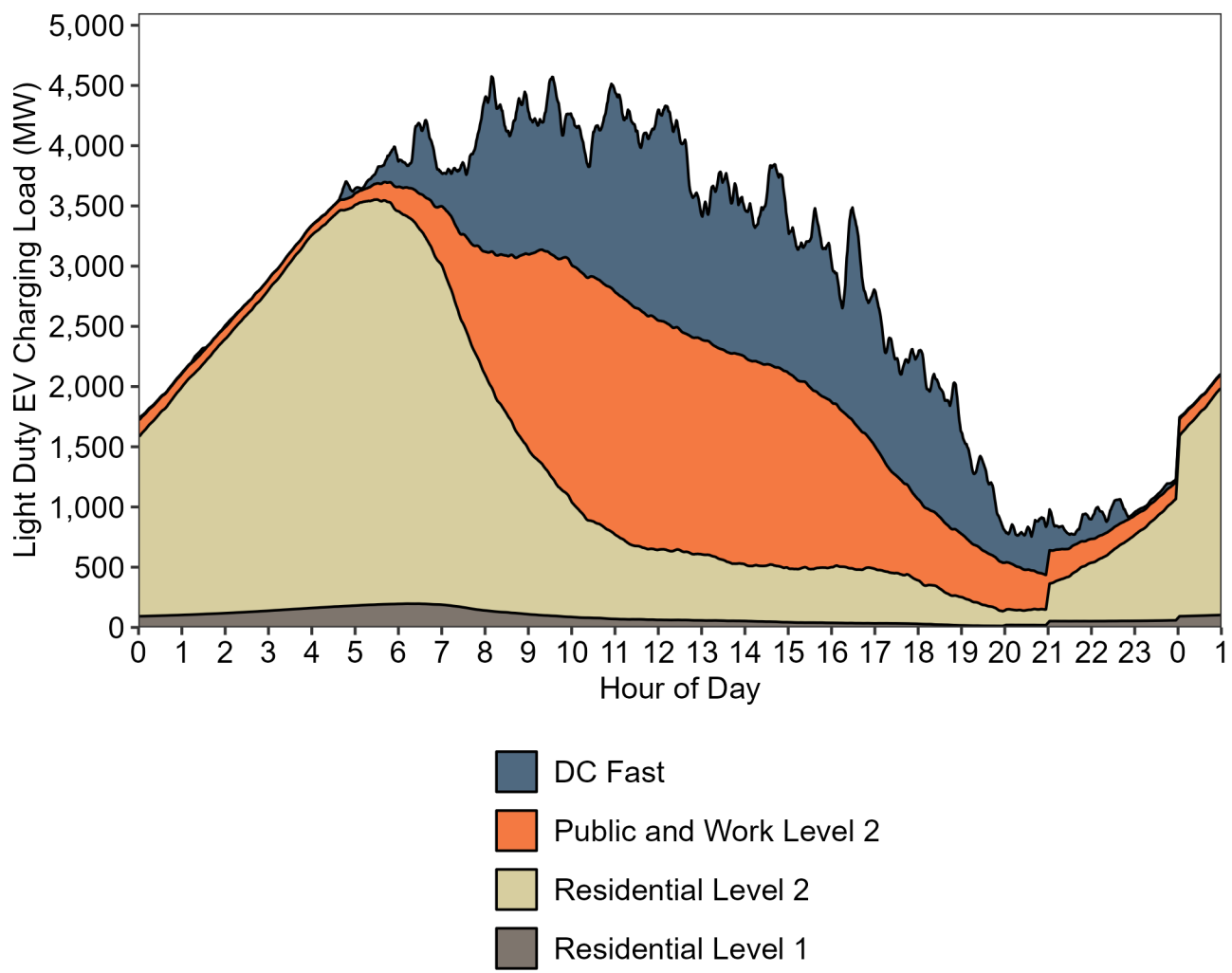


**Figure E-10: LDV charging load curve under home grid: pure TOU scenario**



Source: CEC Staff and NREL

**Figure E-11: LDV charging load curve under home grid: as late as possible scenario**



Source: CEC Staff and NREL

# APPENDIX F:

## WIRED Annual Results and Regional Maps

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This appendix provides detailed results from the WIRED model on DCFC infrastructure needed to support PEVs driving for TNCs under the Clean Miles Standard through 2035. This model is introduced in Chapter 5. Table F-1 contains the total number of DC fast chargers needed to support PEVs driving for TNCs statewide and in each of the three areas of interest.

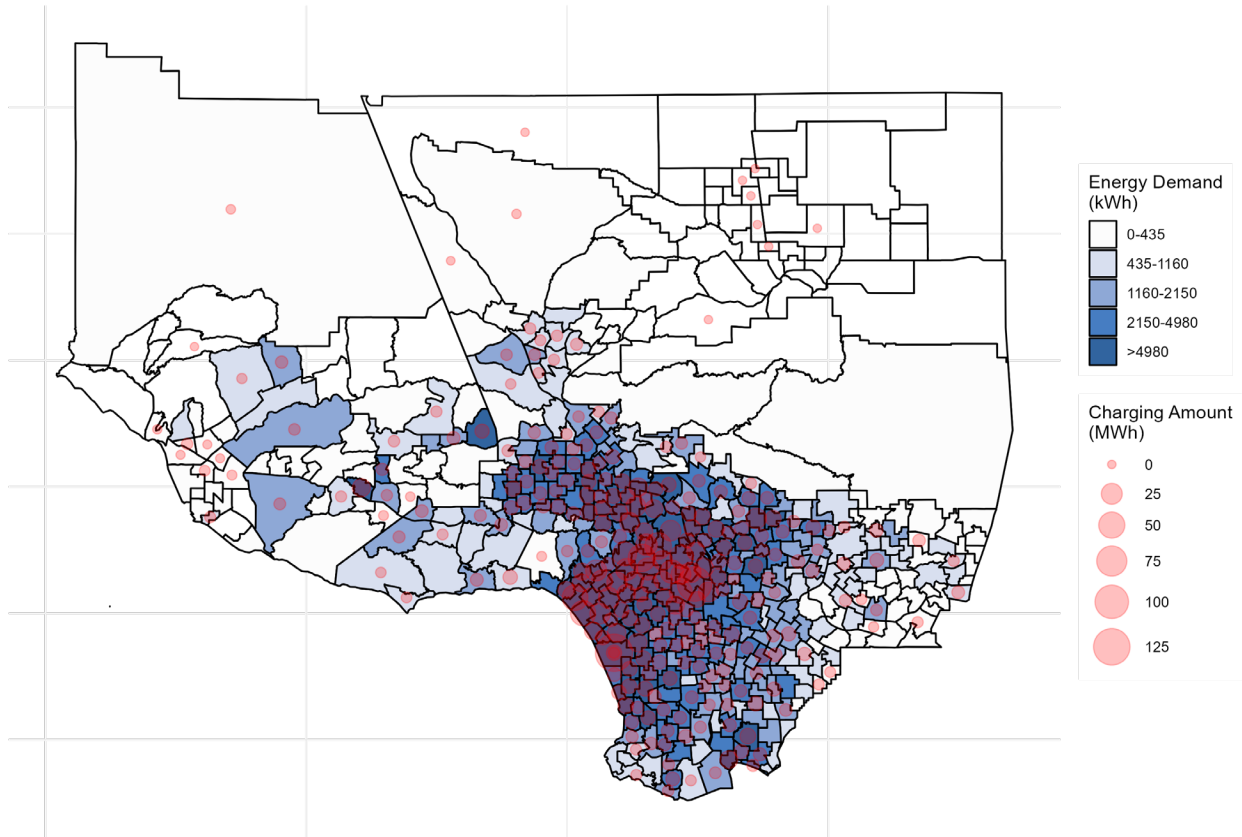
**Table F-1: WIRED model assessment of annual DCFC charger needs for PEVs driving for TNCs under the Clean Miles Standard**

Year	Los Angeles	San Diego	San Francisco	Statewide Total
2023	0	0	0	0
2024	0	0	0	0
2025	2	0	0	3
2026	15	3	32	63
2027	63	8	103	218
2028	141	14	182	421
2029	253	25	292	713
2030	392	36	410	1,048
2031	520	43	519	1,353
2032	636	70	624	1,663
2033	759	89	728	1,970
2034	799	103	775	2,096
2035	820	106	781	2,134

Source: CEC and UC Davis

Figures C-1, C-2, and C-3 show energy demand and total amount of charging performed in each aggregated traffic analysis zone in the Los Angeles, San Diego, and San Francisco Bay Areas. The model assigns charging events to existing chargers where possible, and identifies new charger needs where none are available.

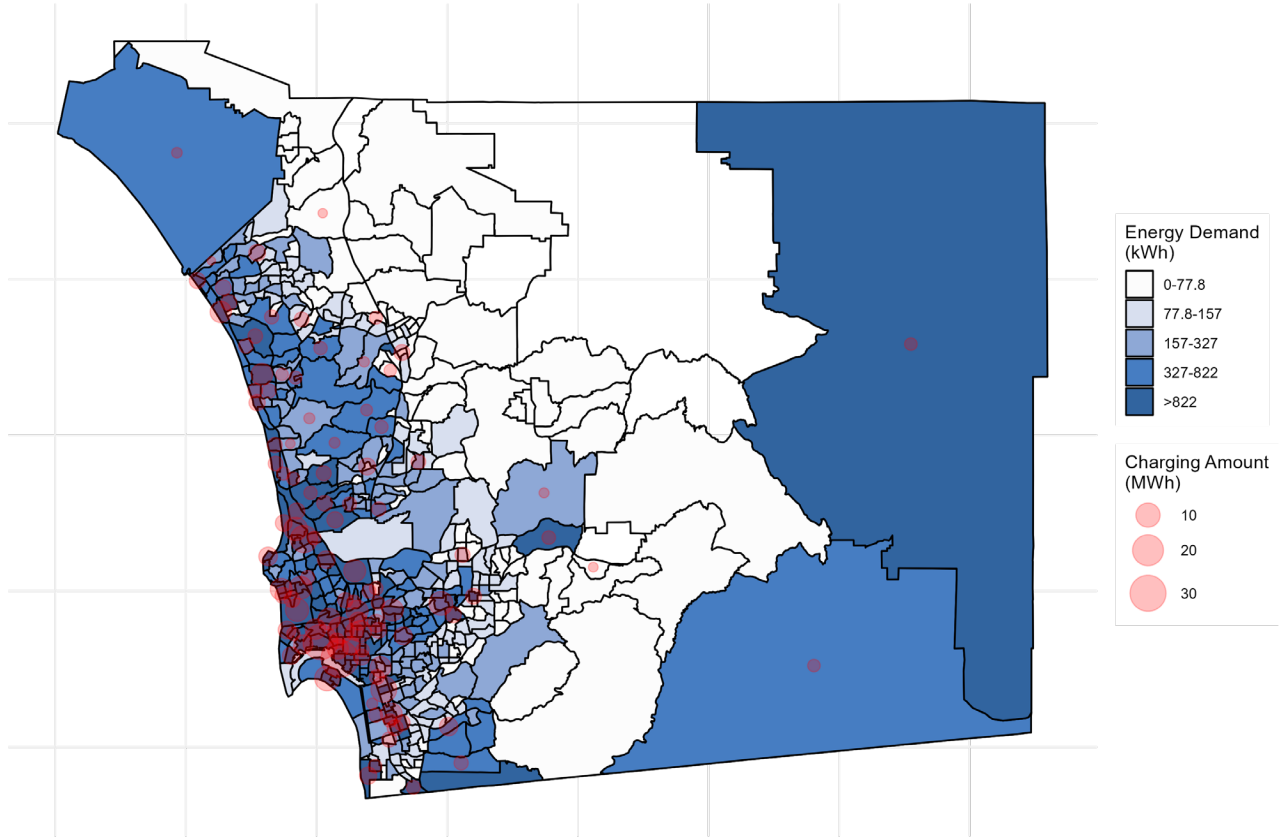
**Figure F-1: Energy demand from TNC PEVs and total charging amount provided to these vehicles in the Los Angeles area**



**TNC use is concentrated in central part of Los Angeles, and TNC vehicles will require the most new chargers in this area, but TNCs are used throughout the region and chargers may need to be installed for these vehicles throughout the region.**

Source: UC Davis

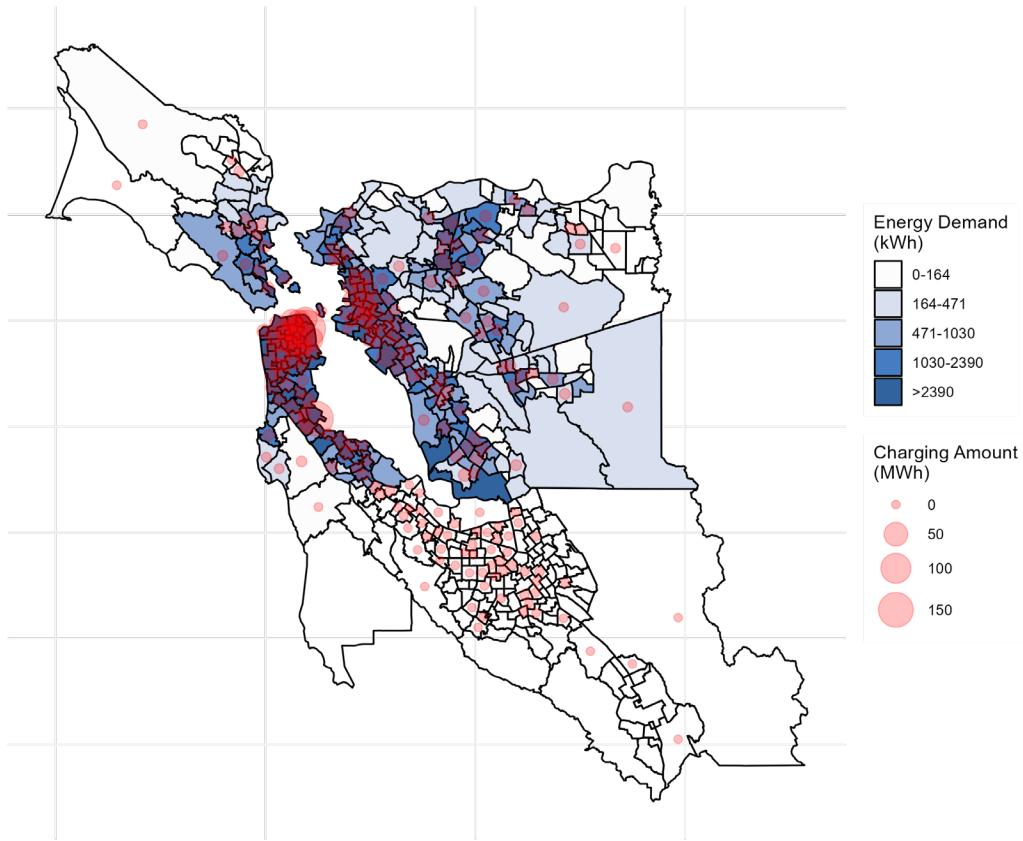
**Figure F-2: Energy demand from TNC PEVs and total charging amount provided to these vehicles in the San Diego area**



**TNC use is concentrated in the coastal part of San Diego County, and TNC vehicles will require the most new chargers in this area. The eastern part of the county also has considerable TNC energy demand and may require additional charging.**

Source: UC Davis

**Figure F-3: Energy demand from TNC PEVs and total charging amount provided to these vehicles in the San Francisco Bay Area**

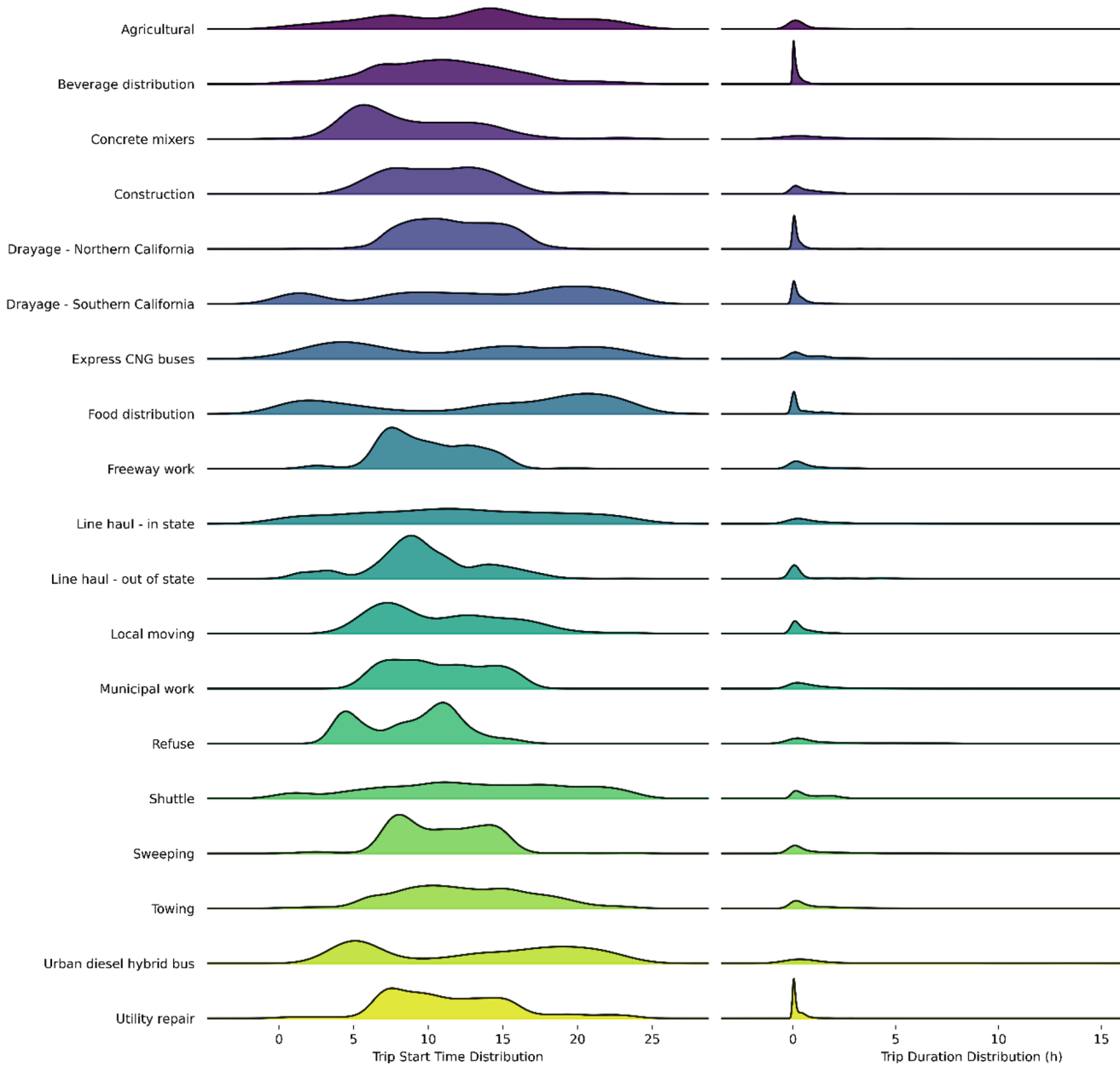


**TNC use in the San Francisco Bay Area is highest in San Francisco. TNCs are used throughout the region and chargers may need to be installed for these vehicles throughout the region.**

Source: UC Davis

# APPENDIX G: HEVI-Load Inputs and Parameters

**Figure G-1: Statistical Distribution of Start Times and Durations for Trips in HEVI-LOAD**



**Statistical distribution of real-world GPS location data used to calibrate the CSTDM trips. Trip start times are shown on the left-hand side and trip durations are shown on the right-hand side.**

Source: LBNL

**Table G-1: Energy efficiency, daily miles, and vehicle counts by vehicle class**

EMFAC Class	Daily miles per vehicle	kWh / mile	kWh per vehicle per day	AATE3 vehicles 2025	AATE3 vehicles 2030	AATE3 vehicles 2035
LHD2 (Class 3)	51.8	0.6	31.1	6,196	26,932	71,755
T6 CAIRP Class 4	83.0	1.1	89.2	3	30	84
T6 CAIRP Class 5	92.2	1.1	99.1	4	57	159
T6 CAIRP Class 6	53.7	1.1	57.7	13	129	342
T6 CAIRP Class 7	219.2	1.1	235.7	28	281	793
T6 Instate Delivery Class 4	38.6	1.1	40.8	583	2,908	6,840
T6 Instate Delivery Class 5	38.6	1.1	40.8	473	2,860	7,046
T6 Instate Delivery Class 6	38.6	1.1	40.7	2,465	12,937	23,789
T6 Instate Delivery Class 7	52.7	1.1	55.6	1	1,466	4,221
T6 Instate Other Class 4	47.3	1.1	50.0	727	3,817	10,951
T6 Instate Other Class 5	47.7	1.1	50.3	2,007	15,505	38,061
T6 Instate Other Class 6	47.5	1.1	50.1	1,237	7,809	18,236
T6 Instate Other Class 7	65.1	1.1	68.7	255	3,155	8,672
T6 Instate Tractor Class 6	63.2	1.1	66.7	4	44	113
T6 Instate Tractor Class 7	78.8	1.1	83.2	0	1,982	4,892
T6 Public Class 4	42.3	1.1	48.0	301	1,660	3,033
T6 Public Class 5	42.3	1.1	48.7	447	2,948	5,270
T6 Public Class 6	41.9	1.1	47.8	215	1,393	2,511
T6 Public Class 7	56.7	1.1	64.5	531	2,643	5,239
T6 Utility Class 5	42.6	1.1	46.4	281	1,543	3,354
T6 Utility Class 6	42.6	1.1	46.5	31	181	372
T6 Utility Class 7	57.2	1.1	62.2	11	86	248
T6TS (Class 7)	82.9	1.1	91.5	4,159	12,389	20,949
T7 CAIRP Class 8	220.9	1.8	400.3	0	0	8,288
T7 Other Port Class 8	325.5	1.8	591.3	232	426	618
T7 POAK Class 8	111.6	1.8	203.1	654	1,236	1,921
T7 POLA Class 8	171.8	1.8	306.9	2,858	6,188	7,637
T7 Public Class 8	56.8	1.9	107.9	446	2,962	5,371
T7 Concrete Mix Class 8	78.4	1.8	141.4	0	319	1,936
T7 Single Dump Class 8	76.2	1.8	137.8	40	1,418	5,035
T7 Single Other Class 8	63.3	1.8	114.3	45	5,162	15,236
T7 SWCV Class 8	64.3	1.8	117.1	120	3,037	10,209
T7 Tractor Class 8	77.2	1.8	139.5	2,298	30,498	67,191
T7 Utility Class 8	56.3	1.8	103.5	11	188	489
T6 OOS Class 4	47.3	1.1	50.0	4	45	125
T6 OOS Class 5	47.7	1.1	50.3	4	56	155
T6 OOS Class 6	47.5	1.1	50.1	16	145	386
T6 OOS Class 7	65.1	1.1	68.7	0	129	369
T7 NNOOS Class 8	77.2	1.8	139.5	0	0	11,129
T7 NOOS Class 8	77.2	1.8	139.5	0	0	3,643

Source: CEC Staff and LBNL



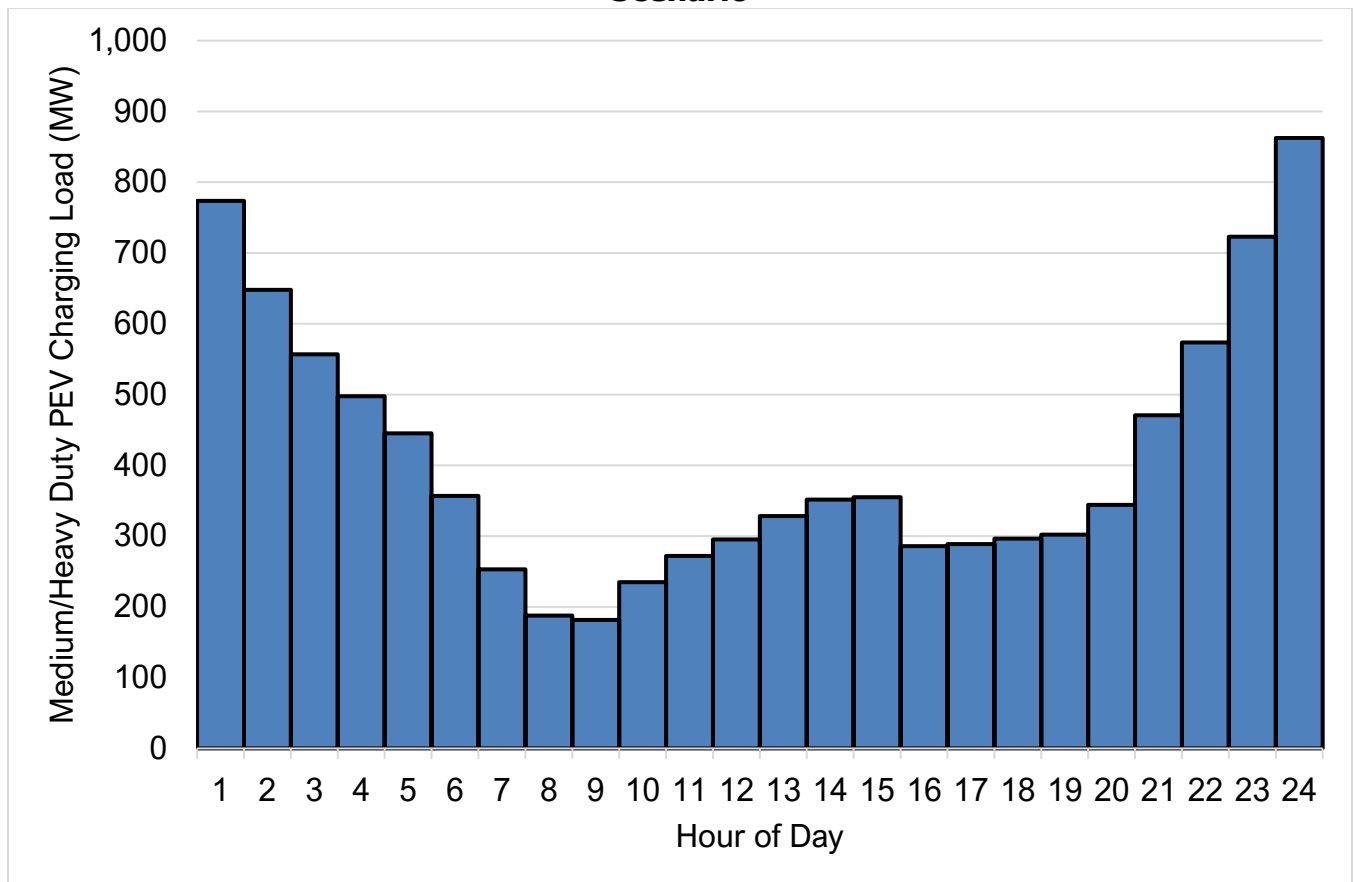
# APPENDIX H:

## HEVI-Load Detailed Results

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Managing the charging loads from an increasing number of MDHD vehicles will be critical for utility investments in grid planning and readiness. The load shape shown in Figure H-1 is for a typical summer day in 2030 for the CAISO planning area using the CEC’s Energy Demand Forecast’s Electric Vehicle Infrastructure Load Model. The EV Load Model distributes charging load over the course of a forecast year based on time-of-use rates and changes in the type of charging over time. These load shapes are used as part of the broader IEPR planning forecast to inform utility plans for resource procurement, distribution planning, and transmission planning. In this model, the total daily MDHD charging power amounts to 12,135 MW while HEVI-LOAD projects a total daily amount of about 14,100 MW. The 17% difference between the two models is due to their inherent design and overall goal. The EV Load Model is used in the Energy Assessment Division’s Transportation Energy Demand Forecast and Integrated Energy Policy Report process for utility grid planning, while HEVI-LOAD’s approach centers around truck travel and charging behavior. HEVI-LOAD uses existing trip data to determine granular energy demand and optimal locations for charging infrastructure without disrupting a vehicle’s normal operational duty-cycle.

**Figure H-1: EAD Load Curve from MDHD BEV Charging in 2030 under AATE3 Scenario**



The CEC’s EV Load Model shows a MDHD charging load shape that is similar to the unmanaged charging case modeled by HEVI-LOAD.

Source: CEC staff

**Table H-1: Statewide charger totals from HEVI-Load under the AATE3 scenario**

<b>Power (kW)</b>	<b>Location Type</b>	<b>2025</b>	<b>2030</b>	<b>2035</b>
20	Depot	3,714	19,001	45,510
50	Depot	6,567	32,940	76,964
100	Depot	6,157	30,473	70,318
150	Depot	5,406	27,083	63,502
<b>Total</b>	<b>Depot</b>	<b>21,844</b>	<b>109,497</b>	<b>256,294</b>
350	Public	1,658	4,226	6,553
500	Public	287	542	829
750	Public	177	338	478
1000	Public	106	236	339
1500	Public	90	185	256
<b>Total</b>	<b>Public</b>	<b>2,318</b>	<b>5,527</b>	<b>8,455</b>
<b>Total</b>	<b>All</b>	<b>24,162</b>	<b>115,024</b>	<b>264,749</b>

Source: LBNL

**Table H-2: County-by-county results for depot chargers (up to 150kW)**

<b>County</b>	<b>2025</b>	<b>2030</b>	<b>2035</b>
Alameda	778	3,835	8,960
Alpine	0	12	33
Amador	28	156	295
Butte	139	621	1,488
Calaveras	23	134	332
Colusa	23	98	226
Contra Costa	568	2,727	6,392
Del Norte	12	57	136
El Dorado	84	477	1,032

Fresno	641	3,331	7,584
Glenn	37	195	461
Humboldt	60	250	587
Imperial	85	462	1,141
Inyo	16	60	159
Kern	730	3,760	8,789
Kings	154	697	1,652
Lake	24	190	402
Lassen	15	81	175
Los Angeles	5,351	26,932	63,496
Madera	150	824	1,780
Marin	101	617	1,497
Mariposa	17	72	165
Mendocino	42	238	617
Merced	205	880	2,148
Modoc	12	74	138
Mono	16	63	125
Monterey	250	1,082	2,506
Napa	80	385	927
Nevada	45	224	553
Orange	1,599	7,956	18,577
Placer	189	1,044	2,450
Plumas	15	63	153
Riverside	1,090	5,440	12,585
Sacramento	1,085	5,127	11,903
San Benito	50	223	483
San Bernardino	1,217	6,260	14,415
San Diego	1,727	8,628	20,522
San Francisco	719	3,523	8,324
San Joaquin	375	1,929	4,619

San Luis Obispo	112	623	1,487
San Mateo	445	2,189	5,308
Santa Barbara	224	1,060	2,458
Santa Clara	1,183	5,700	13,320
Santa Cruz	112	600	1,425
Shasta	81	442	974
Sierra	6	27	86
Siskiyou	23	137	287
Solano	250	1,212	2,808
Sonoma	293	1,357	3,397
Stanislaus	333	1,843	4,106
Sutter	42	327	661
Tehama	43	211	466
Trinity	5	31	41
Tulare	292	1,569	3,601
Tuolumne	32	160	371
Ventura	390	2,219	5,078
Yolo	147	692	1,725
Yuba	79	371	868

Source: LBNL

**Table H-3: County-by-county results for public chargers (350kW to 1500kW)**

County	2025	2030	2035
Alameda	92	223	476
Alpine	0	0	0
Amador	0	0	0
Butte	0	0	0
Calaveras	0	0	0
Colusa	18	49	73
Contra Costa	10	23	41
Del Norte	1	2	3
El Dorado	0	0	0

Fresno	99	231	362
Glenn	18	46	62
Humboldt	24	68	84
Imperial	37	89	140
Inyo	9	26	53
Kern	254	667	1,005
Kings	4	12	22
Lake	0	0	0
Lassen	7	18	30
Los Angeles	158	283	347
Madera	48	112	164
Marin	15	43	58
Mariposa	0	0	0
Mendocino	49	120	207
Merced	102	245	384
Modoc	0	0	0
Mono	1	4	4
Monterey	27	69	119
Napa	0	0	0
Nevada	3	8	15
Orange	23	60	66
Placer	23	58	111
Plumas	5	14	14
Riverside	144	377	582
Sacramento	35	94	144
San Benito	0	0	0
San Bernardino	280	589	935
San Diego	161	387	503
San Francisco	0	0	0
San Joaquin	167	359	514

San Luis Obispo	18	50	95
San Mateo	17	47	58
Santa Barbara	42	78	129
Santa Clara	27	65	97
Santa Cruz	0	0	0
Shasta	24	84	122
Sierra	0	0	0
Siskiyou	5	20	33
Solano	60	148	210
Sonoma	0	0	0
Stanislaus	56	128	215
Sutter	11	41	56
Tehama	49	118	222
Trinity	18	47	78
Tulare	131	295	447
Tuolumne	0	0	0
Ventura	0	0	0
Yolo	46	130	175
Yuba	0	0	0

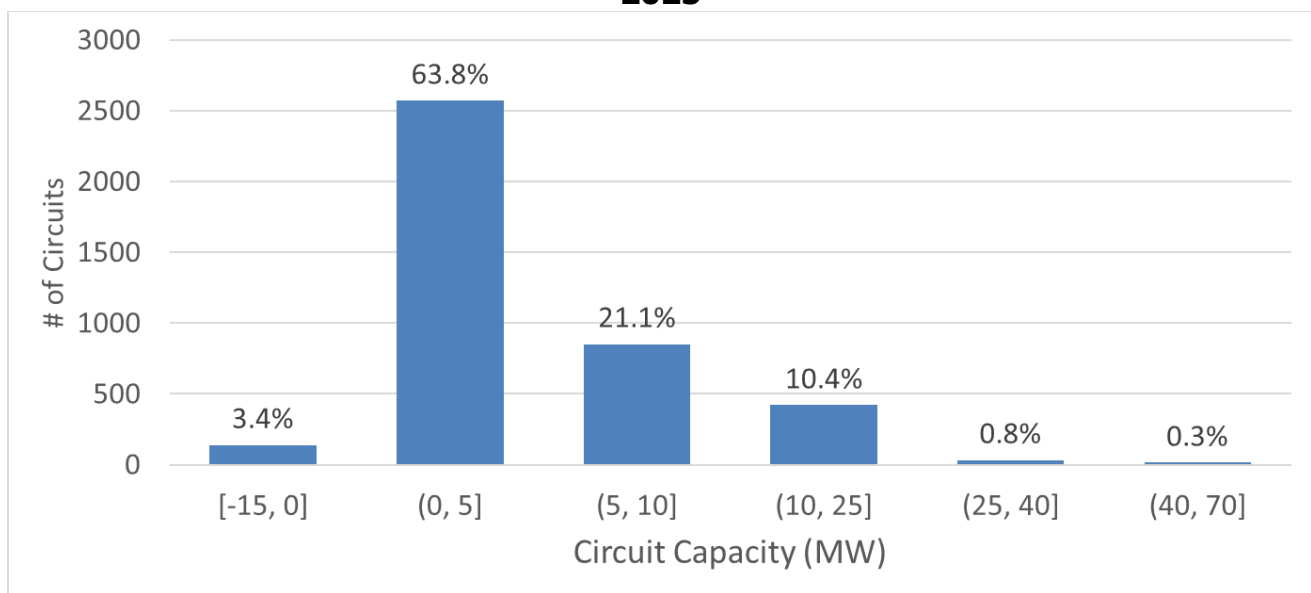
Source: LBNL

# APPENDIX I: EDGE Detailed Results

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To calculate capacity need indicator metric, EDGE uses GNA circuit capacities and the expected peak load of combined load profiles generated by EVI-Pro and HEVI-LOAD. Figure I-1 shows the distribution of capacity among individual circuits in IOU territories in 2025. Over 63 percent of GNA circuits have up to 5 MW of additional capacity and over 3% of the circuits have 0 MW or less of capacity to host additional load. Of the circuits with potentially no additional capacity, 96% of them are in PG&E’s service territory, 0% are in SCE’s service territory, and the other 4% are in SDG&E’s service territory.

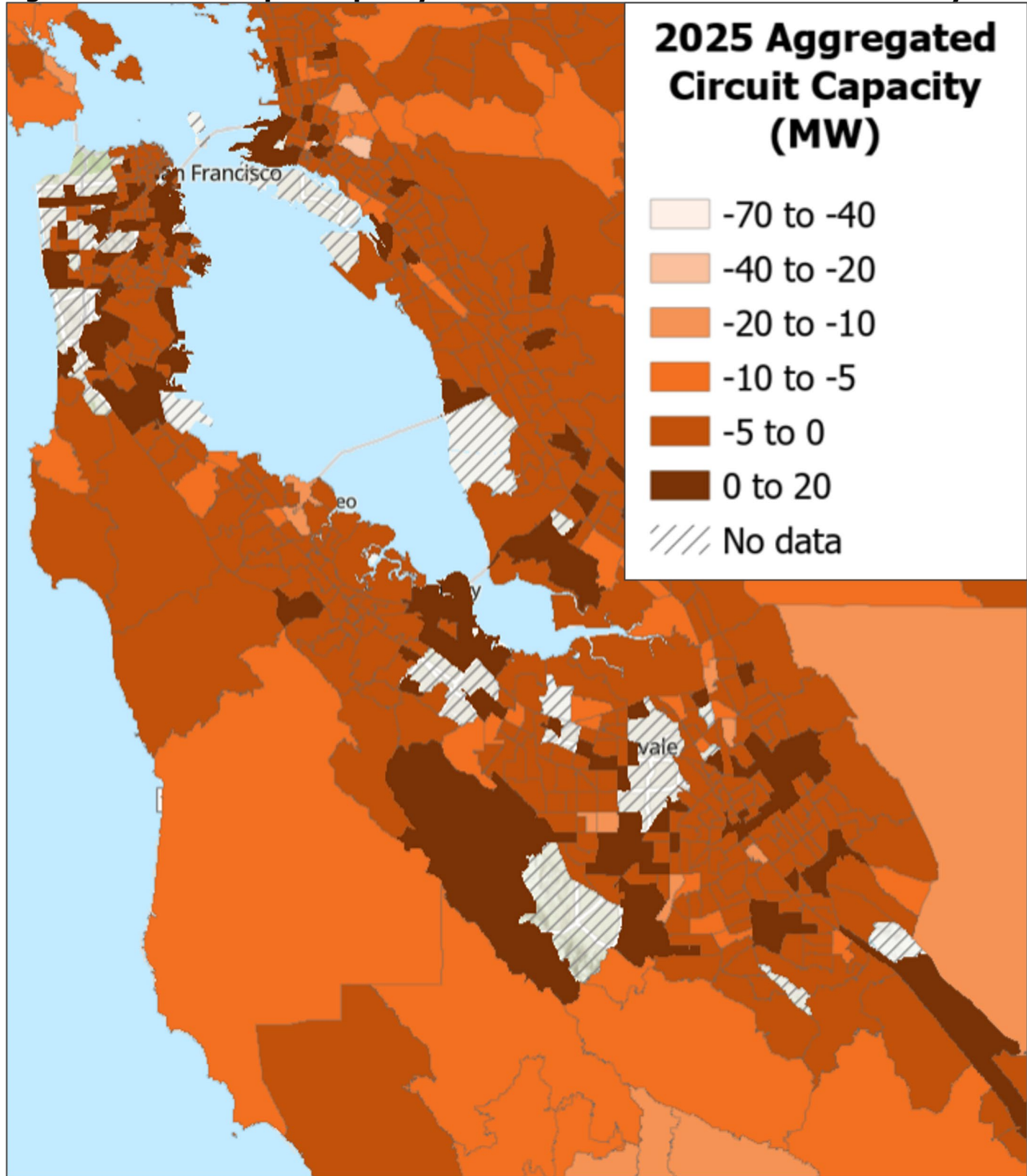
**Figure I-1: Distribution of IOUs’ GNA Circuit Capacity Forecasts in California in 2025**



Source: CEC Staff

Many TAZs in the Bay Area and along the I-5 corridor, especially in the San Joaquin Valley, show positive capacity need indicator metric values, indicating areas where particular attention should be paid in the upcoming years. The same is true for locations around the San Pedro Bay ports. These areas have expected EV charging load that exceeds the available circuit capacity in 2025 and could be regions in which grid planning should focus on addressing near-future grid equipment constraints. Figures I-2 and I-3 show maps of these areas in detail.

**Figure I-2: EDGE Map of Capacity need indicator metrics in TAZs in the Bay Area**

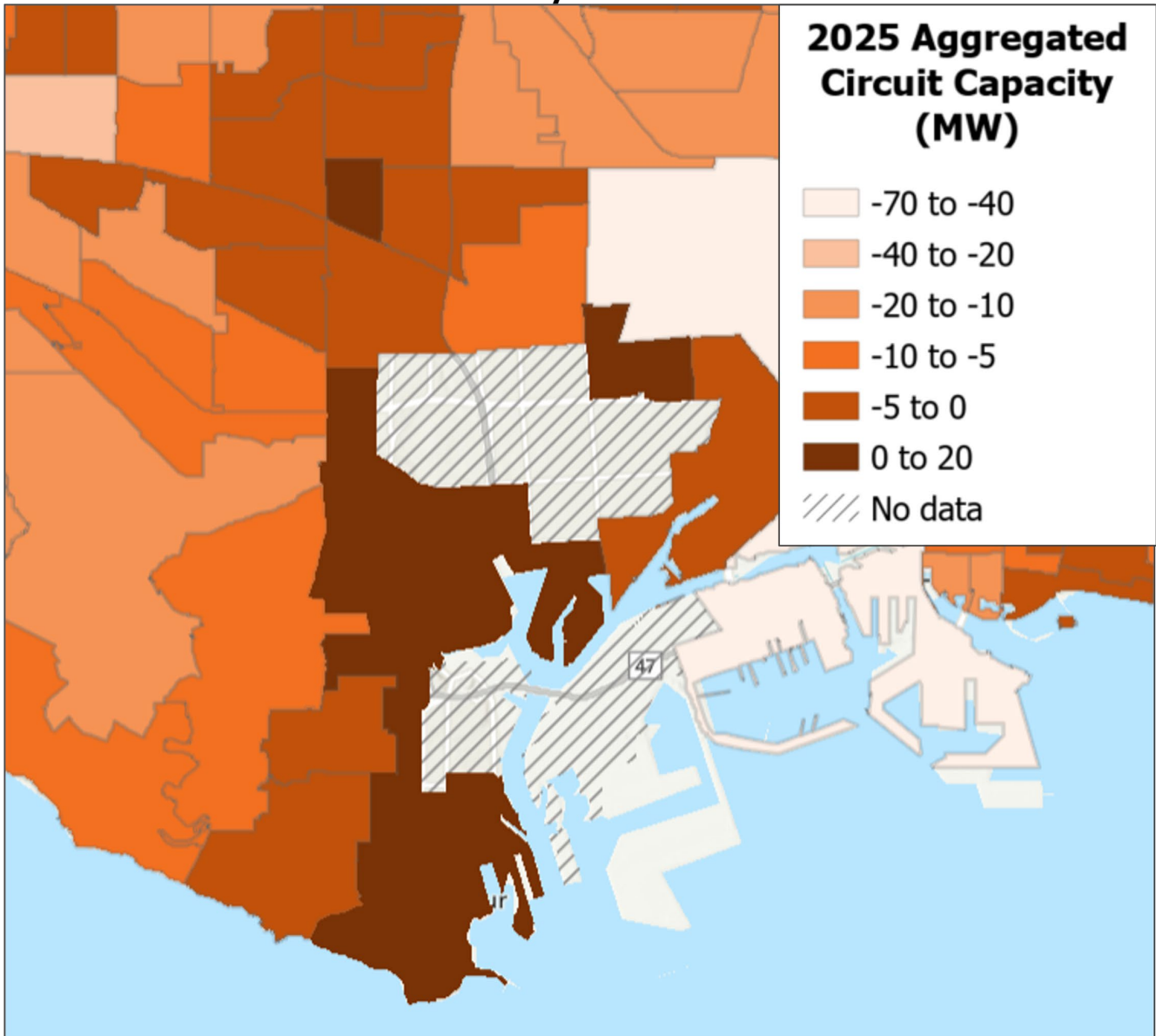


**This map shows capacity need indicator metric values in TAZs in the San Francisco Bay Area. These areas have a high density of TAZs with a positive capacity need indicator metric value and TAZs with up to 5 MW of additional capacity.**

Source: CEC Staff



**Figure I-3: EDGE Map of Capacity need indicator metric in TAZs near the San Pedro Bay Ports**



**This map shows areas near San Pedro Bay ports with clusters of TAZs with positive capacity need indicator metric values and TAZs with up to 5 MW of additional capacity.**

Source: CEC Staff