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Assess the Battery-Recharging and Hydrogen-Refueling Infrastructure Needs, Costs and Timelines Required to Support Regulatory Requirements for Light-, Medium-, and Heavy-Duty Zero-Emission Vehicles

FINAL REPORT

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COORDINATING RESEARCH COUNCIL, INC.

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List of Acronyms

Acronym	Description
AB	Assembly Bill
ACCII	Advanced Clean Cars II
ACF	Advanced Clean Fleets
ACT	Advanced Clean Trucks
AEO	Annual Energy Outlook
AFC	Alternative Fuel Corridors
AFDC	Alternative Fuel Data Center
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
BEV	Battery Electric Vehicle
BIL	Bipartisan Infrastructure Law (2021 Infrastructure Investment and Jobs Act)
BNEF	Bloomberg New Energy Finance
CARB	California Air Resources Board
CBSA	County Based Statistical Area
CCS	Carbon Capture and Sequestration
CEC	California Energy Commission
CFI	Charging and Fueling Infrastructure
CMAQ	Congestion Mitigation and Air Quality
CPUC	California Public Utilities Commission
CRT	Charge Ready Transport
DCFC	Direct Current Fast Charger
DER	Distributed Energy Resources
DOE	Department of Energy
EER	Energy Efficiency Ratio
EIA	Energy Information Administration
EMA	The Truck and Engine Manufacturers Association
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EVI-Pro	Electric Vehicle Infrastructure Projection Tool
EVSE	Electric Vehicle Supply Equipment (i.e., plug-in electric vehicle charger)
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gas
GVWR	Gross Vehicle Weight Rating
H2Hubs	Hydrogen Hubs
H2ICE	Hydrogen Internal Combustion Engine
HD	Heavy-Duty
HEVI-LOAD	Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operations, and Deployment Tool
HRI	Hydrogen Refueling Infrastructure
HVAC	Heating, Ventilation, and Air Conditioning
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
ICT	Innovative Clean Transit
ICCT	International Council on Clean Transportation
ICEV	Internal Combustion Engine Vehicle
IOU	Investor Owned Utility
IRA	Inflation Reduction Act
Kg	Kilogram

L1	Level 1 [Charger]
L2	Level 2 [Charger]
LBNL	Lawrence Berkeley National Laboratory
LCFS	Low Carbon Fuel Standard
LD	Light-Duty
MCS	Megawatt Charging System
MD	Medium-Duty
MDHD	Medium- and Heavy-Duty
MT/MMT	Metric Tons/Million Metric Tons
MOVES	Motor Vehicle Emission Simulator Tool
MY	Model Year
NEVI	National Electric Vehicle Infrastructure
NHTS	National Household Travel Survey
NPRM	[EPA] Notice of Proposed Rulemaking
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PSA	Pressure Swing Adsorption
PTC	Production Tax Credit
RMI	Rocky Mountain Institute
SAFE	Safer, Affordable, Fuel-Efficient
SB	Senate Bill
SCE	Southern California Edison
SMR	Steam Methane Reformation
TIP	Transportation Improvement Plan
TNC	Transportation Network Company (i..e, rideshare)
TPD	Tons per day
TWH	Tera Watt hours (Tera = 10^{12})
VMT	Vehicle Miles Traveled
ZEV	Zero Emission Vehicle

Executive Summary

In 2023, the U.S. Environmental Protection Agency (EPA) proposed new Multi-Pollutant and Greenhouse Gas (GHG) emissions standards for light-, medium-, and heavy-duty (LD, MD, HD) on-road vehicles and engines for model years (MY) 2027 to 2032 requiring auto and truck manufacturers to meet more stringent GHG and criteria pollutant emission standards. To comply with the stringent requirements of those regulations, vehicle manufacturers are expected to increase sales-percentages of zero-emission vehicles (ZEVs), such as battery-electric (BEV), fuel cell electric (FCEV), and plug-in hybrid electric vehicles (PHEV). Simultaneously, the California Air Resources Board (CARB) imposed several regulations mandating ZEV sales for both light- and medium/heavy-duty vehicles through 2036. The Advanced Clean Cars II (ACCII) rule extends the current regulatory standards, setting increased ZEV sales requirements for light-duty vehicles from 2026, culminating in 100% new car sales by 2035. For medium and heavy-duty trucks, the Advanced Clean Trucks (ACT) and the Advanced Clean Fleets (ACF) regulations set increasing ZEV sales requirements from 2024 to 2036. By 2036, the ACF regulation requires 100% ZEV of new MD/HD vehicles sold in California to be ZEV. The Innovative Clean Transit (ICT) regulation also sets sales requirements for transit agencies that 100% of new purchases by transit agencies must be ZEVs by 2029, with a goal for full transition by 2040. Of these, the ACCII and ACT regulations have been adopted in several other states, reflecting the nationwide push towards greener transportation options.

The successful implementation of these regulations will heavily rely on the existence of a widespread, accessible, and efficient network of charging and refueling stations. Potential buyers frequently express range limitation as a key concern when contemplating the purchase of ZEVs. Many plug-in and fuel cell vehicle owners suffer from difficulty finding charging and refueling stations and planning trips, especially during drives not in the daily routine and long-distance travel. That is why the expansion of the charging infrastructure is a critical factor in accelerating the adoption rate of ZEVs. To better plan for the deployment of ZEVs and their infrastructure, it is important to fully comprehend the scope, costs, and timeframes involved in developing the ZEV infrastructure that will be needed to support the multiple state and federal ZEV regulations. This report evaluates the national demands and costs of the charging and hydrogen fueling infrastructure necessary to support the transition of LD, MD, and HD vehicles to ZEVs. To evaluate the rate and scale of ZEV adoption, the project team assumed that the adopted and proposed policies could be fully implemented at both national and state levels, and conducted extensive fleet modeling to estimate the number of various types of ZEVs (BEVs, PHEVs, FCEVs) at the state level, in five-year increments from 2025 through 2050. The project team leveraged this modeling exercise to determine the number, capacity, hardware and installation costs[1], and timelines for creating the necessary charging and refueling stations to support the anticipated transition of U.S. on-road transportation sector to ZEVs. In addition, the report also evaluates the impact of fleet transition on the overall power sector and on hydrogen production.

Significant Investment Needed

$294 billion investment will be needed by 2033 to install approximately 6.6 million depot and public EVSE ports as well as 1,750 hydrogen fueling stations across the country.

Assuming that the ZEV regulations at issue can be implemented as adopted and proposed, by 2035, it is anticipated that 36% of LD fleets and 19% of MDHD fleets will be ZEVs. Approximately $289 billion will

[1] Cost estimates for BEV charging infrastructure include EVSE hardware and installations, while utility upgrades, land acquisition, and other soft costs are not quantified. Cost estimates for FCEV refueling infrastructure include refilling station compressors/boil off management and retail site distribution pumps, while costs associated with hydrogen production and distribution such as electrolysis unit, compression or liquefaction unit, distribution pipeline, compressed hydrogen delivery trucks or purification units are not quantified.

need to be invested by 2033[2] to install approximately 6.6 million depot-based and public electric vehicle supply equipment (EVSE) ports across the country by 2035, as shown in Figure 1. Due to the large-scale deployment of BEVs and PHEVs, the electricity demand from the transportation sector will reach 674 TWh, accounting for over 14% of the total national electricity demand of 4,700 TWh across all sectors of the economy (Figure 2). The number of hydrogen refueling stations must be increased to 1,750 to meet the national fueling demand of over 2,800 metric tons (MT) per day, with roughly 1,350 stations serving MDHD vehicles, and 400 stations serving LD vehicles by 2035. The total required investment to install the necessary hydrogen refueling infrastructure is approximately $5.2 billion, as illustrated in Figure 3.

Figure 1. Total public and depot EVSE ports and cumulative investment needed for EVSE equipment and installation.

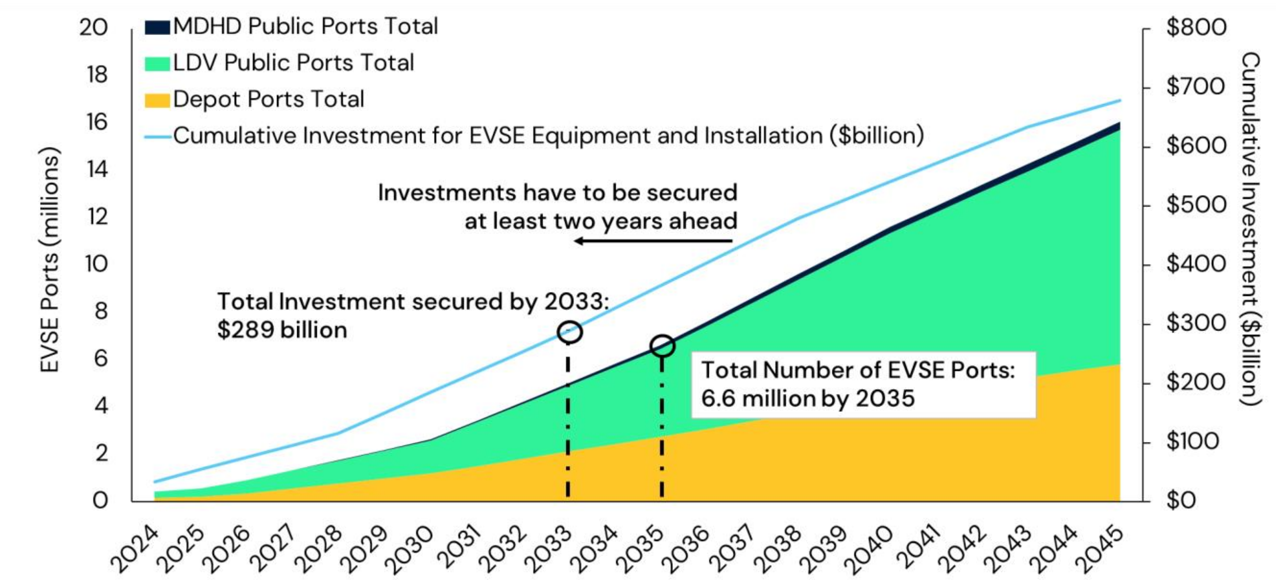
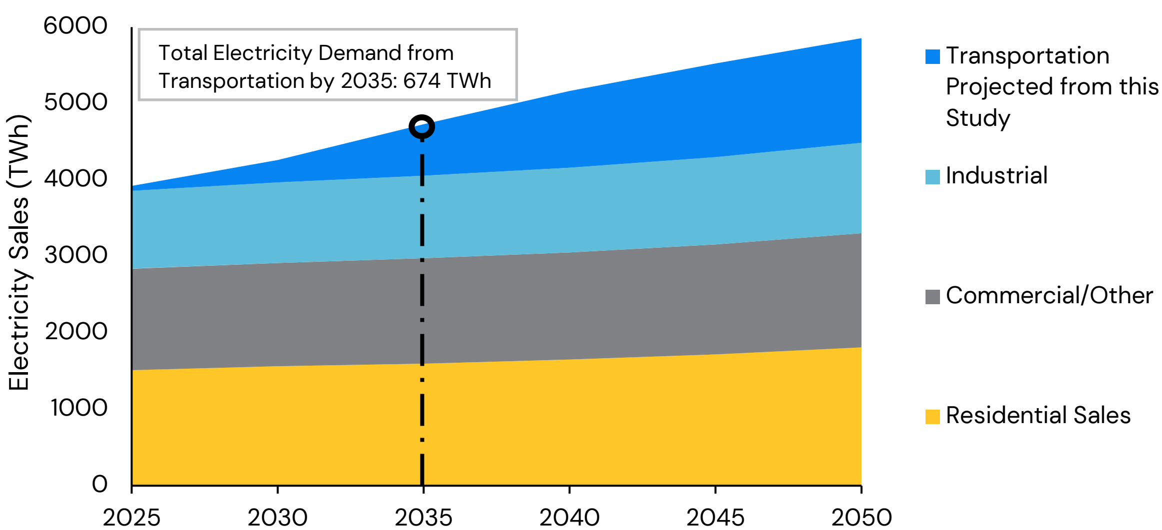
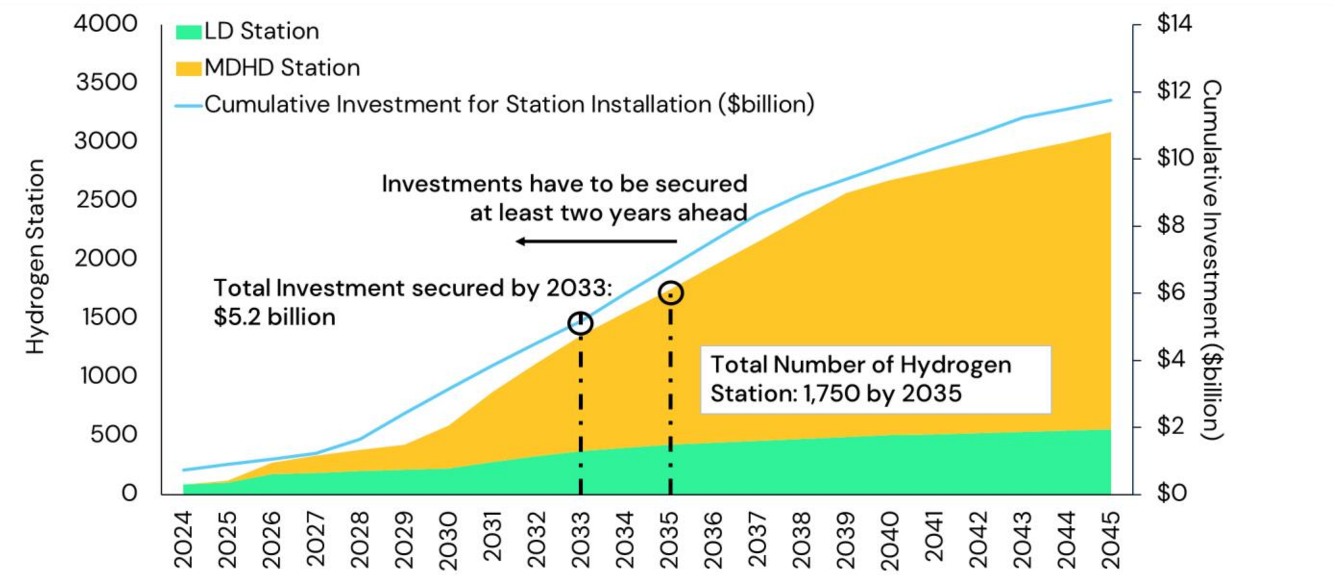


Figure 2. Forecasted economy-wide electricity demands and sales by sector.[3]



[2] Investment has to be committed at least two years ahead to account for site development lead time before deployment. Same assumption applies to hydrogen infrastructure development.
[3] Sales from non-transportation is from 2023 Annual Energy Outlook (AEO) Reference Case [85].

Figure 3. Total hydrogen fueling stations and needed investment for station installation.

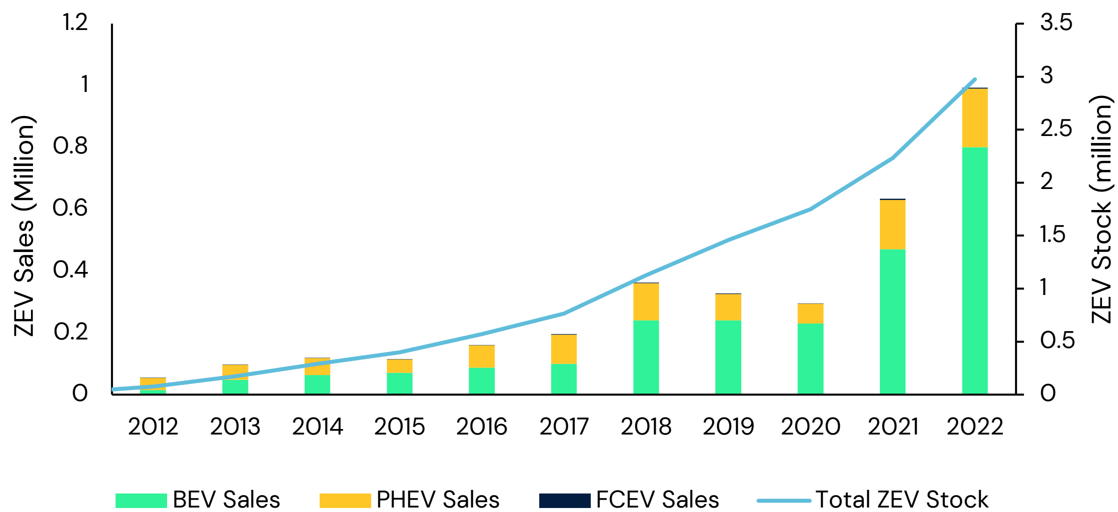


Background

Currently there are about three million zero-emission vehicles (ZEV) operating on the road in the U.S., which accounts for approximately 1% of the total vehicle stock. Figure 4 illustrates the annual sales of battery electric vehicles (BEV), plug-in hybrid vehicles (PHEV), and fuel cell electric vehicles (FCEV), as well as the total ZEV stock, in the last decade [1, 2]. Due to the recent regulations proposed and adopted by the U.S. Environmental Protection Agency (EPA) and State Clean Air agencies, such as the California Air Resources Board (CARB), it is expected that there will be a significant increase in the number of light-duty (LD), medium-duty (MD), and heavy-duty (HD)[4] ZEVs over the next decades.

In April 2023, EPA announced proposed standards that leverage advances in clean car technology to further reduce harmful air pollutant and greenhouse gas (GHG) emissions from LD, MD, and HD vehicles, for model years (MY) 2027 through 2032 [3, 4]. CARB has also adopted several regulations setting both ZEV sales and purchase requirements for on-road vehicles, trucks, and buses, with statewide targets of 100% ZEV sales for transit buses by 2029, LD vehicles by 2035, and MDHD trucks by 2036 [5, 6, 7, 8]. Under Section 177 of the Clean Air Act, which authorizes other states to adopt California's vehicle emission standards in lieu of federal requirements, multiple states have also adopted California regulations, with more expected to follow. Furthermore, the federal government's unprecedented investment in both ZEVs and their supporting infrastructure through the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) is expected to expedite the adoption of these ZEVs [9, 10]. More information on these regulations can be found in Appendix I: Sales Curves.

Figure 4. U.S. ZEV sales and total stock in the last decade (2012-2022).[5]



According to the U.S. Department of Energy (DOE) Alternative Fuels Data Center (AFDC), there are more than 55,000 public electric vehicle (EV) charging stations with roughly 143,000 electric vehicle supply equipment (EVSE) ports in the U.S. [11]. The vast majority of the available public chargers are Level 2 (L2), with only 20% being direct current fast charging (DCFC)[6]. The total number of public charging stations varies significantly

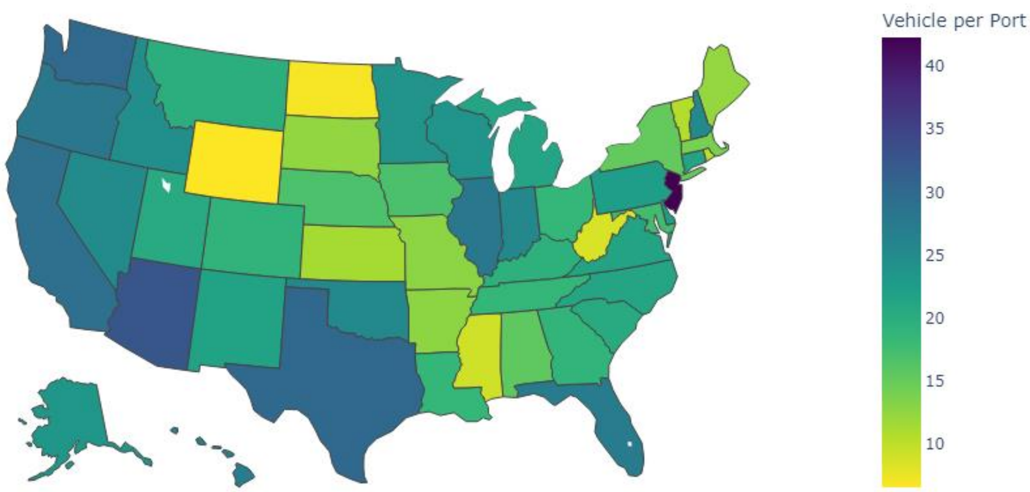
[4] LD vehicles refer to vehicles <=8,500 lbs. in gross vehicle weight rating (GVWR); MD: GVWR > 8,500 lbs. and <=14,000 lbs.; HD: GVWR > 14,000 lbs.

[5] BEV and PHEV data retrieved from the International Energy Agency (IEA) Global EV Data 2023 [2] and FCEV data retrieved from the Hydrogen Fuel Cell Partnership FCEV Sales Data Sheet [1].

[6] Tesla currently owns the biggest DCFC network in the U.S., followed by Electrify America and ChargePoint.

from state to state, with California having more than 40,000 public EVSE ports and Alaska having less than 200 ports. However, a higher number of ports does not necessarily guarantee improved charging access. This is because the effectiveness of charging infrastructure is dependent on the overall number of EVs that these stations must support, as well as the availability of charging options at homes or workplaces. As illustrated in Figure 5, the average EV-per-port ratio in the U.S. is roughly 24, ranging from a high of 42.24 in New Jersey to a low in Wyoming of 6.57.[7] While fewer public chargers can suffice to cover current EV charging needs in the states that have higher shares of residential or workplace charging, the reliance on public charging is expected to increase as the EV market evolves, even in places with high shares of single-family houses.

Figure 5. Current EV-per-port ratio at the state level.



Unlike EV charging infrastructure that spans the entire country, public hydrogen retail stations only exist in California. According to the latest data published by the California Energy Commission (CEC), there are 63 LD and 6 HD open hydrogen stations in California, with more in the planning phase [12]. In response to the anticipated ZEV growth, a major expansion of the infrastructure for both electric charging and hydrogen refueling is imperative.

Successful development and implementation of national and state ZEV policies requires a full understanding of the scope, cost, and timeframes involved in developing this ZEV infrastructure to support the envisioned transition to ZEVs. This study is focused on several key areas to understand the comprehensive implications of electric charging and hydrogen expansion. Firstly, it estimates the rate and scale of ZEV adoption at the state level and the total energy demands to sustain this increase and its impact on the power grid and hydrogen refueling capacity, assuming that the various ZEV regulations at issue can be fully implemented as proposed and adopted. Secondly, and again using that same assumption, it determines the specific number, location, size, station installation and equipment costs, and timelines for creating the necessary charging and refueling stations. Although electrical utility upgrade costs, as well as hydrogen production and distribution costs are not quantified because they depend on project and site specifics, key factors that may affect such costs have been discussed comprehensively. Moreover, it analyzes the aggregated impact of transportation electrification on the electricity grid, and how different methods of hydrogen delivery could impact its quality, costs, and the end-users. Lastly, it reviews the current and potential governmental regulatory and financial incentives regarding DCFC stations and cross-country networks of HD charging and refueling stations, and compares those available incentives against the estimated aggregate costs of transitioning to ZEVs.

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[7] EV-per-port ratio is calculated using the total plug-in electric vehicle (BEV and PHEV) population, divided by the total number of public EVSE ports (all levels included).

Approach

Fleet Modeling

To fully assess the anticipated charging and refueling infrastructure needs, the project team first conducted vehicle fleet modeling at the state level to calculate the projected on-road ZEVs by fuel technologies. The U.S. EPA's MOtor Vehicle Emission Simulator (MOVES) model was used to assess the baseline national vehicle fleet mix [13]. While the MOVES3 model reflects the impact of EPA rulemaking efforts such as the Heavy-Duty Greenhouse Gas Phase 2 Standards and the Safer Affordable Fuel-Efficient (SAFE) Vehicles Standards[8], it does not consider any ZEV technologies penetration [14, 15]. In this study, the project team incorporated recent federal and state regulations mandating increased ZEV penetration into MOVES3[9] baseline data to project the future ZEV population.

Market Penetration and Sales Curves

As part of this task, a series of ZEV sales curves (i.e., percentage of new vehicle sales that are ZEV) by weight class for the contiguous United States have been developed. Light-duty vehicles (LDV) sales curves are categorized by three major groups: California (LD), Clean Car States, and non-Clean Car States. Medium- and heavy-duty vehicles (MDHD) have been combined together, also classified into three types: California (MDHD), Clean Truck States, and non-Clean Truck States. Each state's overall ZEV goal and regulatory strategy is mapped to one of these groupings. Additionally, each ZEV goal has a specific vehicle technology distribution (BEV, PHEV, FCEV percent share) applied to it based on state and vehicle type. Using this approach, a total of 22 sales curves (e.g., percent BEV/PHEV/FCEV new sales by state and vehicle MY) have been developed for various states and vehicle weight groups, again assuming that the multiple state and federal ZEV-forcing regulations can be fully implemented. The detailed sales curves can be found in Appendix I: Sales Curves, and the definition of each grouping is provided below:

- **California (LD):** The State of California is the only U.S. state that has the authority[10] to set and enforce its own emission standards, which must meet or exceed federal emission regulations. For LDVs, the vehicle component of California's Advanced Clean Cars II (ACCII) regulation incrementally raises ZEV sales requirements from approximately 35% in 2026 to 100% by 2035 for passenger cars and passenger trucks [5]. Following the same assumptions as ACCII rulemaking[11], the technology mix of the projected ZEV population is primarily going to consist of BEVs with a small penetration of FCEVs, while for passenger trucks, there will be a greater market for PHEV and FCEV options as compared to passenger cars.
- **Clean Car States (LD)**: A "Clean Car State" is a State which has adopted California's ZEV regulations under Section 177 of the Clean Air Act (42 U.S.C. §7507) [16]. States that have adopted California's LD ZEV standards under Section 177 include: California, New York, Massachusetts, Vermont, Maine, Connecticut, Rhode Island, Washington, Oregon, New Jersey, Maryland, Colorado, Minnesota, Nevada,

[8] The SAFE rule was officially repealed in December 2021. More information available at: https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-revise-existing-national-ghg-emissions
[9] EPA has released MOVES4 in August 2023. However, since the official release was not yet available during the development of this study, the analysis was done using MOVES3 instead. More information available at: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves
[10] Subject to EPA preemption waivers [110]
[11] Data retrieved through communication with CARB's ACCII rule making team.

Virginia, and New Mexico.[12] While Clean Car States are assigned the same ZEV goal as California's ACCII regulation, they may still follow a different penetration of fuel technologies. The technology mix for the projected ZEV population in Clean Car States is assumed to align with the EPA's Notice of Proposed Rulemaking (NPRM) for the Light-Duty Multi-Pollutant Emissions Standards, which only considers BEV and PHEV technologies.

- **Non-Clean Car States (LD)**: A "Non-Clean Car State" is a State which does not follow California's ZEV regulations. Instead, Non-Clean Car States are assumed to follow the U.S. EPA's NPRM for the Light-Duty Multi-Pollutant Emissions Standards. The NPRM projected fleet average BEV penetration rates for passenger cars and passenger trucks were used as a proxy to estimate the total ZEV penetration rates, and California's ACCII technology mix assumptions were applied to further distribute the BEV and PHEV[13] technologies. Note that FCEVs are not considered in these states.
- **California (MDHD):** The Advanced Clean Trucks (ACT) regulation, adopted in 2020, initially established MDHD ZEV sales targets in California, of 55% ZEV sales for Class 2b – 3 vehicles, 75% ZEV sales for Class 4 – 8 Vocational trucks, and 40% ZEV sales for Class 7 – 8 tractors by 2035 [7]. Subsequently, in April 2023, CARB adopted the Advanced Clean Fleets (ACF) regulation, which not only has established 100% MDHD ZEV sales mandates starting in MY 2036, but also requires fleets that are suitable for early electrification to replace their existing conventional internal combustion engine vehicles (ICEV) with comparable ZEVs over the next two decades [8]. Given that the ACF ZEV requirements are above and beyond what ACT has established, California MDHD ZEV penetrations have been estimated using the latest ACF rulemaking assumptions. A combination of BEV and FCEV technologies is considered based on vocational and vehicle weight classes, consistent with assumptions presented in the ACF rulemaking document.
- **Clean Truck States (MDHD)**: A "Clean Truck State" is a state which has signed a memorandum of understanding (MOU), committing to voluntarily accelerating the adoption of MDHD ZEVs [17]. States that have signed the MOU include California, Connecticut, Colorado, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington. Given the MOU has established an interim target of 30% ZEV sales by 2030 [17], the Clean Truck States have adopted or are expected to adopt the same ZEV sales requirements under California's ACT regulation, but not the ICT or ACF. The technology mix distribution is set to be consistent with ACT as well, which ascribes a 10% market share for FCEVs in the HD tractor segmentation between 2030 and 2050 [7].
- **Non-Clean Truck States (MDHD)**: A "Non-Clean Truck State" is a State which does not follow California's MDHD ZEV sales requirements. Instead, it follows ZEV penetration rates projected from the EPA's Proposed Medium-Duty Multi-Pollutant Emissions Standards and Heavy-Duty Phase-3 Standards [3, 4]. Note that although the Phase-3 NPRM primarily includes projected market penetration of BEV technology, it assumes that FCEVs are viable technology options for certain long-

[12] While not all the abovementioned states have adopted the latest ACCII standards, it is very likely that they will choose to opt in eventually. Note that only states who have adopted the ZEV standards are considered, while states who have adopted the Low-Emission Vehicle (LEV) standards are not included in the Clean Car States and are treated as Non-Clean Car States instead.
[13] An electric mile utilization factor of 45% has been assumed for PHEV.

haul HD applications, and they are expected to be available in the 2030 timeframe. Therefore, the ACT technology mix assumptions were adopted for Non-Clean Truck States as well.

In summary, the project team has assumed that each State has a ZEV goal or strategy, informed by either the U.S. EPA proposed standards[14] or California policy. The projected ZEV population is then segmented by technology, using fuel technology assumptions from the California ACC II, ACT, and ACF regulations. The resultant sales curves are the State's ZEV goal for a given vehicle category, apportioned by regulatory technology mix assumptions. The project team's sales curve assignments for both LDVs and MDHD vehicles are visualized in *Figure 6*. Generally speaking, transit buses should follow the same ZEV penetration schedule as proposed in the Phase-3 NPRM for MDHD vocational trucks. However, recent data have suggested that the transition to zero-emission buses has already commenced across the country [18]. Therefore, a uniform 20% ZEV penetration between 2020 to 2026 is assumed nationwide before the Phase-3 NPRM comes into place. This assumption is applied to all states except California (ICT), Massachusetts, and Washington D.C., which all have established respective 100% transit targets [19, 20, 6]. FCEV penetrations are kept consistent with assumptions of long-haul tractors for the same state.

Figure 6. Statewide ZEV goals for LDV (left) and MDHD (right).

CO_2Sight Modeling

ICF's CO_2Sight On-Road Vehicle Tool was used to model vehicle miles traveled (VMT), vehicle population, and the energy consumption impacts of switching the national vehicle fleet of ICEVs to BEVs, FCEVs, and PHEVs. The tool uses the national EPA MOVES3 model as an input for current and projected ICEV populations, VMT, and energy consumption through 2050, which varies by the state, regulatory class, propulsion type, and vehicle "source type" (passenger car, passenger truck, transit bus, etc.). CO_2Sight then models national ZEV adoption driven by predetermined the BEV, FCEV, and PHEV sales curves. As outlined in the previous section, the sales curves determine the technology composition (i.e., ICEVs, BEVs, FCEVs, and PHEVs) of vehicle sales each year from 2020 to 2050 based on the assumed implementation of the latest ZEV regulatory standards and statewide targets.

For each year in the MOVES3 model, CO_2Sight converts new car sales to total fleet mix by replacing a percentage of newly purchased vehicles to BEVs, FCEVs, and PHEVs determined by the sales curves. That proportion is distributed evenly among all ICEV fuel types. The total vehicle population in any given year is the

[14] The ZEV sales in Non-Clean Car or Non-Clean Truck states may be lower than the EPA penetration rates, which already considered the offset brought by states who have exceeded the average sales through adopting California's ZEV requirements. Therefore, applying EPA goals directly to those states serves upper bound estimates of ZEV sales.

sum of the existing vehicles and new vehicles for that year, minus the vehicles at the end of their lifetime[15]. The same basic approach is used to reallocate VMT[16]. Energy consumption is reallocated by multiplying the BEV, FCEV, and PHEV VMT by their energy efficiencies (in kWh/mi or g H_2/mi) respectively, as listed in Appendix II: BEV and FCEV Vehicle Efficiency. Energy efficiencies are calculated based on data from the currently available commercial models by vehicle type and weight class, using information available through the U.S. DOE and EPA fuel economy data, California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) program, and information provided by the original equipment manufacturer (OEM) [21, 22]. A 15% adjustment factor was applied to transit and other buses to account for the energy consumption due to heating, ventilation, and air-conditioning (HVAC) system [23].[17] In addition, a 10% charging loss adjustment has also been applied to all BEVs and PHEVs to account for the energy lost during charging events due to heat and other causes [24]. For FCEV categories that are not currently available, the project team calculated the FCEV energy efficiencies based on their BEV counterparts, assuming the energy efficiency ratio (EER) of BEV to FCEV are constant.[18]

Infrastructure Modeling

EVI-Pro for Personal LDV Daily Charging Needs Assessment

Charging needs for the projected personal plug-in electric vehicles (PEV, e.g., BEV and PHEV) are estimated using the publicly available version of the National Renewable Energy Laboratory's (NREL) Electric Vehicle Infrastructure Projection Tool (EVI-Pro) [25]. EVI-Pro is a tool for projecting consumer demand of EV charging infrastructure, developed through a collaboration between CEC and NREL. The tool uses detailed data on personal vehicle travel patterns, EV attributes, and charging station characteristics in bottom-up simulations to estimate the quantity and type of charging ports necessary to support regional PEV adoption. Specifically, EVI-Pro estimates charging demand for daily travel based on personal vehicle travel patterns from the 2017 National Household Travel Survey (NHTS). The 2017 NHTS respondent data is most consistent with the MOVES passenger car and passenger truck vehicle categories. For this reason, only the passenger car and passenger truck PEV populations are considered in this EVI-Pro LDV charging needs assessment. Light commercial trucks are excluded due to the potential difference in vehicle travel and activity patterns to those reflected in the 2017 NHTS.

EVI-Pro estimates regional charging port distributions using two key inputs: the number of PEVs[19] to support and the percentage of PEV owners with access to home charging. The number of PEVs to support by region and calendar year is taken directly from the fleet modeling exercise described in the previous section and the resulting vehicle portfolio is dominated by BEVs due to assumed sales curves. Residential charging potential, or the percentage of PEV owners with access to home charging, is a critical variable determining the amount of residential and public charging infrastructure needed. The higher the access to home charging, the lower the need for public charging infrastructure. NREL's research, which examines the potential for residential charging according to housing type, takes into account various scenarios derived from a residential parking and electrical survey conducted by the organization. This study was designed to understand the correlation

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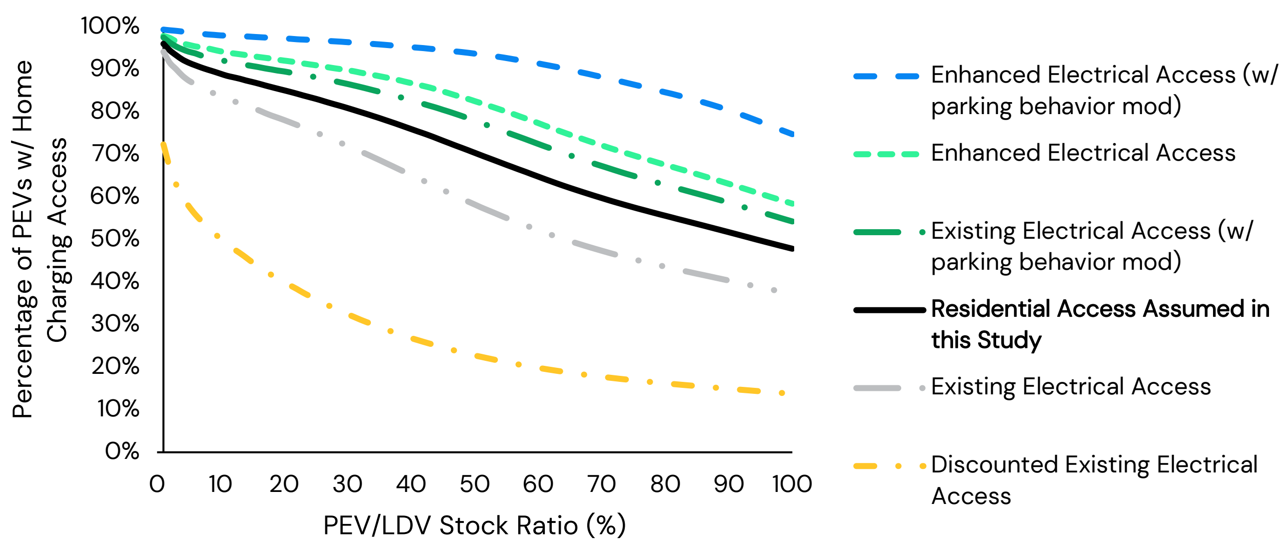
[15] ZEVs are assumed to exist in the vehicle fleet for the same length of time as ICEVs.
[16] ZEV's accrual rates are assumed to be identical to ICEV's.
[17] HVAC system may consume up to 30% of the battery power at maximum. Due to seasonal and temperature variances across the country, the project team assumed that on average transit and other buses are 15% less efficient compared to their "sticker" values.
[18] Class 2b trucks are assumed to be similar as LD trucks, with a BEV/FCEV EER of 1.34; Class 3 and above vehicles are assumed to be similar as Class 8 tractors and transit buses, with a BEV/FCEV EER of 2.
[19] Note that the ratio of BEVs versus PHEVs serves as an input to EVI-Pro as it impacts the overall PEV charging needs.

between the percentage of PEV owners with access to home charging facilities and the changes in PEV stock share [26]. The outcome of NREL's research was a set of home charging access scenarios as a function of the LD PEV stock ratio, based on different grid-readiness levels and shifts in PEV owner parking behavior[20]. These home charging access distributions are illustrated in Figure 7. The project team, after personal communication with NREL staff, developed a new home charging access scenario (solid black line) using a 50%-50% combination of the "Existing Electrical Access"[21] and the "Enhanced Electrical Access"[22]. This assumption reflects home charging access potential as some future PEV owners are able to add electrical outlets at their normal parking locations (e.g., garage, driveway, curbside outside the house).

Figure 7. Residential charging accessibility projection with the change of PEV stock share.



With the number of supported PEVs by region and calendar year, as well as the percent home charging access by region's PEV/LDV stock ratio per calendar year, detailed charging needs for personal LDVs can be queried using EVI-Pro, which is shown and discussed in the Results section.

EVI-OnDemand for Non-Personal LDV Charging Needs Assessment

EVI-OnDemand is another NREL simulation platform which estimates fast-charging infrastructure requirements necessary to support ride-hailing electrification [27]. Although the tool was designed to estimate the charging needs for transportation network companies (TNC) such as Uber and Lyft, the project team used it to estimate fast-charging infrastructure requirements necessary to support both ride-hailing services and long-distance road trips.

EVI-OnDemand estimates the DCFC infrastructure needed to electrify ride-hailing across 384 States Core Based Statistical Areas (CBSAs) using numerous inputs, most notably shift duration, total VMT in different CBSAs, and the electrified TNC market share. The project team kept most of the input variables the same as

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[20] If a vehicle is currently not parked in an area with electrical access but can be moved to a home parking location with electrical access, then residential charging can become available with "*parking behavior modification*".
[21] Residential charging is considered available if the vehicle is parked near existing electrical access.
[22] Residential charging is considered available if a vehicle is parked at a location where there is either existing electrical access or where it is likely that new electrical access can be installed.

default, while modifying the electrified TNC market share to reflect the progressive DCFC needs from ride-hailing services as both EV adoption and TNC service expands. As large TNC companies have committed to reaching 100% ZEVs by 2030 [28, 29], the project team assumed that 50% of the TNC vehicles will be PEVs by 2025, and 100% starting at 2030. Based on a study conducted in 2019, the total TNC market share was around 1.5% on average in metropolitan regions [30]. While the TNC industry has experienced a significant decrease in service due to the COVID-19 pandemic, recent data suggests that trips and riders have returned to the pre-pandemic levels and the TNC market continues to expand [31, 32]. Based on the observed trends, the project team assumed the TNC VMT share will continue to grow linearly and increase from 1.5% in 2020 to 16% in 2040, consistent with the 2020 BloombergNEF (BNEF) Electric Vehicle Outlook projection [33].

In order to use EVI-OnDemand to estimate DCFC infrastructure needs to enable electrified long-distance or interregional travel for LD vehicles, the project team modified the input VMT to match with the total long distance travel miles based on the 2017 NHTS data [34]. There are about 2.6 billion long distance trips conducted by Americans every year, and 90% of these trips are via personal vehicles. The average trip distance of these trips is 194 miles. Therefore, the average daily VMT for long-distance trips using personal vehicles is roughly 1.24 billion miles. Once the VMT input was adjusted, the project team assumed the EV ratio to be consistent with the overall fleet PEV/LDV ratio to proceed with the rest of the calculation.

MDHD PEV Charging Infrastructure

With respect to source types that are not considered in EVI-Pro and EVI-OnDemand, a separate model that evaluates the charging needs for light commercial trucks and MDHD BEV fleets was developed. The model takes into account the operational characteristics of vehicles across the nation by source type, including daily operation hours, dwelling time, and duty cycles, etc. These variables were also considered in the Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operations, and Deployment Tool (HEVI-LOAD), developed by the Lawrence Berkeley National Lab (LBNL) [35].[23]

Light commercial trucks and MDHD BEVs will use two primary charging models: depot charging and public (or en-route) charging. Vehicles that regularly return to their designated home sites and park overnight often are suitable for depot charging, whereas long-haul and interstate trucking mainly relies on public or en-route opportunity charging, which requires high-power DCFCs or the ultrafast Megawatt Charging Systems (MCS) that can quickly recharge depleted batteries to meet their operational needs. It is assumed that vehicles that are regularly parked at their home base more than 8 hours each day will have access to depot charging, while the rest will need public infrastructure. For this study, the project team leveraged CARB's ACT Large Entity[24] Fleet Reporting data [36] to determine the depot vs. public charging ratios for the various vehicle categories assessed in this study. The early phase of ZEV adoption in MDHD and commercial fleets is likely to be led by large entities, hence the ACT Reporting data should provide reasonably accurate estimates regarding depot charging access. However, these assumptions could change over time as more small businesses, fleets, and individual owner-operators begin transitioning to ZEVs as well.

[23] The HEVI-LOAD model is not yet publicly available and is only customized for California. It cannot be used for any other states without significant modification to the model.
[24] Had more than $50 million in revenues in the 2019 tax year from all related subsidiaries, subdivisions, or branches, and have at least one vehicle; or owned 50 or more vehicles in 2019; or dispatched 50 or more vehicles into or throughout California in 2019; or government agencies (federal, state, local, and municipalities) with at least one vehicle in 2019.

Daily operation hours of different source types are used to determine the optimal vehicle-to-port ratio at depots [37]. The depot vehicle-to-port ratio is assumed to be 1:1 if average daily operation time is longer than 6 hours. Otherwise, the ratio is set to 2:1. The depot charging cycle is assumed to be 8 hours every day.

For public charging, the charger power output level is consistent with typical recommendations from the OEMs[25] and the battery acceptance rate is assumed to be the same as the maximum output. For long-haul tractors, telematics data has suggested that 25% of trips are slip-seat operations, meaning the truck is driven for more than 700 miles or 16 hours without stopping for a break of 4 hours or longer [38]. Therefore, given the potential ultrafast charging demands for slip-seat operations, 25% of Combination Long-haul Trucks that require public charging access are assumed to use MCS (1 MW) and the rest will need DCFC 350 kW instead. Due to limited information available regarding public charging infrastructure utilization rates for commercial BEVs, a 20% constant rate is applied to all charger types [39].[26] The major assumptions for this charging assessment are listed in Table 1.

Table 1. Assumptions utilized for estimating charging requirements for light commercial vehicles and MDHD fleets.

MOVES3 Source Type	Operation Days	Daily Operation (Hours)	Depot Charging Ratio	Depot Vehicle to Port	Public Charging Ratio	Public Charger Level (kW)	Public Charger Utilization[27]
Combination Long-haul Truck	312	9.77	0.1	1 : 1	0.675	350	0.2
					0.225	1000	0.2
Combination Short-haul Truck	312	6.5	0.59	1 : 1	0.41	350	0.2
Light Commercial Truck	312	2.81	0.72	2 : 1	0.28	150	0.2
Other Buses	292	8.73	1	1 : 1	0	N/A	N/A
Refuse Truck	312	5.68	1	2 : 1	0	N/A	N/A
School Bus	327	2.45	1	2 : 1	0	N/A	N/A
Single Unit Long-haul Truck	312	5.18	0.59	2 : 1	0.41	150	0.2
Single Unit Short-haul Truck	312	3.42	0.72	2 : 1	0.28	150	0.2
Transit Bus	327	9.06	1	1 : 1	0	N/A	N/A

Hydrogen Refueling Infrastructure

Hydrogen refueling stations are in the early stage of development and deployment. As of mid- 2023, the hydrogen station market is growing, predominantly in California, with over 100 total stations as either open-retail or in development though either state co-funding or completely private funding. Within this total, 63

[25] Data available through ICF's proprietary EV Library.

[26] Based on recent LDV public DCFC data, the average utilization is about 5% [109]. While this is lower than the 20% assumed, we anticipate MDHD public charging may behave differently and as the market matures, the utilization can reach 20%.

[27] The actual charger utilization has been adjusted to account for extended charging time due to energy loss.

light-duty hydrogen stations are open to retail, and available, and 6 heavy-duty stations are operating [12]. Three of the heavy-duty refueling stations are deployed for transit buses and the other three are for trucks.

This research follows the general guidelines of the hydrogen station deployment schedule and forecast methodology under CARB's Assembly Bill (AB) 8 Hydrogen Self-Sufficiency Report [40]. The schedule for new station installations is primarily determined by the projected number of fuel cell electric cars, trucks, and buses, and the estimated hydrogen demand. Additionally, it is assumed that stations with larger capacity will phase in gradually over time, while a natural increase in stations with smaller capacities is expected earlier to ensure broader spatial coverage. These factors set the pace of hydrogen station buildout and are crucial in determining the total number of stations with varying capacity combinations. Each hydrogen refueling station is capable of supporting a far larger community of vehicles than a single EVSE, but requires significant investments, and it is essential to plan the deployment strategically. Beginning with smaller capacity stations and gradually progressing to larger capacity stations as demand increases allows for a more controlled and manageable expansion of the infrastructure. Starting with smaller capacity stations also helps gauge the demand and utilization, allowing for adjustments and optimizations before scaling up to larger stations.

For light-duty stations, while a couple of higher capacity refueling stations have already been built out or planned to be upgraded (e.g., since 2020, First Element Fuels began installing 1200 kg/day stations and Iwatani is planning to install 800 kg/day), this study assumes that average station capacity is low between 2020 through 2027, ranging from 200 to 600 kg H_2 per day. One contributing factor that drives the current development of stations with higher capacity is that they are designed for dual purposes that serve both LD and HD FCEVs. Since this study does not consider the colocation between LD and HD stations, a more conservative capacity range for early LD station buildout was assumed [41]. Between 2028 and 2031, mid station capacities from 900 to 1200 kg H_2 per day are assumed to be widely available, which allows more time and space for the low-capacity stations to phase-in to increase spatial coverage. Beginning in 2032, high station capacities (1,600 -2,000 kg H_2 per day) will be the primary stations built to meet the surging demand. The capacity phase-in schedule could evolve when more states are installing hydrogen stations.

For heavy-duty stations, due to the larger size of the truck's hydrogen tanks and higher fuel consumption, higher capacity is required, with the following detailed assumptions:

- **California**: With the adoption of ACF and ICT, the phase-in of fuel cell electric trucks and buses, along with their hydrogen demand for refueling, will occur much earlier in California than in other states. This project assumes that heavy-duty stations will initially have an average capacity of 1,200 to 1,600 kg per day in the early years, which aligns with the capacities of California-funded heavy-duty refueling stations and is sufficient to refuel a fleet of 30-40 medium and heavy-duty vehicles [42, 43].[28] In later years between 2026 and 2029, capacities between 1600 and 2,000 kg per day are assumed to become available. Starting in 2030, stations with capacities ranging from 3,000 to 5,000 kg per day will become dominant, capable of refueling 100-150 vehicles per station on average, which is comparable to the current average diesel fueling capabilities of 130-200 vehicles per station per day[29].

[28] Current tank capacity of commercially available MDHD FCEVs is roughly 30-40 kg.
[29] A diesel station on a major highway has a typical capacity of 20,000-40,000 gallon, a diesel tank is in the range of 150-200 gallon, so on average a station can fully refuel 130 - 200 trucks every day.

- **Other States**: Based on the U.S. EPA Phase-3 NPRM, MDHD FCEVs in other states could start to phase-in as early as 2030, which could reflect a six-year delay compared to California. Thus, the phase-in schedule of hydrogen station capacity is also assumed to start six years later than California's.

Additionally, this study assumes that once a station capacity is established, there will be a five percent year-over-year natural growth rate of average network capacity until the maximum station capacity becomes available (i.e., by 2034 for California, and by 2040 for non-California states). The expansion of low-capacity stations increases the number of smaller stations in the early stages, helping to build out the refueling network and ensure adequate spatial coverage. However, as technology matures and spatial coverage becomes saturated, stations with higher capacity will enter the market and stations with smaller capacity may also be upgraded. Due to their lower cost per kilogram of installed capacity, these larger stations will become more financially competitive.

Cost Modeling

EVSE Infrastructure

The project team has used ICF's Fleet Assessment Tool and its EVSE cost assumptions to estimate the total hardware and installation costs of public (both LD and MDHD) and depot charging ports that can be expected to be deployed over the time horizon of this analysis. Residential and shared private charging costs are not evaluated in this analysis because of their distinct development processes and funding schemes from the others. The EVSE cost assumptions are composite data initially gathered for the California Energy Commission's (CEC) MD/HD vehicle choice model, which is used to project vehicle stock by technology for various MD/HD vehicle classes. Data in this literature review include equipment and installation costs from Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, a tool for assessing the environmental and economic costs and benefits of alternative fuel and advanced vehicles [44]. Data from the International Council of Clean Transportation (ICCT), Rocky Mountain Institute (RMI), NREL, and other sources was also included in the literature review for hardware and installation costs by varying power levels [45, 46, 47, 48, 49]. The project team calculated the average hardware and installation costs for chargers by power level, as shown in Table 2. The hardware and installation costs are per charging port, and the project team has assumed a 10% cost reduction for dual port chargers.

Table 2. Per-port EVSE hardware and installation cost assumptions.[30]

Power Range	Average Hardware Cost - Networked	Average Installation Cost – Networked	Total Hardware & Installation Cost - Networked
L2 (3-6 kW)	$2,500	$3,500	$6,000
L2 (6-8 kW)	$3,000	$3,500	$6,500
L2 (8-11 kW)	$3,500	$3,500	$7,000
L2 (12-15 kW)	$4,000	$3,500	$7,500
L2 (15-19 kW)	$4,500	$3,500	$8,000
DCFC (50 kW)	$35,800	$28,100	$63,900
DCFC (150 kW)	$100,000	$42,200	$142,200
DCFC (250 kW)	$125,000	$51,900	$176,900

[30] Composite data from Atlas Policy 2021, AFLEET 2020, RMI 2020, ICCT 2019, RMI 2014, and EPRI 2013 cost survey publications. DCFC 250 kW is interpolated using DCFC 150 kW and DCFC 350 kW. 2 MW from Atlas Policy 2021, as the only source that investigated MCS cost.

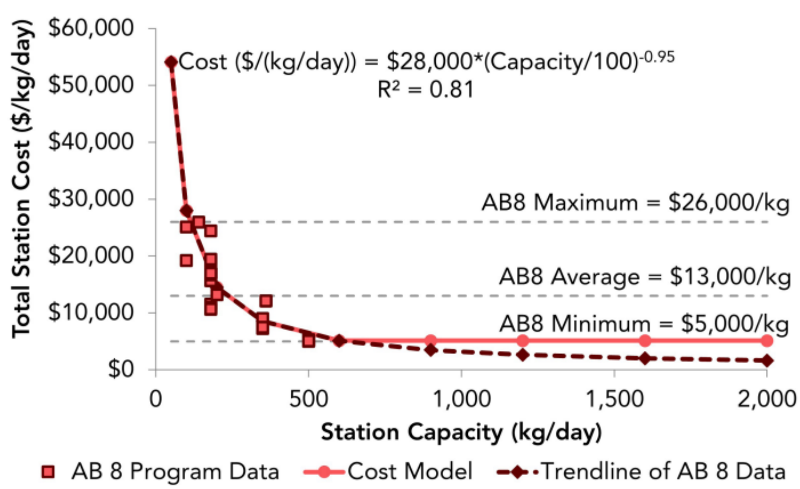
Power Range	Average Hardware Cost - Networked	Average Installation Cost – Networked	Total Hardware & Installation Cost - Networked
DCFC (350 kW)	$150,000	$61,600	$211,600
2 MW	$600,000	$130,000	$730,000

Note that Table 2 provides hardware and installation cost estimates for networked chargers. Here, networked chargers refer to a charging technology platform that is connected to the Internet, which can be used to modulate power delivery at a charging site during peak-demand and provide smart charging management strategies to optimize vehicle charging patterns. Non-networked chargers are standalone units that are not connected to the service network, so they cannot be centrally managed or adjust power delivery based on the grid's capacity. The analysis assumes charging needs will be mainly met by networked chargers for two main reasons: 1) smart charging management will play a key role in meeting increased charging needs as grid upgrades are executed to accommodate PEVs; and 2) many incentive programs for public and commercial chargers require the use of networked chargers to be eligible to receive funding, which will be crucial for accelerating charging infrastructure deployment.

Hydrogen Refueling Infrastructure

The capital costs for installing hydrogen stations have been estimated, relying mainly on two parameters: 1) individual station capacity, and 2) cumulative network scale. Stations previously funded by the H_2 portion of the Clean Transportation Program authorized under Assembly Bill 8 (and referred to as the AB 8 program), as shown in Figure 8, have shown several key metrics and trends related to the cost of hydrogen station installation. This analysis adopts CARB's truncated cost model and assumes that cost per kg of daily capacity follows a power law function when the station capacity is 600 kg per day or smaller, and then a constant installed capital cost of $5000 per kg daily capacity is used for stations with larger capacity. Data from six hydrogen infrastructure projects funded by CEC's Clean Transportation Program suggest that on average a MDHD hydrogen fueling station with a capacity of over 1000 kg per day would cost around $4,978 per kg/day at the initial deployment [50], which is very close to what CARB has suggested.

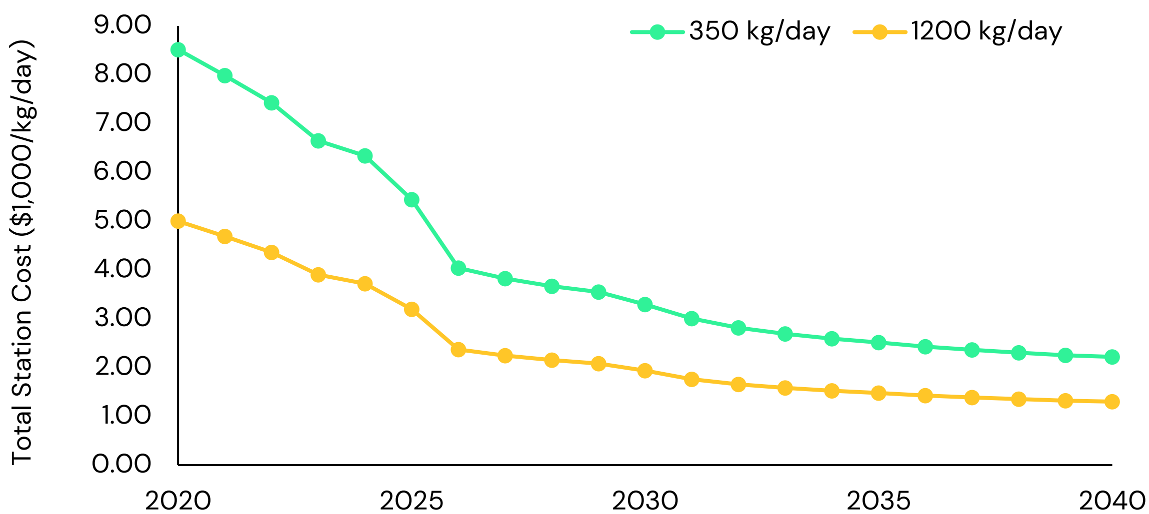
Figure 8. Fully Installed station capital expense model.[31]



[31] Image source: CARB Hydrogen Self-Sufficiency Report

The AB 8 analysis only represents the costs of the very first hydrogen fueling stations built in California, when the supply chain was extremely limited with little cost reduction. In order to reflect potential equipment capital cost reduction due to technology progression or economies of scale, similar to what has been observed for other emerging technologies like solar and wind electricity generation and BEV battery manufacturing, Moore's Law with 12% reduction per doubling of installed capacity is applied to the initial cost model. While a 12% cost reduction rate might appear slow and conservative compared to other clean energy technologies, it aligns with trends observed for specific technologies related to fuel cells and hydrogen, such as those reported in CARB's hydrogen self-sufficiency report [40] and industry's estimate of hydrogen production cost [51]. For this analysis, a roughly 70% cost reduction from the 2020 baseline level is expected by 2035, as demonstrated in Figure 9. The figure shows that the installed capital cost would decrease from $5,000 in 2020 to $1500 per kg per day in 2035 for a mid-station with a capacity of 1,200 kg per day. Similar reduction trends apply to small and large stations. This reduction from 2020 costs is more aggressive than the 30% - 50% cost reduction estimates made by CARB. Given that CARB's hydrogen self-sufficiency report is limited to the California market, it is very likely that the expanded national network can further reduce the capital cost. The combination of the initial capital cost model and the cost reduction curve based on Moore's Law is used to estimate hydrogen refueling infrastructure cost by capacity in future years.

Figure 9. Hydrogen Installation Cost Reduction by Capacity and Installation Volume



Results

Fleet Modeling Results

Incorporating state level ZEV new vehicle sales curves and technology mix assumptions into the MOVES3 baseline fleet inventory, the CO2Sight model calculated the resulting vehicle stock, as well as electricity and hydrogen demands from 2025 through 2050. As illustrated in Figure 10, the current sales and technology penetration scenarios will achieve a national average of 37% ZEV fleets in the LD sector and 19% ZEV fleets in the MDHD sector by 2035, and 73% for LD and 46% for MDHD by 2050, respectively. It is also noteworthy that although the overall FCEV penetration may seem low, FCEV plays a significant role in the HD long-haul sector (as illustrated in Appendix I: Sales Curves), accounting for 1% of the total fleet by 2035, and 6% by 2050. The projected home charging access curve is also determined using the LDV fleet composition forecast, as illustrated in Figure 11.

Figure 10. Projected fleet composition for LD vehicles and trucks[32] (left) and MDHD trucks and buses (right).

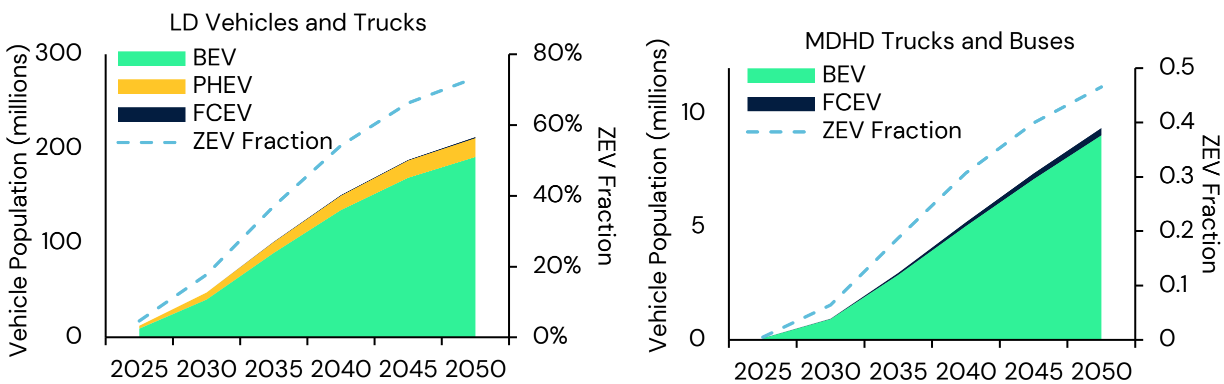


Figure 11. Change in home charging access with projected LDV[33] technology mix.

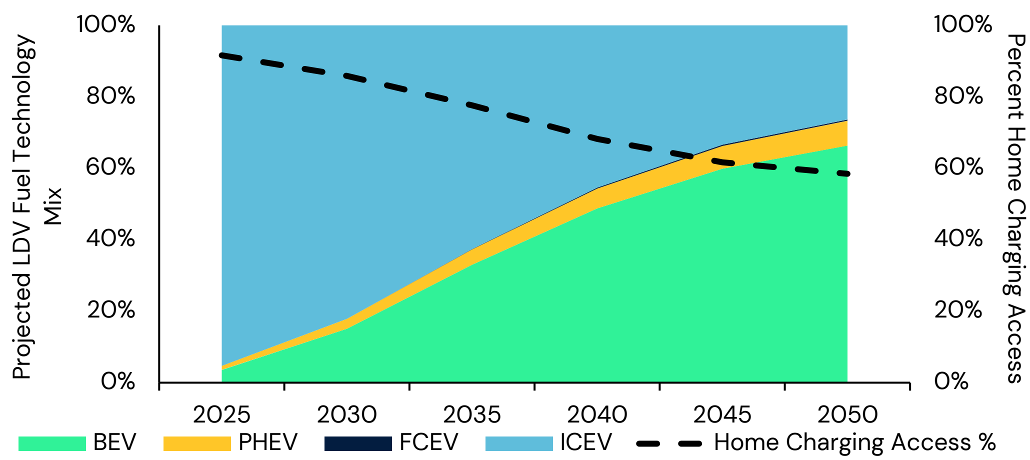
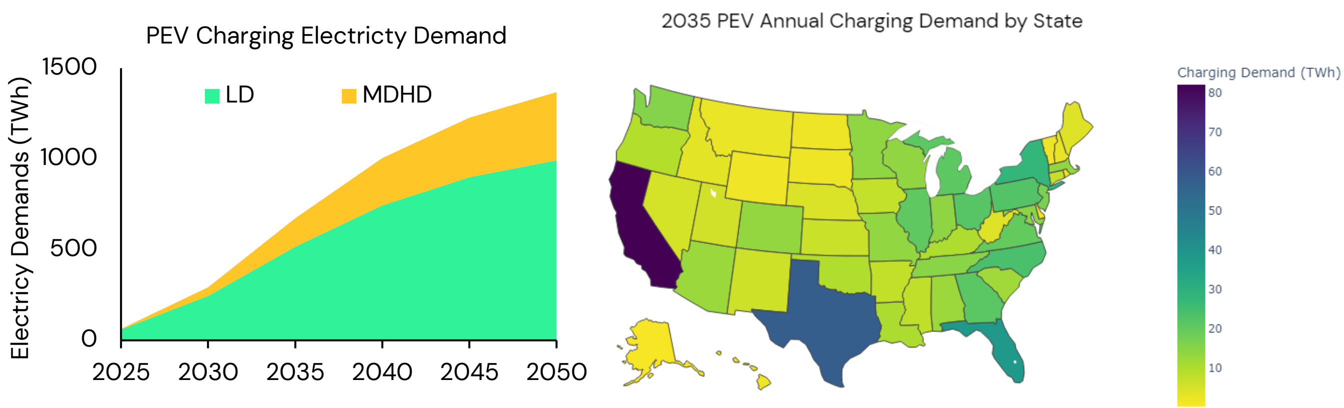


Figure 12 illustrates the electricity generation demand forecast for PEV charging. By 2035, the national electricity demand from the transportation sector will be 674 TWh, and 1,368 TWh by 2050. In 2035 the top

[32] Includes passenger cars, passenger trucks, and light commercial trucks from CO2Sight outputs.
[33] Since home charging access serves as an input to EVI-Pro that assesses personal EV charging infrastructure needs, only passenger cars and passenger trucks are considered.

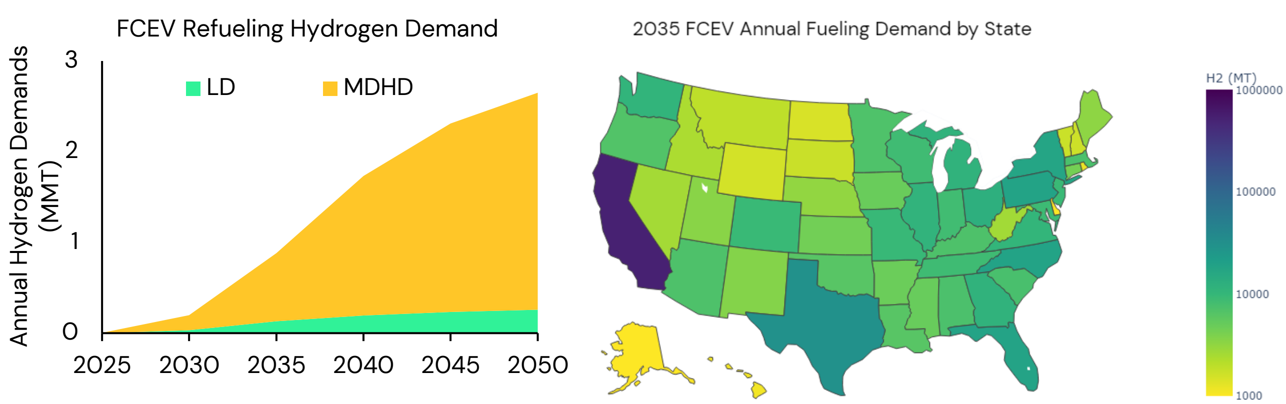
ten states with the highest charging demands are California, Texas, Florida, New York, North Carolina, Pennsylvania, Ohio, Georgia, Michigan, and Illinois, in descending order.

Figure 12. Projected electricity demands from PEV charging, including LD, MD, and HD vehicles.



Similarly, the hydrogen demand forecast is illustrated in Figure 13. Given the relatively conservative assumptions of FCEV penetration, the current fleet modeling results indicate the need for annual production of 0.89 million metric tons (MMT) of hydrogen for direct use in on-road transportation in 2035, and 2.67 MMT in 2050. In 2035, the top ten states with the highest hydrogen demands are California, Texas, Pennsylvania, North Carolina, Florida, New York, Ohio, Michigan, Georgia, and Illinois, in descending order.

Figure 13. Projected annual hydrogen demands from FCEV refueling, including LD, MD, and HD vehicles[34].



Infrastructure Modeling Results

PEV Infrastructure

Based on the PEV charging infrastructure approach and assumptions discussed in the previous section, the project team has estimated the total number of ports by type for every state between calendar years 2024 through 2050. The results for LDVs are output from EVI-Pro and EVI-OnDemand and the results for MDHD vehicles are based on the ICF proprietary model as descrbied earlier. Estimates of the number of chargers by state, type, and power level have been interpolated to develop cumulative charger cost estimates.

[34] Statewide fueling demand result is plotted using $\log_{10}$ scale. Same scale is applied to all the hydrogen refueling and station maps throughout this study.

LD Charger Needs by Type and Power Level

Appendix III: EVI-Pro and EVI-OnDemand Modeling Outputs summarizes the number of passenger LDV chargers (e.g., private-access, shared-private access, and public DCFCs) by state. Given the current assumptions regarding potential access to home charging, a significant portion of the forecasted LDV charging infrastructure necessary to meet charging demands is expected to be deployed within the residential sector, as illustrated in Figure 14. The total number of L1 and L2 ports across the U.S. for LDVs is shown by EVI-Pro designated use-cases. EVI-Pro projects that L1 and L2 ports will be deployed between residential, public, and private access zones. By 2035, 92% of all L1 and L2 ports are expected to be installed at residential sites, such as single-family homes with a garage and 120 V or 240 V electrical access. The proportion of residential ports slowly diminishes over time as the PEV to LDV ratio rises. This increase in the ratio is a key factor prompting the installation of more public and shared private access ports.

Figure 14: Projected L1 & L2 charger needs for passenger LDVs from EVI-Pro.

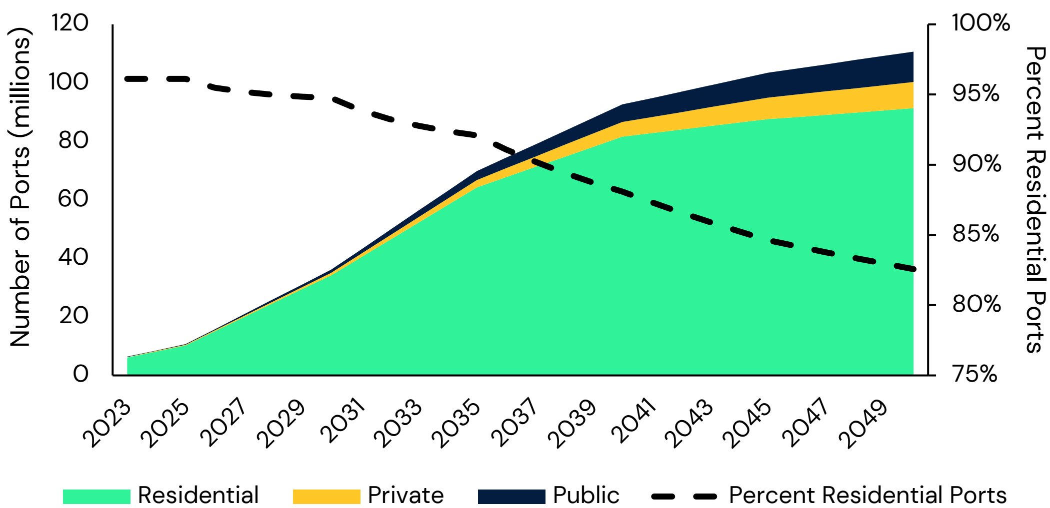
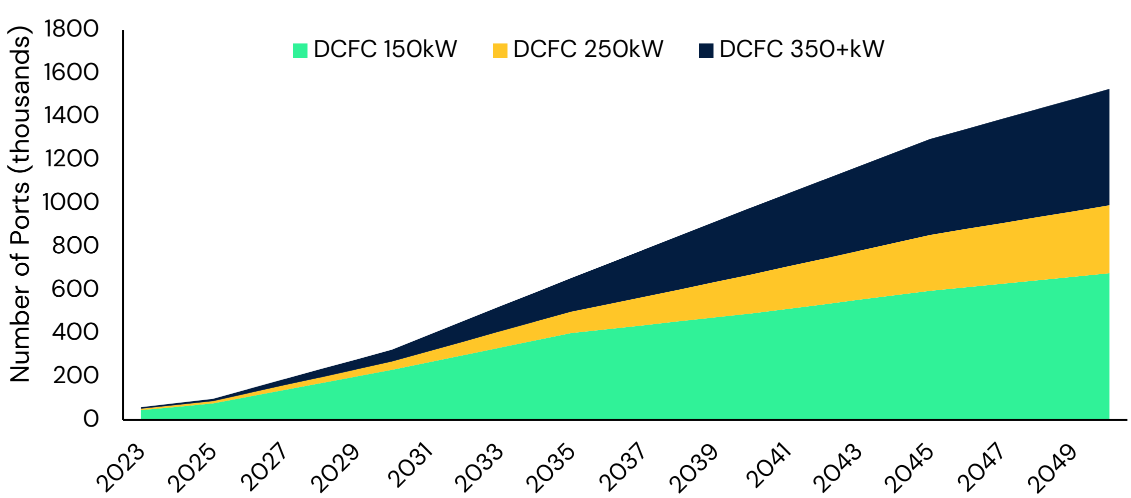
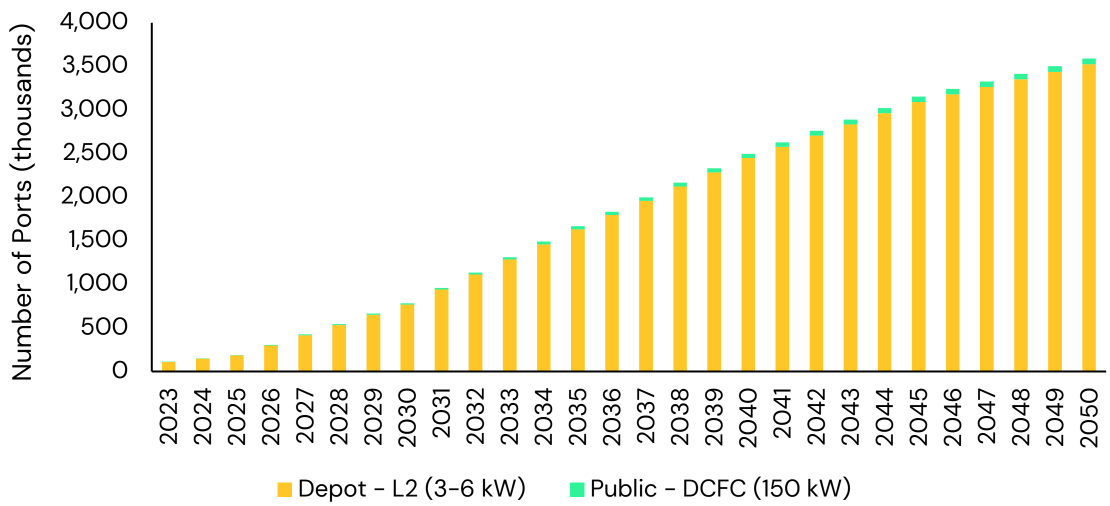


Figure 15: Projected public DCFC charger needs for passenger LDVs from EVI-Pro and EVI-OnDemand.



In Figure 15 the total number of public DCFCs across the U.S. for passenger LDVs is shown by power level. While EVI-OnDemand assumes all DCFC ports are 150 kW by default, EVI-Pro apportions public fast-charging needs for LDVs to be evenly met by 150 kW, 250 kW, and 350+ kW power levels, and access to both 250 kW and 350+ kW DCFC ports are expected to outgrow access to 150 kW ports.

Figure 16: Projected needs for light commercial truck chargers from the ICF proprietary model.



As discussed earlier, while the majority of light commercial trucks have a GVWR less than 10,000 lbs, the travel and activity patterns of these trucks are different from those included in the NREL tools. Table 3 shows the projected needs for light commercial trucks across the U.S. using the ICF proprietary model. A significant share of light commercial trucks charging needs can be met by depot-access or private-access L2 ports. Note that a portion of the depot charging needs of light commercial trucks can potentially be met using residential charging as well, especially for individual owner-operators.

Table 3. Summary of recent 2030 U.S. and California LDV charging infrastructure assessments.

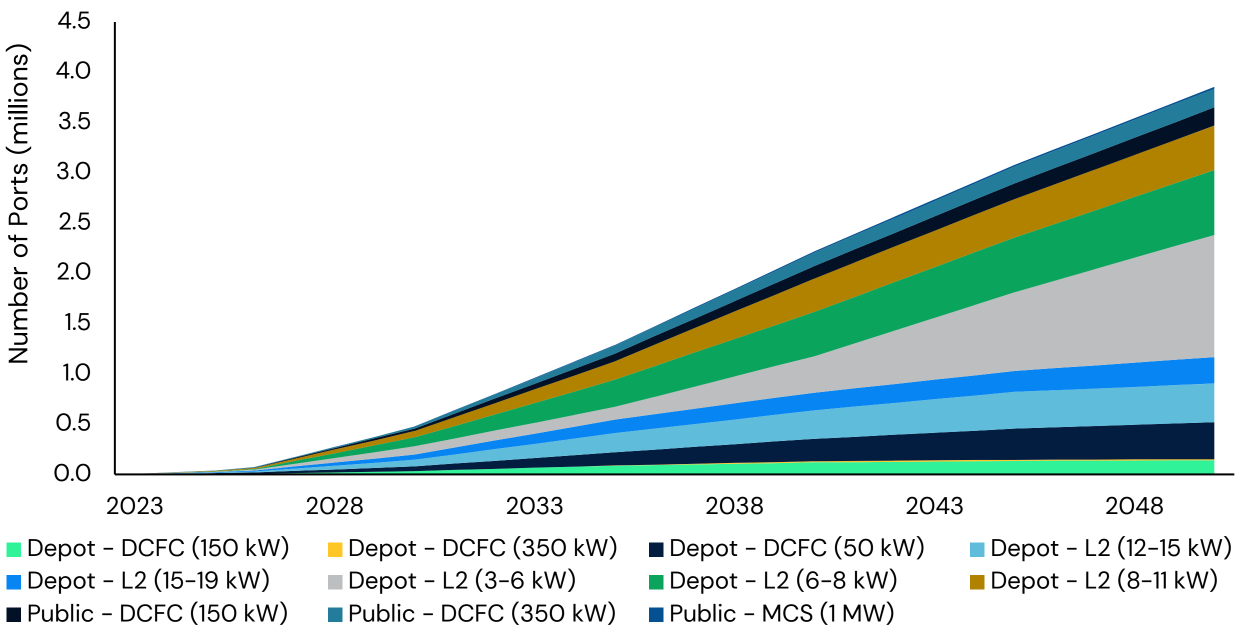
Scope of Study	Organization (reference)	LDV PEV Stock	Est. 2030 Public Ports (including DCFC)	Est. 2030 DCFC Ports
National	ICCT (Bauer et al. 2021)	26,000,000	2,400,000	180,000
	Atlas Public Policy (McKenzie and Nigro 2021)	48,000,000	600,000	300,000
	McKinsey (Kampshoff et al. 2022)	44,000,000	1,200,000	600,000
	S&P Global (S&P Global Mobility 2023)	28,000,000	2,300,000	172,000
	NREL (2023)	33,000,000	1,250,000	182,000
	ICF (current report)	**47,000,000**	**1,391,000**	**341,000**
California	CEC AB 2127 (2023)	7,100,000	408,000	39,000
	ICF (current report)	**5,600,000**	**131,000**	**26,300**

In early 2023, NREL also conducted a national charging network study that projected the amount of LDV charging infrastructure and estimated hardware and installation costs [52]. The study contains many parallels to the project team's analysis and includes a summary of other recent 2030 U.S. charging infrastructure assessments. Table 3 shows a high-level overview of 2030 U.S. charging infrastructure assessment, including the results from this analysis, with the range in the number of LD PEVs, public access ports, and DCFC ports. In addition, Table 3 also compares the 2030 PEV stock and charging needs in California with the latest California AB 2127 Assessment, recently published by CEC [53]. The LDV fleet projection in this analysis is consistent with other assessments' methodologies for determining the future national LDV PEV population. The summary table also shows that the project team's estimate for the total number of public-access LDV ports agrees reasonably well with other studies, with some variances. Factors that may lead to different PEV and EVSE port projection include various baseline vehicle inventory models (e.g., the AB 2127 Assessment relies on CEC's own vehicle forecast model while this study uses MOVES3), ZEV penetration rates, residential charging access, ride-hailing market expansion, interregional trip needs, etc.

MDHD Charger Needs by Type and Power Level

The results for the total number of ports to serve MDHD PEV charging needs across the U.S. are shown in Figure 17. Illustrating the number of ports by type and power level for MDHD vehicle, reveals that MDHD PEVs are projected to have their charging needs met by a diverse portfolio of charging ports. Around 1.1 million depot charging ports and 161,000 public EVSE ports are anticipated to be needed by 2035. Approximately 13% of all MDHD PEV EVSE ports are projected to be publicly accessible DCFC facilities by 2035, including 7,000 megawatt charging systems (MCS).

Figure 17: Projected needs for MDHD EV chargers across the U.S.



The project team has compared the findings from the MDHD EVSE needs assessment with other studies, as shown in Table 4 [49, 54, 53]. While the estimated number of EVSE ports is comparable to others, discrepancies still exist between both vehicle and charger forecast. Due to the different technology penetrations and fleet turnover assumed in this study, the total on-road battery-electric truck populations are slightly different from other studies. In addition, the ratio of depot versus public charging access, as well as the preferred public charger power output, also contributes to the disparities observed in different studies. For instance, since the Ricardo study applied EPA's assumptions that almost all fleets would use depot-based overnight charging, the projected needs for public en-route charging are much smaller than the results presented in this study, which does not rely on EPA's assumptions.

Table 4. Summary of recent U.S. and California MDHD charging infrastructure assessments.

Year	Organization (Reference)	Est. MDHD BEVs	Est. Depot Ports	Est. Public Ports	
				DCFC	MCS
2030	Atlas Public Policy (McKenzie et. al 2021)	N/A (No detailed information on vehicle population was reported in the Atlas study)	470,000 -564,000	53,000 – 93,000	10,000 – 19,000
	ICF (current report)	**920,000**	**432,000**	**44,000**	**1,500**
	CEC AB 2127 (2023)	155,000	109,000	5,100	421
	ICF California (current report)	**183,000**	**76,000**	**8,500**	**172**
2032	Ricardo[35] (Kuhn et.al 2023)	1,500,000	1,500,000	7,500	
	ICF (current report)	**1,700,000**	**709,000**	**88,000**	**3,800**

Stations Buildout Timeline

As noted in the previous section, the need for PEV chargers will be driven by the growing demand for EVs across the country and by new regulations requiring vehicle markets to sell higher shares of ZEVs. As a rule of thumb, EV chargers with higher capacities, including both those used by the public and by fleets, typically have longer installation timelines. For example, Level 1 and 2 chargers in single family housing typically can be installed in a day, with many not even requiring an electrician. For houses without easy access to a 240 V plug, a typical homeowner might be able to contract an electrician and have a charger installed in a matter of weeks. As such, when the need for residential L2 charging arises, it is generally satisfied within days to weeks, so long as chargers remain readily available for purchase.

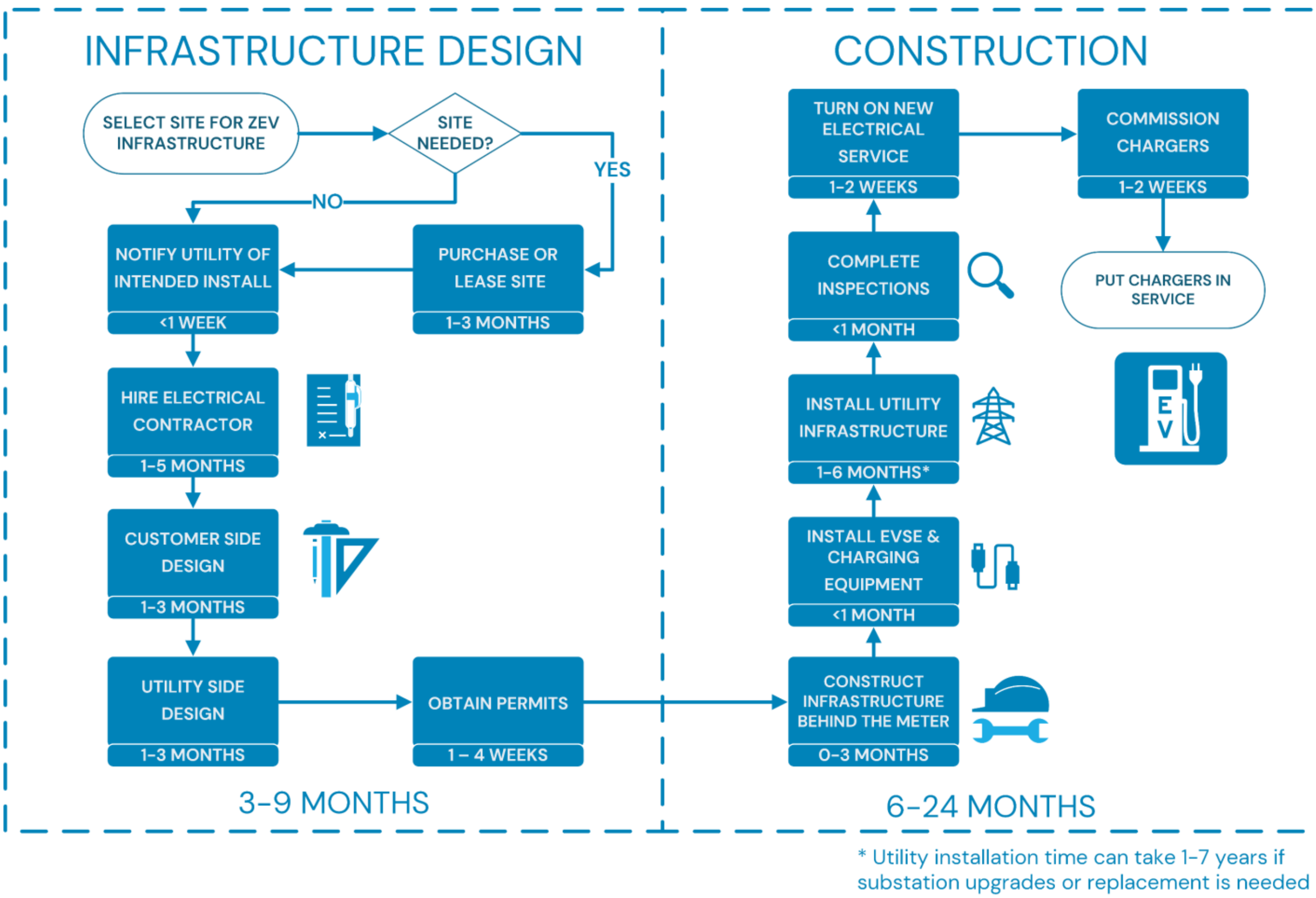
However, in the case of multifamily dwellings, retail and workplace charging, construction timelines are considerably longer. Instead of simply buying an EVSE to plug into an outlet, these types of properties often require utility upgrades and new services to handle the load and proper metering for the chargers [55]. Usually this involves adding a new connection to a nearby substation and installing an on-site transformer with a utility meter, and in the case of massive charging depots could require a new substation transformer. They also are likely to require site upgrades like new panels, new conduit, trenching and repaving to bring power from existing service locations to where cars will park. This often necessitates early cooperation with the local utility and hiring of a contractor to submit necessary drawings, get permits and install needed upgrades. This process is highlighted in Figure 18 below.

As illustrated by this timeline, large EV charger projects usually take 1-2 years from start to finish. Thus, in estimating when ZEV infrastructure projects need to start to meet increasing demand, we conservatively estimate that at least two years of lead time will be needed. As it currently stands, many fast charger projects have even longer lead times, but it is likely that improving experience from utilities and contractors will keep average lead times under a year [56, 57]. For example, Tesla cited a median time from “lease signed to open-to-public” of roughly 300 days, with significant variance to the high and low end [58].

[35] The Ricardo study is not publicly available.

According to existing utility programs, charger installations for HD depot and public charging will often have much longer installation times. The California investor-owned utilities (IOU) with the most experience in this sector quote timelines from 11-16 months [55, 59, 60]. Locations which only require L2 chargers may still require extensive design, utility work and heavy construction but are nonetheless expected to fall on the lower end of these estimates [61]. Locations such as public chargers with large numbers of DCFCs typically have timelines extending well above one year, up to several years depending on the utility side changes needed. For example, the 3 California IOUs stated in a presentation that when distribution capacity needs to be increased, this adds anywhere from 1-5 years to the project timeline [62]. Smaller upgrades like increases to conductor size or modification of underground conduit may take only 1-3 years, however larger upgrades like new distribution feeders or increases in substation capacity can take closer to 3-5 years. Very larger projects like megawatt charging for trucks may take even longer due to needs for subtransmission or new substations. This is backed up by comments from nationwide charging network EVgo & Electrify America to the state of California for their NEVI plan [63].

Figure 18: Overview of timeline for major charger installations highlights long lead time. [55, 59]



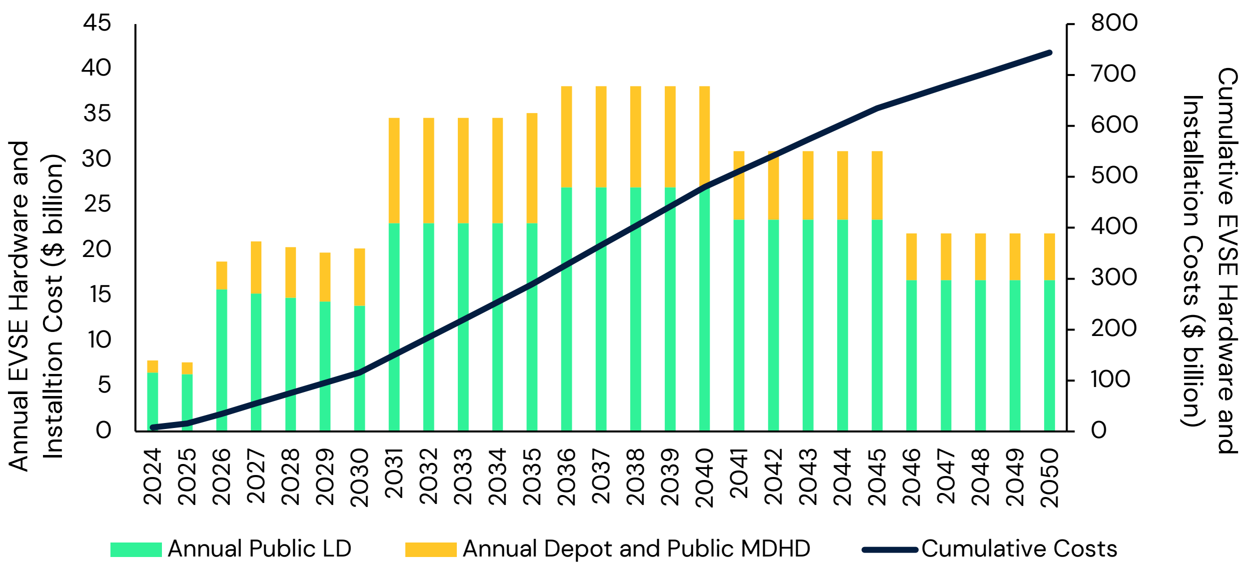
In the future, it might be expected that POUs and IOUs outside of California will gain the expertise needed to complete HD charger projects on similar timeframes. However, in the short term we estimate many projects will mirror the early experiences of California utilities – with a conservative timeline estimate of two years from conceptualization to operation. Notably, larger utilities with more staff and more experience will be best equipped to do this work, while smaller municipal utilities will impose greater costs and have longer timelines

[58]. Similarly, projects in rural areas will see longer timelines because they often lack high-capacity transmission and distribution equipment [58].

PEV Infrastructure Cost

The project team has estimated the total cost per year and cumulative cost over the time horizon for the purchase and installation costs of PEV charging infrastructure. These estimates are based on the total number of ports by state, type, and power level for both LDV and MDHD PEV segments, as well as the average total cost estimates for networked chargers outlined in Table 2. The project team assumes that public-access and depot charging sites will likely install dual port chargers, in accordance with the many utility, state, and federal programs that require dual-port and networked chargers to remain in compliance with PEV program guidelines and funding eligibility. Additionally, dual port chargers benefit from economies of scale, where the unit cost per charger is approximately 10% lower than that of single-port chargers. The project team has applied this 10% discount to reflect a charging network supported by dual-port charging stations. The project team also models a 3% cost reduction per year until 2030, in alignment with research from Atlas Policy on discounted charging hardware and installation costs [49]. Significantly, costs for infrastructure upgrades to support these chargers (transmission/distribution lines, transformers, substations, new generation) are not included in this study.

Figure 19. Estimated total LDV and MDHD EVSE hardware and installation costs by year



The LDV and MDHD PEV charging hardware and installation costs have been consolidated into one cost summary. The results for the projected annual cost to support new infrastructure buildout over the time horizon of this analysis are illustrated in Figure 19. Cumulative investment is also presented in the figure. It is important to note that while the results shown in the figure represent the total costs to install the necessary chargers to meet the demand of a certain year, the actual funding or required investment have to be secured at least two years ahead to accommodate for application, survey, permitting, and construction phases discussed in the previous section. The cumulative costs of deploying the number and types of ports suggested in this analysis amount to approximately $115 billion by 2030, $289 billion by 2035, $480 billion by 2040, and $744 billion by 2050. These are unprecedented figures to consider as the number of PEVs requiring charging access continues to grow.

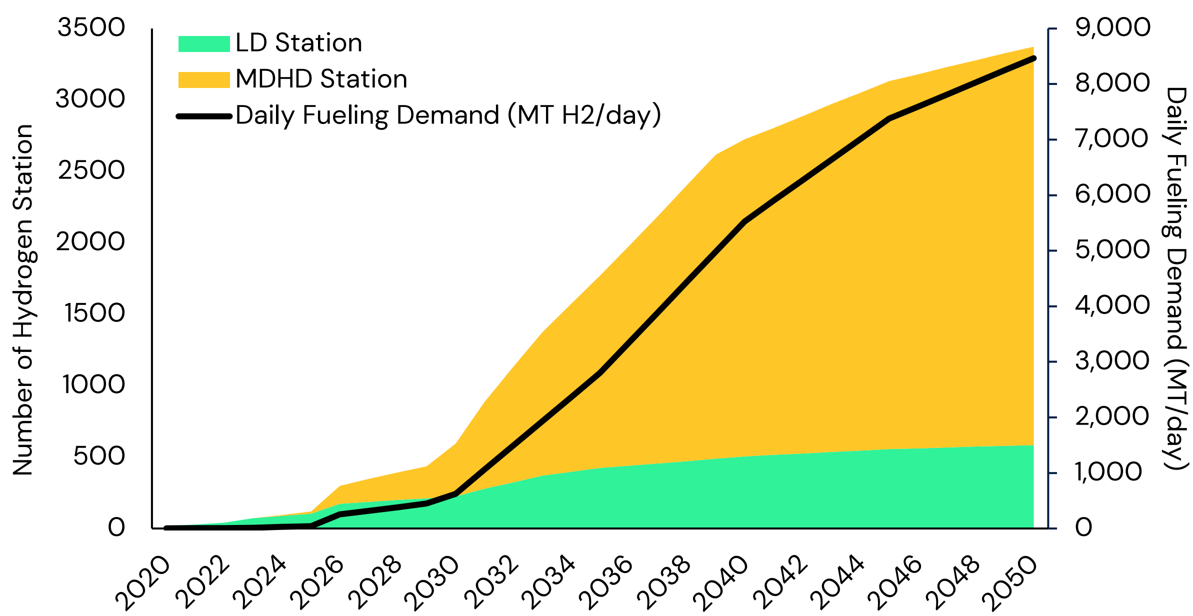
The project team has also compared the cost analysis to other studies. For instance, the NREL's No Place Like Home study estimated a $32-$55-billion cumulative national charging infrastructure investment by 2030 (not considering grid upgrade costs) [26]. For public passenger LDV charging infrastructure, the project team's analysis estimated a $77 billion cumulative investment from 2024 through 2030. Considering the differences in LDV public charging needs between the two studies as shown in Table 3, the discrepancies in costs are well expected. For MDHD charging infrastructure, the project team's analysis estimated a $143 billion cumulative investment between 2024 and 2040, which falls between the $100-$166-billion range published in the Atlas study [49].

Hydrogen Infrastructure

Stations by State, Type, Capacity

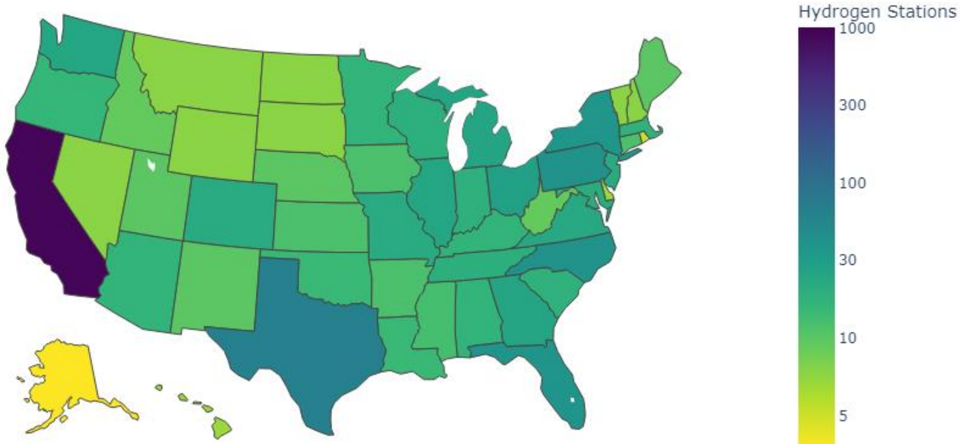
Based on the hydrogen station buildout approach and assumptions discussed in the previous section, approximately 600 stations will be needed to provide a hydrogen demand of 620 MT per day by 2030. 370 stations will be used to refuel MDHD trucks and buses, and 230 stations will be used for LD cars in California. This is further illustrated in Figure 20. By 2035, the number of stations will increase to almost 1,800 to meet the hydrogen demand of over 2,800 MT per day, with 1,350 stations serving MDHD, and over 400 stations dedicated to LD. By 2040, around 2,700 hydrogen stations are expected to meet the hydrogen demand of 5,500 MT per day, with approximately 2,200 to refuel MDHD trucks and buses, and 500 to refuel LDVs. By 2050, a total of 3,400 hydrogen stations will be needed across the country, 2,800 of which are dedicated MDHD stations, and 600 are for LDVs.

Figure 20. Total estimated hydrogen refueling stations and demand (MT/day).



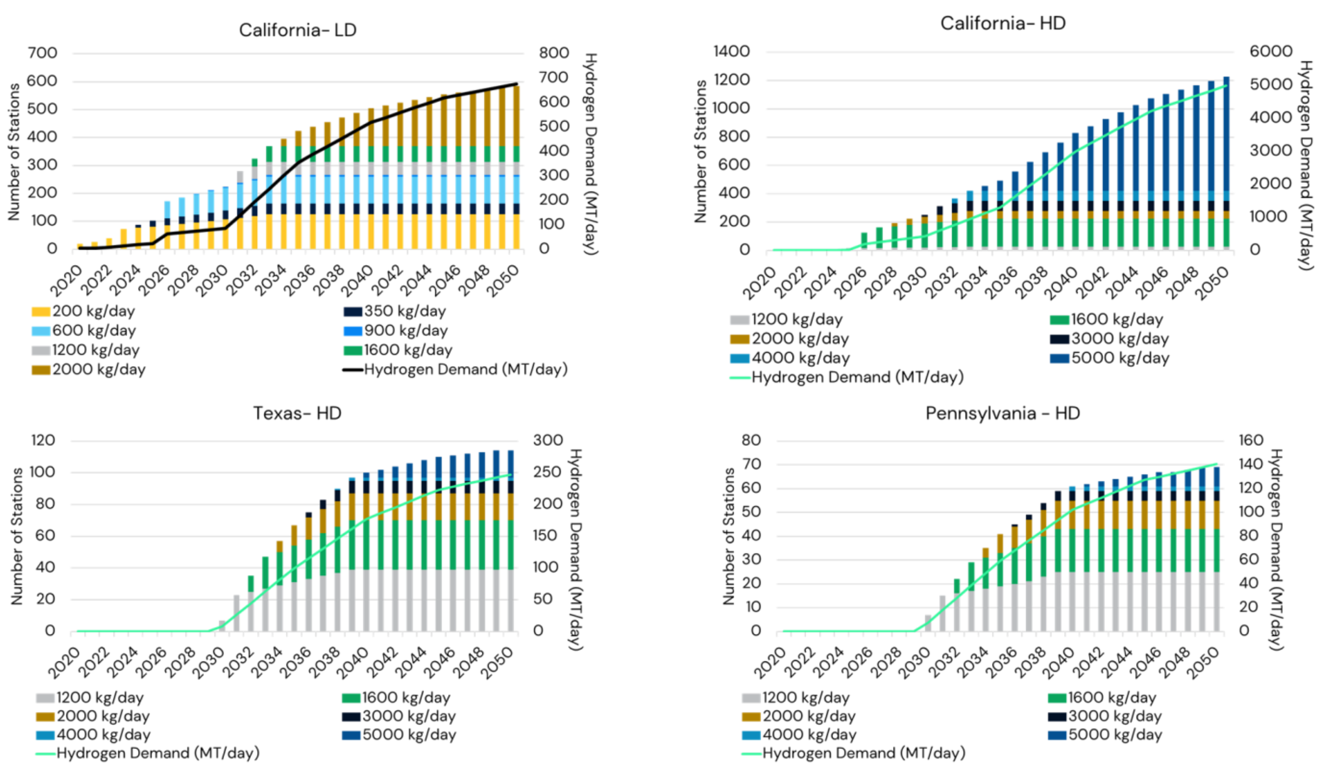
The largest demand for hydrogen on a daily basis and hydrogen infrastructure is expected in California, driven by the ACC II, ACT, ICT, and ACF regulations. Particularly in the early years, as shown in Figure 21, California will dominate hydrogen and infrastructure demand. By 2030, 80% of the total hydrogen stations are expected to be in California. This percentage drops to 52% by 2035, and further down to 49% by 2040 when fuel cell electric truck populations begin to surge in other states. Besides California, Texas will be the second leading state in terms of hydrogen demand and infrastructure needs, with 100 stations projected by 2040. Pennsylvania, North Carolina, Florida, and New York follow in this progression.

Figure 21. Estimated hydrogen refueling stations by state in 2035.



As shown in Figure 22, the results of hydrogen refueling station by capacity suggest that stations with lower capacity (e.g., 200 to 600 kg per day for LD and 1,200 to 1,600 kg per day for MDHD) will play significant roles in the early stages of FCEV development to achieve higher spatial coverage and station utilization. High-capacity hydrogen stations (e.g., 2,000 kg per day for LD and 5,000 kg per day for MDHD) will be commercially available in California by 2034, while other states may expect them by 2040 due to relatively lower demand.

Figure 22. Hydrogen refueling stations by capacity and demand (kg/day) in selected states (California, Texas, and Pennsylvania)



Stations Buildout Timeline

A typical process of hydrogen refueling station development, assuming there are no administrative holdups and other major hiccups, takes approximately two years. This timeline is reduced from the four-year-long process when the first retail stations were built in California [64]. The 2022 joint agency staff report on AB 8 [65] shows that although the COVID-19 pandemic slowed down many station development activities, station development over time could become faster and easier as station developers have incorporated lessons learned and local authorities are more familiar with hydrogen safety and usage as a transportation fuel. This trend should continue as local authorities streamline hydrogen stations permitting, more entities enter the supply chain, and economies of scale are achieved. It should also be noted that the buildout timeline could vary widely due to permitting from municipality and local agencies, public education and general awareness of hydrogen, property owner changing of demands or backing out, construction delay, hardware supply issues and others. California is taking steps to address these issues, but they may still be inevitable. Based on the development process of more than 50 stations, NREL's analysis showed that the sum of the average days for design, permitting, construction, and commission is around 2.0 years (746 days), whereas the average timeline for the 20% most recent projects goes up to 2.6 years (942 days) [66].

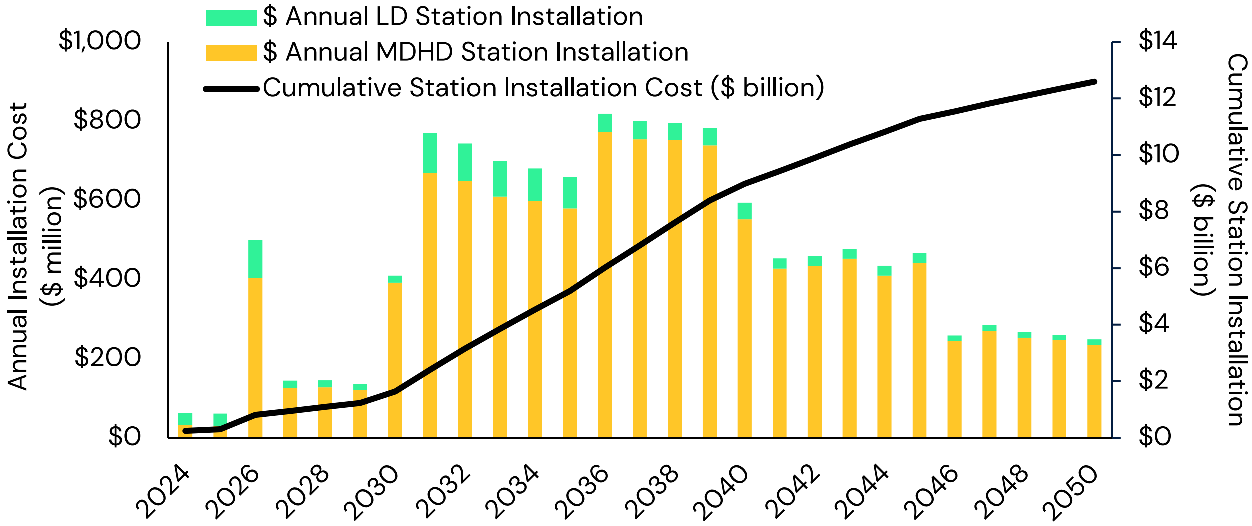
The process in general comprises five stages, as set out in California's Hydrogen Station Permitting Guidebook [64]:

1) *Pre-application outreach,* which allows developers to engage with a city or county's planning agency, understand local requirements, uncover potential issues upfront, and establish channels of communication and a permitting pathway;
2) *Planning review*, which is required by the permitting process to ensure that a proposed station fits within a community's zoning codes, General Plan, and overall aesthetics. Acquiring planning approval has been the most time-consuming step of the permitting process, which could last from one day to six months, while a much longer timeframe, such as greater than one year, could be expected based on station developers' experience;
3) *Building review*, which could occur in parallel with planning review in some jurisdictions. The review process is to ensure that the projects comply with applicable structural, mechanical, and electrical codes and local ordinances, with an estimated timeframe ranging from one day to six months;
4) *Construction,* which typically takes three to nine months to complete; and
5) *Commissioning*, which includes several steps of performance inspection and tests before official opening to the public and typically takes one to three months.

Hydrogen Infrastructure Cost

To meet the hydrogen refueling infrastructure demand outlined in the previous section, it is conservatively estimated that station development, along with its corresponding investment, needs to commence at least two years in advance or even longer. Figure 23 summarizes the capital cost estimates for hydrogen refueling station installation, which indicates that the first substantial investment peak should occur around 2024. This is primarily due to the rising hydrogen demand in LD FCEVs in California in 2026 to meet the ACC II requirements. The second, more substantial wave of investment comes after 2028, which is two years before the significant deployment of MDHD FCEVs due to the suite of CARB and EPA MDHD ZEV regulations or similar programs. To support the fueling capacity in 2035, the necessary investment in hydrogen refueling station installation is approximately $5.2 billion. By 2050, the total required investment increases to $12.6 billion. Of all the states, California accounts for approximately 62% of the total capital cost by 2035, while other states individually contribute less than three percent. Note that the current model only accounts for hydrogen station installation capital costs, while costs related to the distribution and delivery of hydrogen will be discussed later.

Figure 23. Estimated hydrogen refueling station capital cost.



Discussion and Conclusion

PEV Charging Outlook

The number of ports by type needed to address both LDV and MDHD PEV charging needs have been estimated between 2024 and 2050 (Figure 14-Figure 17) . The results show that different regions across the United States will soon face significant challenges to serve the growing number of PEVs with varied electricity demand. One of the most pressing challenges different regions will be facing is addressing the gap or disparity in the projected number of charging ports needed versus the number of charging ports that are actually available in a given year. This challenge is made more complex by the time and costs required for make-readiness measures prior to the installation of EVSE ports across the United States, given that both of those attributes are dependent on specific utility, site, and electrical infrastructure (e.g., transmission) characteristics.

Home Charging Access

Studies from NREL, CEC, and the International Council on Clean Transportation (ICCT) have all examined how home charging access may decrease over time as EV adoption expands, and how electrical access and parking behaviors may alter or improve such access [67, 68, 26]. In general, three gaps are mentioned in their residential charging access projections: an education gap, an investment gap, and a parking behavior gap.

Most early EV adopters live in detached homes where it is relatively easy to install a home charger, and have relied on low-cost, overnight, at-home charging for their primary charging needs [69]. Therefore, the current projected home charging access may be potentially biased due to the overrepresentation of these early adopters in survey responses. As the EV market expands, access to home charging is likely to decrease over time. According to the latest American Community Survey data, only 61.6% of U.S. households live in single-unit detached homes, and residents of attached homes (6%) and multi-unit homes (32.4%) are less likely to have access to parking options where charging infrastructure can be easily installed [70, 67]. As more EV owners without garages and residential charging access enter the market, the dependence on public charging will also increase in the future.

Recall that this analysis also assumes new residential-level investment is likely to occur for improving residential electrical access. Currently, a normal residential electrical upgrade to add dedicated circuits and outlets can cost $300-$1,000, and upgrading a panel to standard higher electric capacity can cost $1,000 - $2,500. The costs could escalate to $30,000 if service upgrades are needed [71]. Most existing federal, state, and local utility programs focus on directing charging infrastructure investments towards public-access destinations. While federal tax credits are available up to $600 for improving electrical panels to enable home charging, out-of-pocket payment may still be required given the current cost estimates [72].

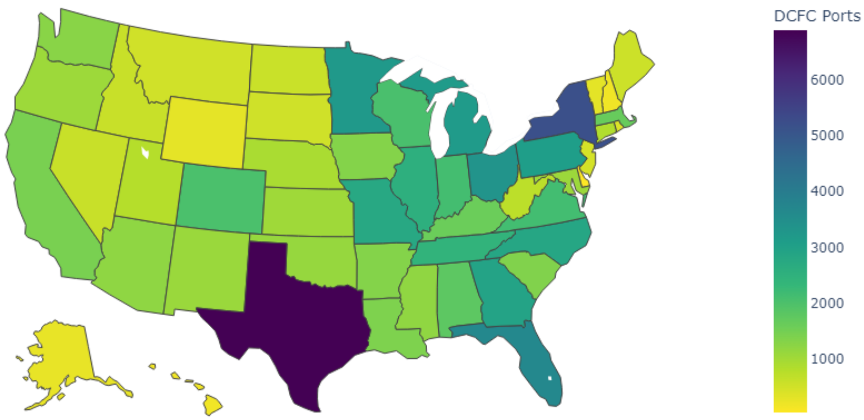
The disparity in housing conditions, investment for residential electrical access expansion, and lead time of grid upgrades and make-readiness measures significantly complicates the process to determine the support required to improve home charging access across the county. The limited residential charging access can also pose significant barriers for EV adoption in low- and moderate-income communities.

Public Charging Infrastructure

To provide some insight into the current charging needs gap, the number of DCFC ports estimated in this analysis by 2025 is compared against the AFDC's 2022 existing charger data by state. The regional gap in LDV DCFC ports by 2025 is illustrated in Figure 24. The median number of new public LDV DCFC needed before 2025 is 1,238, meaning that half of all regions across the United States will be required to install more than

1,200 LDV DCFC ports within the next two years to meet the projected charging needs. This figure serves as an illustration of potential gaps and challenges confronting near-term ZEV adoption. As emphasized throughout this analysis, improved home or workplace charging access for EV owners can also help to offset the lack of public infrastructure.

Figure 24. Number of new DCFC charging ports needed by 2025.

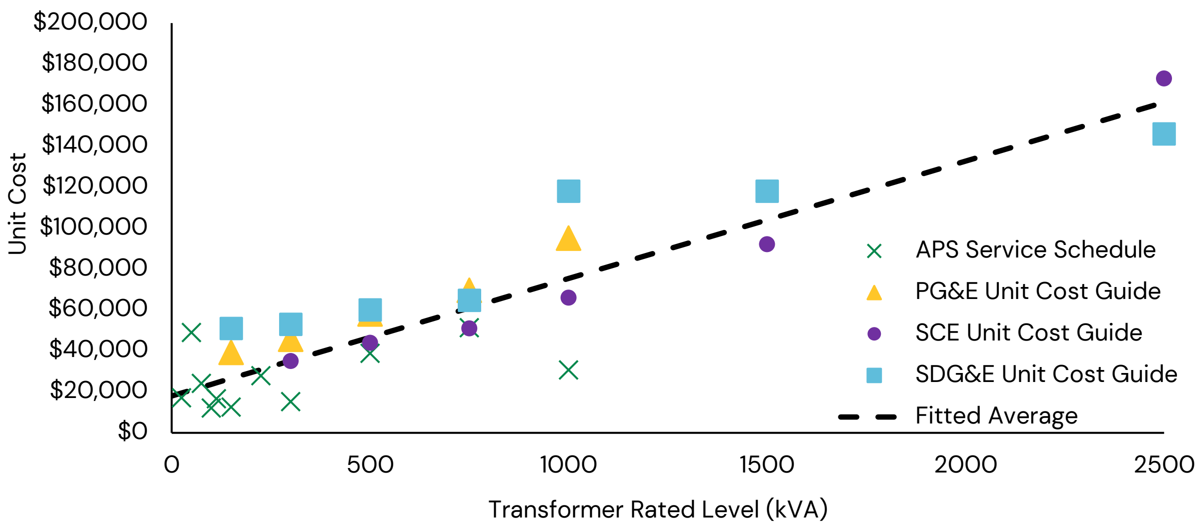


Access to public charging also remains a major concern for MDHD fleets. There are only a handful of public MDHD charging stations scattered across California, with the first public MDHD DCFC (250 kW) station commissioned in March 2023 close to a busy truck stop just north of the Otay Mesa Port of Entry [73]. The largest public MDHD station so far, developed by WattEV at the Port of Long Beach, features a total of 5 MW capacity for concurrent charging of 26 trucks at up to 360 kW each [74]. As the first state to gradually phase-in MDHD ZEVs, California will need almost 9,000 public DCFCs by 2030 to meet the charging demands with the projected fleet penetration, which is equivalent to building 100 stations every month between now and 2030, in California alone. As the rest of the country gradually starts MDHD electrification, the total public DCFCs needed nationally are 92,000 by 2032, and 161,000 by 2035. That is to say, on average, 200 new MDHD DCFC stations need to be built every week between now and 2032, and 450 new stations every week between 2032 and 2035. Considering the potential extended lead time due to transmission and submeter upgrades, planning for MDHD charging infrastructure has to start immediately. In addition, as small fleets and individual owner-operators enter the EV market, more dependence will be shifted towards public charging as compared to depot charging.

EVSE Site Development

While the analysis has examined the anticipated investment needed for EVSE hardware and installation, there are many more cost aspects that developers and planners need to consider when it comes to charging infrastructure development, including land acquisition, grid upgrades, and soft costs such as marketing, the cost of delays in permitting, etc. These costs may vary greatly given the scale and location of the development project and local utility programs and policies. The NREL's Distribution System Upgrade Unit Cost Database provides the most up-to-date unit cost information for different components that may be used for line extension, grid upgrades, and integration distributed energy resources (DER) systems onto distribution systems [75]. The data comes from a variety of utilities, photovoltaics developers, technology vendors, and published research reports, and includes components such as voltage regulators, capacitor banks, transformers, substation protection upgrades and control modifications.

Figure 25. Transformer unit cost as a function of rated kVA. [36]



As shown in Figure 25, the cost associated with utility upgrades can vary significantly with desired project capacities and the current electricity infrastructure must be evaluated before the costs of upgrades can be calculated. Depending on program policies, costs of grid upgrades and line extension sometimes can be split among site developers and utilities, while in other cases costs are entirely borne by developers alone [46]. Whether or not utilities can help to alleviate part of the financial burden, the utility-side infrastructure costs are still significant. For higher-powered MCS sites, the cost to include a dedicated customer substation and subtransmission interconnection can be up to $10 million [76].

There are federal and state government regulations and funding programs that can help address the site development cost barriers in charging infrastructure development. This collection of programs is not meant to be an exhaustive list, but can serve as a starting point for developers, site owners, and other stakeholders to consider the support available to bridge charging infrastructure disparities. At the federal level, several laws and incentives offer support for developers and alternative fuel producers in the charging infrastructure landscape.

One such is the Congestion Mitigation and Air Quality (CMAQ) Improvement Program, which has been extended by the BIL. The CMAQ program provides funding to state DOTs for projects and programs that help meet the requirements of the Clean Air Act, including electric vehicles and infrastructure. Funding for EV and charging infrastructure projects is available through CMAQ, with an average $2.6 billion per year between 2022 through 2026 expected to be dispersed. Each state has an individual CMAQ funding apportionment, calculated based on a ratio specified in the BIL. Under 23 U.S. Code § 151, the CMAQ program also prioritizes funding for projects or programs to establish electric vehicle charging stations along fuel corridors with the possibility to redesignate for rural and inter-city corridors [77, 78]. For example, the Minnesota DOT's transportation advisory board oversees the Transportation Improvement Plan (TIP), an inventory of all proposed federally-funded transportation projects within the metropolitan planning area, including highway, transit, bike and pedestrian improvements. The most recent TIP program stipulated $31 million in funding for electric bus infrastructure projects between 2023 through 2026. As of April 2021, a total of $49.1 billion use in

[36] Information based on Arizona Public Service (APS) and three California utilities: Southern California Edison (SCE), Pacific Gas and Electric (PG&E), and San Diego Gas & Electric (SDG&E).

federal grant funding has already been announced to support EV charging infrastructure deployment across a total of 15 specific programs, including the CMAQ and TIP programs [79].

Similarly, the BIL's NEVI Formula program is slated to provide $5 billion in funding to states for the development of charging infrastructure along alternative fuel corridors. The NEVI formula program prioritizes states to develop networks of EV charging infrastructure within acceptable ranges of alternative fuel corridors or other publicly accessible locations, which will likely be fulfilled by DCFC equipment. In addition to NEVI, BIL has also allocated $2.5 billion over five years for the Charging and Fueling Infrastructure (CFI) Discretionary Grant Program to strategically deploy publicly accessible EV charging infrastructure along designated Alternative Fuel Corridors (AFCs). The U.S. DOE has also awarded $7.4 million to seven projects to develop MDHD charging and hydrogen corridor infrastructure plans that will benefit millions of drivers across 23 states [80]. These projects would also help improve air quality in underserved areas of major American cities, including New York, Los Angeles, Houston, Chicago, San Francisco, Oakland, and Salt Lake City.

Other federal programs, such as the Inflation Reduction Act, have modified tax credits available for the purchase of charging infrastructure. For example, the Alternative Fuel Infrastructure Tax Credit can provide a tax credit of 30% of the cost for EV charging station. The Alternative Fuel Infrastructure Tax Credit focuses on rural and disadvantaged areas, and consumers within these regions that purchase qualified residential charging equipment between January 1, 2023, and December 31, 2032, may receive a tax credit of up to $1,000 [81]. A full list of federal programs can be found in Appendix IV: Available Federal Funding and Incentive Programs.

As discussed above, federal laws and funding programs tend to take a top-down approach to support national charging and fueling infrastructure deployment, allowing states to manage allocated funds. There are also several state and utility programs that help drive investments to more localized levels. These more localized investments also provide funding opportunities for capital costs and installation of hardware. Some state and utility programs also help streamline permitting, siting, and make-readiness processes that often contribute to reduced buildout times and soft costs—these streamlined permitting process practices can be applied in other authority having jurisdictions where appropriate. For example, California's AB 1236 (Chiu, 2015)[37], also known as the California permit streamlining law, sets statewide rules that streamline local government permitting processes for charging stations. In some other states, state and public agencies have also provided guidance to local jurisdictions to accelerate such processes. For example, the Building Standards and Codes of New York State issued a technical bulletin with codes for charging stations in new and existing facilities, and the State's energy research and development authorities have also published EV Charging Station Permitting Resources to guide municipalities [82, 83]. To address the concerns of the lead time between submitting siting application to energizing chargers, the California Public Utilities Commission (CPUC) has also issued Resolution E-5247 in December 2022, which establishes an interim 125-business day average service energization timeline for projects taking service under the EV Infrastructure Rules [84]. While the Resolution excludes projects that must go through Rule 15 for distribution upgrades, projects above two MWs, and projects that require substation upgrades, it certainly serves as a starting point for public agencies to take the lead and expedite the overall site development processes.

There are also a number of utility make-ready programs that typically cover the costs associated with infrastructure development up to the point of EVSE. This includes expenses related to transformer and panel upgrades, wiring, conduit installation, and labor. The primary goal of these programs is to alleviate the financial

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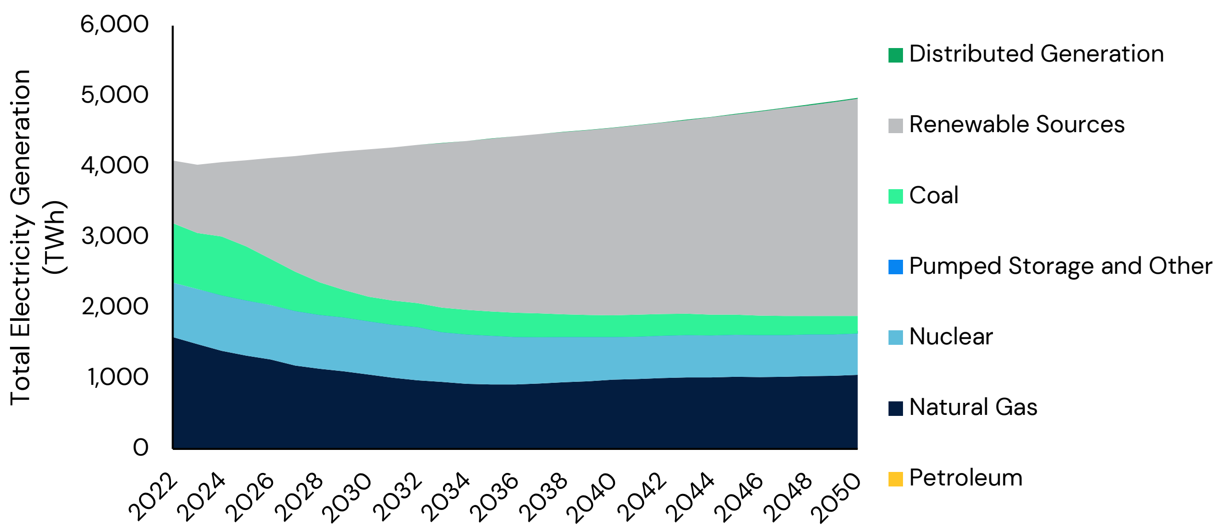
[37] CA Govt Code § 65850.7 (Chiu, 2015)

burden of installing EV charging infrastructure and subsidizing a portion of the installation costs to make it financially more feasible for property owners to host charging stations. An example of these programs is the Southern California Edison (SCE) Charge Ready Transport (CRT) program, which provides site owners and developers with better PEV time-of-use rates to reduce electricity costs within their jurisdiction. Programs such as SCE's CRT can help fleet owners by recommending specific PEV replacement recommendations and utility-approved networked charging infrastructure. Additionally, SCE expedites the site assessment and can offer different solutions based on localized zoning and codes. Other states with similar utility and make-ready programs, such as New York and its NY EV Make-Ready Program, make use of a joint-utilities commission to support charging infrastructure projects in disadvantaged communities, particularly along multi-family dwellings and destination properties. These state and utility programs have been highly successful in recent years to distribute funding and facilitate grid upgrade and make-readiness services, which creates huge cost savings opportunities for developers and site owners.

Electricity Generation and Demand

In order to more fully understand the impact of transportation electrification on energy demand, the potential electricity demand that is expected to arise from the transition to PEVs has also been compared against the projected electricity and supply from Energy Information Administration's (EIA) 2023 Annual Energy Outlook (AEO) Reference Case [85]. The EIA forecast considers the impacts of existing legislation, technological advancements, and evolving energy needs on the power grid, including some on-road transportation electrification. As shown in Figure 26, the EIA 2023 forecast estimates future power generation and consumption, considering various energy sources such as coal, natural gas, nuclear, and renewables.[38]

Figure 26. EIA 2023 AEO forecasted total power sector electricity generation by fuel type.



According to project team's assessment, the EIA's assumed transportation electrification rate is significantly lower than what is modeled in this analysis, as illustrated in Figure 27. Therefore, additional generation above the EIA forecast for total electricity generation will be needed to support the modeled rise in PEVs (represented by the Additional Transportation category). While the current transportation sector only accounts for 1% of the total electricity sales, with the upcoming PEV surge, this value can increase up to 14%

[38] Includes conventional hydroelectric, geothermal, wood, wood waste, biogenic municipal waste, landfill gas, other biomass, solar, and wind power in the electric power sector.

by 2035, and 23% by 2050. In order to estimate the total needed generation with the projected transportation demand, the project team applied a 7% adjustment factor to account for the efficiency loss in the transmission and distribution systems based on current data [86], as represented by the dotted black line. Comparing the original EIA generation forecast (Figure 26) and the new projection (Figure 27), roughly 690 TWh additional generation will be needed from the power sector by 2035 and 1,300 TWh by 2050. It is also important to keep in mind that the actual incremental need for generation will be impacted by many other factors, including electrification activities in other sectors, such as residential and commercial buildings, which could deplete any excess capacity currently in the system, while factors such as distributed generation or additional managed charging could reduce the need for additional centralized generating resources.

Figure 27. Impact of transportation electrification on overall electricity sales and generation.

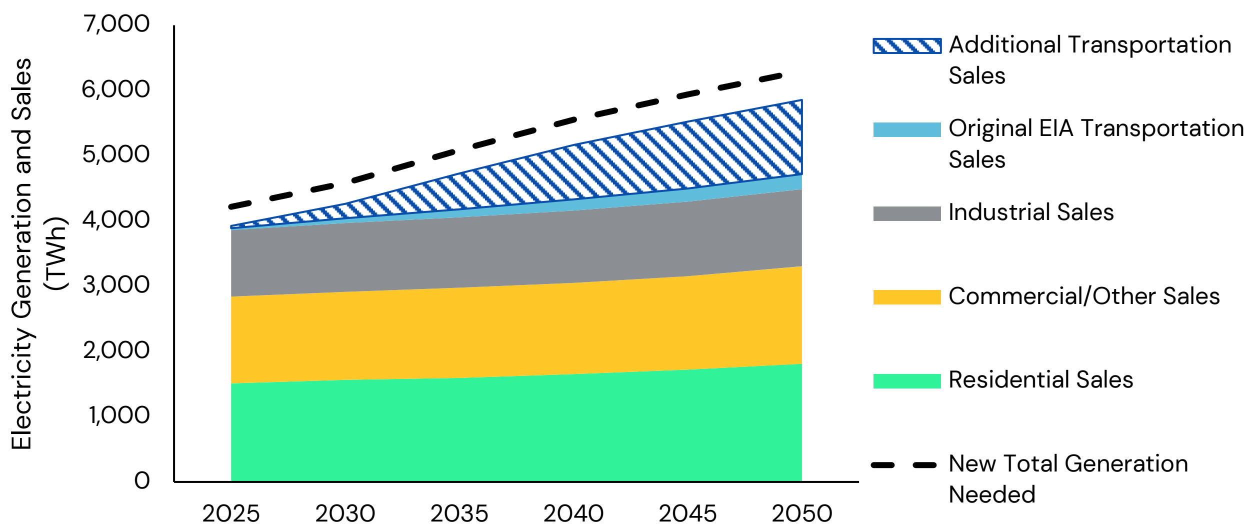
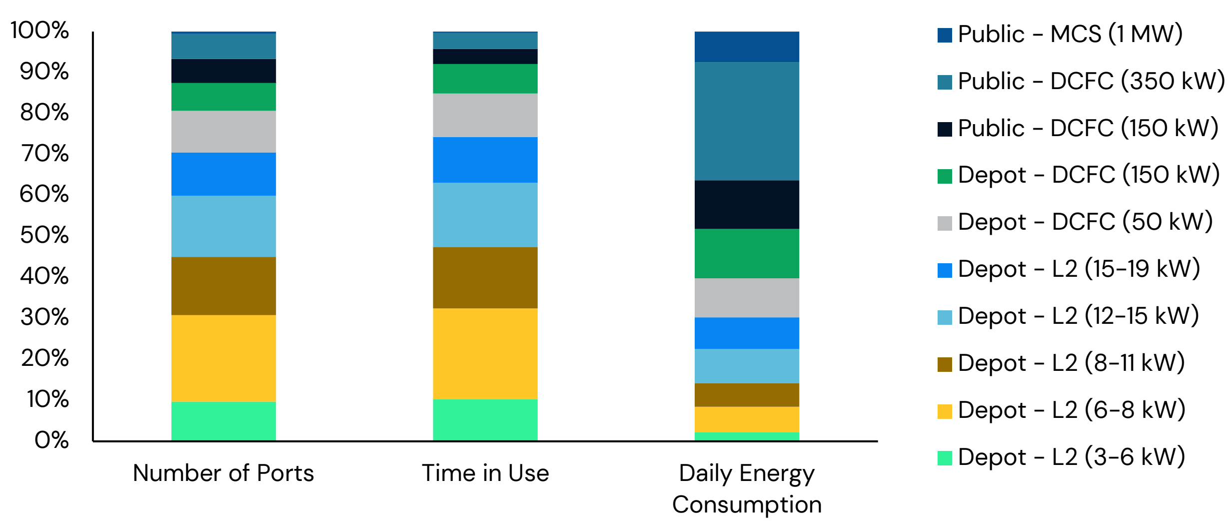


Figure 28. MDHD EVSE ports, daily charging time, and energy demands by charger type in 2035.



While Figure 27 demonstrates the impact of transportation electrification on the power sector electricity generation and sales, it is also noteworthy that the transition to EV will also affect the grid capacity based on their time-of-use. For instance, if charging demands for PEVs occur alongside existing system peaks in other demands for electricity, they could significantly increase the peak demands and necessary generation capacity, which adds requirements to the type of generating resources that would need to be developed to meet that aggregate demand. To meet higher peak demand, more dispatchable resources would be needed (e.g., renewables plus storage, or natural gas). This may occur if charging is not managed across a region, but rather multiple vehicles all charge at once. For example, as shown in Figure 28, despite the number of ports and total usage time for public MDHD chargers being minimal compared to depot chargers, they represent over 48% of the total daily charging demands for MDHDs. If MDHD en-route charging consistently occurs during peak demand hours in the daytime, it could potentially impose a significant strain on the power grid.

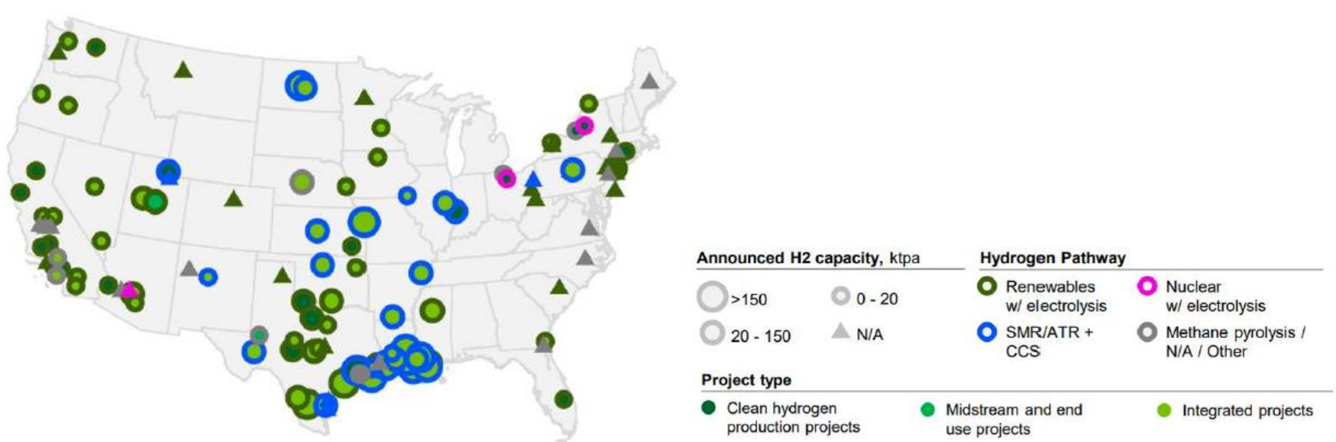
FCEV Refueling Outlook

As shown in the infrastructure modeling section, the biggest gap of hydrogen infrastructure is the refueling station installation, simply because of the development of refueling stations is still in a relatively early stage with over 100 stations –open or planned – in California. Further up the supply chain, the infrastructure to support hydrogen production and its delivery and distribution is also in a very early state. High price at the pump is another gap that needs to be bridged through economies of scale within the hydrogen supply chain, technology improvement in hydrogen production, and an increase in both hydrogen demand and hydrogen refueling station utilization.

Hydrogen Production

Funding and incentives in hydrogen production will help to bridge the gap between the increasing demand for hydrogen as a transportation fuel and currently limited clean production. The 2021 Bipartisan Infrastructure Law, or BIL, authorizes and appropriates $8.0 billion to support the development of regional clean hydrogen hubs (H2Hubs), which are networks of clean hydrogen producers and consumers and include a connective infrastructure within a region. In December 2022, the DOE decided on a shortlist of 33 public-private teams from an original list of 79 applicants for up to $7 billion to develop hydrogen hubs covering all sectors, not just transportation [87, 88]. It is largely focused on production, but funds could also be used for refueling infrastructure if decided by the hub awardee.

Figure 29. Current publicly announced clean hydrogen production projects as of December 2022 [89]



As shown in Figure 29, the U.S National Clean Hydrogen Strategy and Roadmap [89] demonstrated that over 100 clean hydrogen production projects with a total of approximately 12 MMT per year in production capacity have been announced across the U.S with more than $15 billion of potential investment. However, only around

1.5 MMT of the announced capacity has reached a final investment decision, largely owing to a lack of contracted offtake. The announced projects are also clustered in several states with rich solar and wind resources or with carbon capture and sequestration (CCS) potential. Due to limited midstream infrastructure, the announced hydrogen production projects to date have focused on offtakers that can be co-located with production. It calls for the development of midstream infrastructure for hydrogen delivery and distribution.

Refueling Station Operation - Hydrogen Delivery and Distribution

Current hydrogen delivery systems for transportation use include gaseous hydrogen delivery, liquid hydrogen delivery, and on-site hydrogen production and storage [90]. Gaseous hydrogen delivery entails compressing hydrogen prior to transport, which is then delivered by truck or pipeline to the customer. Among the California stations in operation, more than half of the hydrogen refueling stations have pursued compressed gaseous trucking, one-third use a liquid distribution network, and the rest rely on either on-site production or pipeline. [91]

- **Gaseous trucking:** H_2 gas is compressed at ambient temperature to 300 – 500 bar. Tube trailers for compressed hydrogen typically can accommodate 200-1,000 kg of hydrogen, but federal restrictions on pressure and gross weight limit the carrying capacity to about 280 kg H_2. This delivery mode is ideal for short distances (less than 150 – 200 miles) and small volumes due to lower capital costs for compressors and tube trailers as compared to liquid and pipeline transport. As distribution distances increase, the higher transportation capacities of liquefied hydrogen trailers become economically favorable. The estimated cost of gaseous trucking including compression would be expected to range from $0.9 to $1.9 per kg by 2030 [92].
- **Liquid trucking***:* Liquid hydrogen delivery converts hydrogen to liquid form where it must be cooled to below -423 degrees Fahrenheit using a process called cryogenic liquefaction. It is then transported as a liquid in super-insulated, cryogenic tanker trucks to its end destination. Before dispensing the hydrogen, it is vaporized to a high-pressure gaseous product. This mode is ideal for larger volumes where pipelines are not feasible and for longer distances to minimize the number of trips and drive labor cost. It has higher capex costs than gaseous trucking, driven by the higher installation cost of a liquefier, but still lower than building hydrogen pipeline. It also suffers from boil-off that can result in losses in delivered hydrogen capacity. DOE estimated the levelized cost of liquid hydrogen trucking including liquefaction could range from $2.7 to $3.2 per kg by 2030 [92], while other studies show a reduction from $2 per kg in 2020 to $1.3 per kg in 2030 [93].
- **Dedicated Gaseous Hydrogen Pipeline:** Approximately 1,600 miles of dedicated hydrogen pipelines exist in the U.S., all of which are owned by merchant hydrogen producers. These pipelines are predominantly located in areas where substantial hydrogen consumers, such as petroleum refineries and chemical plants, are concentrated. The Gulf Coast region is a prime example. Pipeline transportation presents the lowest levelized cost at high volumes (50+ TPD) and long distances due to its minimal operational expenses. However, this method is not typically used for lower volumes. The cost could be below $1 per kg [94], with a range as low as $0.2 to $0.5 per kg [92]. Establishing a new hydrogen distribution pipeline network entails substantial investment spread across several years. Nevertheless, it can prove to be cost-effective for large volume cases. The process requires permit approval and considerable upfront capital expenditure costs, ranging from $2 to $10 million per inch-mile for pipelines with diameters of 6 to 14 inches. It's important to note that the conversion of existing natural gas pipelines for the transportation of pure hydrogen may necessitate significant modifications [95]. But repurposing natural gas pipelines or blending hydrogen into

natural gas pipelines could be a more cost-effective alternatives to pipeline hydrogen. The capital cost to repurpose natural gas pipeline could reduce by as much as 60%, comparing to building a new hydrogen pipeline [96].

- **Hydrogen/Natural Gas Blended Pipeline***:* It may be possible to blend up to ~20% hydrogen by volume into natural gas pipelines for use in the power and heating sectors, which enable end-use equipment that can take a blend fuel. A study by UC Riverside assessed the operational and safety concerns associated with hydrogen blending into the existing natural gas pipeline system at various percentages [97]. Due to high hydrogen purity requirements for FCEVs, hydrogen would need to be separated from natural gas at or near the point of end use. This delivery mode could add cost to the total cost of ownership to FCEVs, as separation of hydrogen from natural gas can be costly. The primary types of hydrogen separation technologies include pressure swing adsorption (PSA), cryogenic distillation, membranes, and electrochemical hydrogen separation. Studies have found that recovery of hydrogen at concentrations below 20% by volume are likely to be economically unviable [98]. The costs to separate hydrogen from the blends also depend on blending volume, recovery rate, and pipeline pressure. A study by the National Grid in 2020 identified minimum specific cost of hydrogen recovery for 20% by volume feed blends in the range of $1.4 – $1.8 per kg (£1.0 - £1.6 per kg) for the membrane-PSA system and $1.0 - $1.6 per kg (£0.9 - £1.4 per kg)[39] for the cryogenic process when minimum compression costs are accrued because the downstream natural gas systems operate at low pressure. When recompression is required, the cost could increase by 80% [98]. An NREL review in 2013 estimated cost of hydrogen extraction by PSA at a pressure-reduction facility could range from $0.3-$1.3 per kg for a 10% hydrogen blend, and lower for a higher hydrogen blend; when recompression of separated natural gas is considered, the extraction cost could be $3.3 - $8.3 per kg for a 10% hydrogen blend [99]. Note that PSA systems can yield high-purity hydrogen around 98%–99.999%, with hydrogen recovery rates between 60% and 90%, while cryogenic hydrogen separation is capable of producing high-purity hydrogen (98%–99%) at high pressure with recovery rates typically between 80%–90% and up to 95%.

  A Hydrogen Internal Combustion Engine (H2ICE), which has advantages in very large vehicles such as construction and agriculture applications with significant vibration and dust, could be tolerant to contaminants and make use of hydrogen from natural gas blended pipelines. Studies have predicted that FCEVs may have a total cost of ownership advantage over H2ICE, but it could be a close call [100, 101]. However, unlike FCEVs with zero tailpipe emissions, H2ICE still emits NOx, potentially N_2O, and minor GHG [100]. As part of the agreement between CARB and the Truck and Engine Manufacturers Association (EMA) released in July 2023, a public workshop will be held to discuss the appropriate role of H2ICE towards meeting the requirements of the ACT and ACF regulations [102].

- **On-site production:** On-site production can reduce transportation and distribution costs but increase production costs due to the high capital costs of constructing production facilities. On-site production can be particularly suitable for more remote locations where regular delivery of hydrogen is not feasible, with one example being fuel cell electric buses deployed at Sunline Transit in the Coachella Valley.

[39] Considering an average exchange rate of 1.142 from EUR to USD in 2020.

Hydrogen distribution infrastructure will be essential to unlock use cases for hydrogen where production/offtake are not co-located. Pipelines could be critical anchors to this system, as they provide low-cost distribution and storage at scale. With the expected cost reduction in clean hydrogen production, the delivery and distribution cost could represent more than half of the delivered cost of hydrogen. By 2030, half of the necessary clean hydrogen investment dollars are expected to be for midstream and end-use infrastructure ($45 to $130 billion) [92].

Hydrogen Station Fueling Prices at the Pump

The interplay of the hydrogen supply chain, including production, delivery, distribution and refueling station installation, will eventually be reflected in hydrogen prices at the pump. The current price of hydrogen ranges from approximately $13 to $16 per kg, with some cases as high as $19 per kg [65]. Due to the increase in diesel prices in 2022, hydrogen delivery cost also increased, which resulted in even higher retail prices for hydrogen. In addition, due to an increase in feedstock costs and significant reduction in the value of the Low Carbon Fuel Standard (LCFS) credits, there was also a surge in retail hydrogen prices at the beginning of 2023 [103, 104].

The retail price of hydrogen is structured much like that of other transportation fuels. It encompasses the cost of hydrogen production, its delivery and transport to the refueling station, recovery of the station's capital costs, operational and maintenance expenses, marketing costs, and any relevant taxes. The retail price of hydrogen is anticipated to decrease with the expansion of economies of scale, advancements in technology, and growth in utilization and demand.

- **Economy of scale of hydrogen supply chain***:* Scaling up hydrogen production is a significant factor to reduce production costs. Expanding distribution channels and the number of fueling stations can likewise reduce retail prices of hydrogen. Provided there is an expanded network and substantial hydrogen volumes, pipelines can serve as viable and cost-effective solutions to hydrogen delivery. Economies of scale in operating hydrogen stations enhance the density of the hydrogen station network, promote higher utilization, and lower costs across the hydrogen supply chain. This, in turn, eventually drives down the unit cost of hydrogen at the pump. Therefore, expedited development of the hydrogen station network, characterized by high capacity and demand, would lead to significant cost reduction across the network.
- **Technology improvement in hydrogen production***:* Several studies have examined the costs of green hydrogen from electrolysis [51, 105]. Based on these publications, green hydrogen production costs will likely continue to decrease, because of enhanced efficiency, increased availability of cheap and renewable electricity, improved electrolysis performance in terms of both efficiency and lifetime. In addition, decreased capital costs associated with increased production scale, less expensive system components, and advanced manufacturing technologies can also contribute to cost reductions.
- **Increase of utilization and demand***:* With California leading the way, the ZEV requirements will continue expanding FCEV fleets in the U.S., especially in the application of long-haul trucks and transit buses, which have higher hydrogen demand per vehicle. For instance, a typical FCEV passenger vehicle utilizes 1 kg per day of hydrogen, while a fuel cell transit bus with a daily operation of 200 miles consumes more than 20 kg of hydrogen per day. Transit agencies, such as the AC Transit, the Sunline Transit, and the Orange County Transportation Authority, as well as trucking fleets, such as Port of Long Beach and Port of Oakland, are considering FCEV as a competitive option to meet CARB's ZEV requirements [106, 107, 108]. More FCEVs on-road would increase end use needs, increase the utilization of stations, and thus reduce the per-unit hydrogen price.

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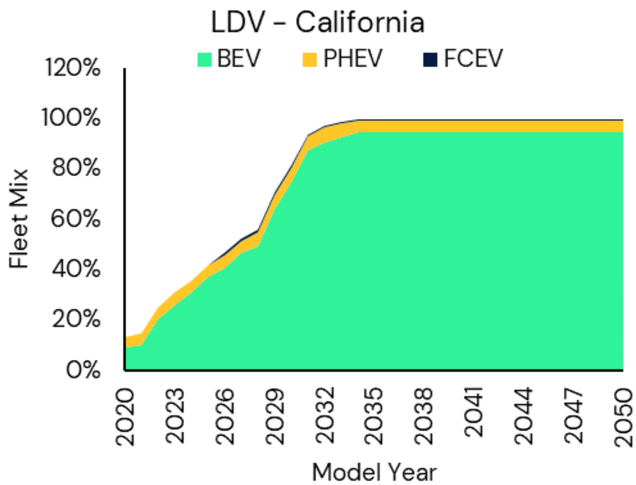
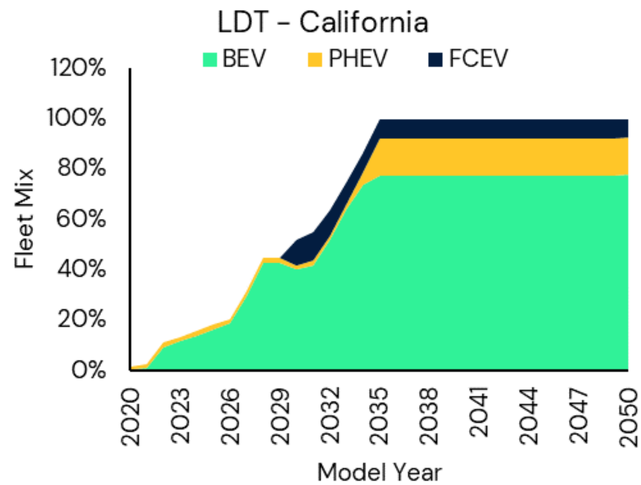
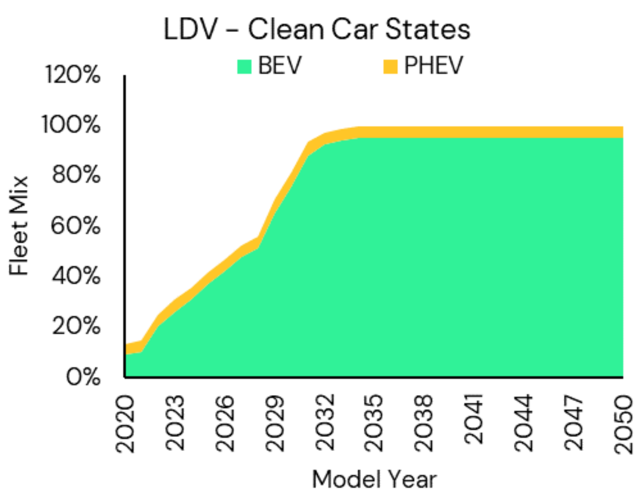
Appendix I: Sales Curves

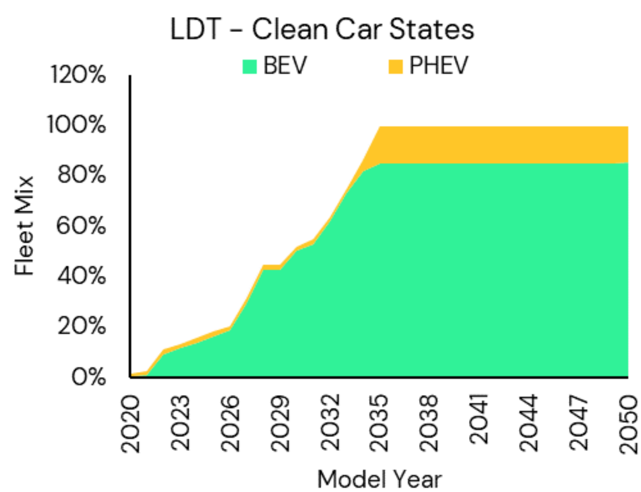
California LD sales curves are consistent with the Advanced Clean Cars II (ACCII) ZEV targets and rule-making assumptions for technology mix. Note that the sales fractions presented here are solely dependent on the regulatory requirements and have not been cross-checked with the real-world EV sales data.



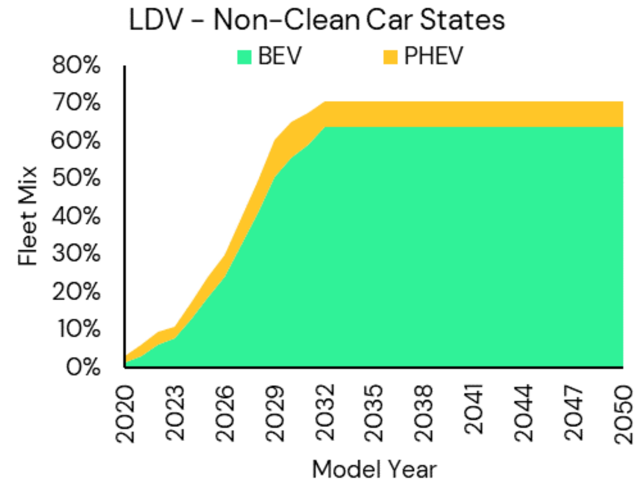


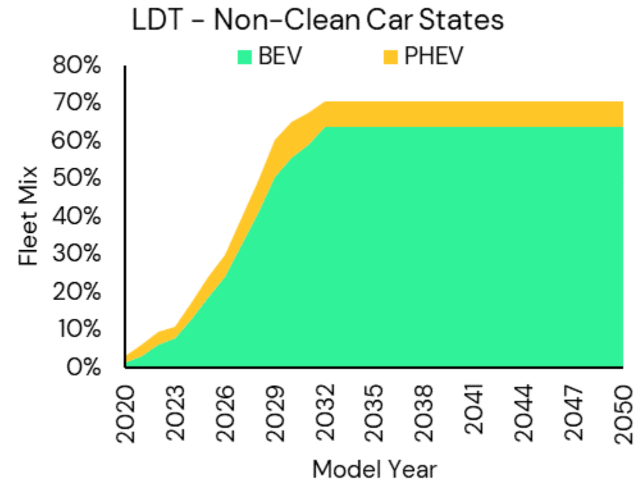
States that follow LD Scenario II: Clean Car States include CO, CT, MA, MD, ME, MN, NJ, NM, NV, NY, OR, RI, VA, VT, and WA. ZEV goals are in line with California ACCII Regulation that all new passenger cars, trucks, and SUVs sold in these states will be zero-emissions by 2035. However, no FCEV penetration was assumed for these states.



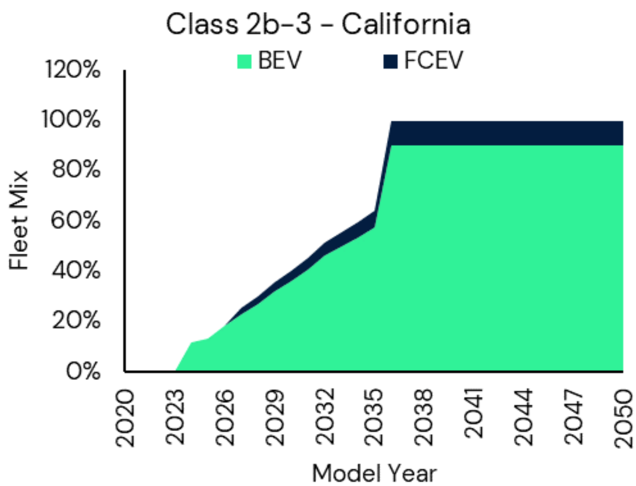


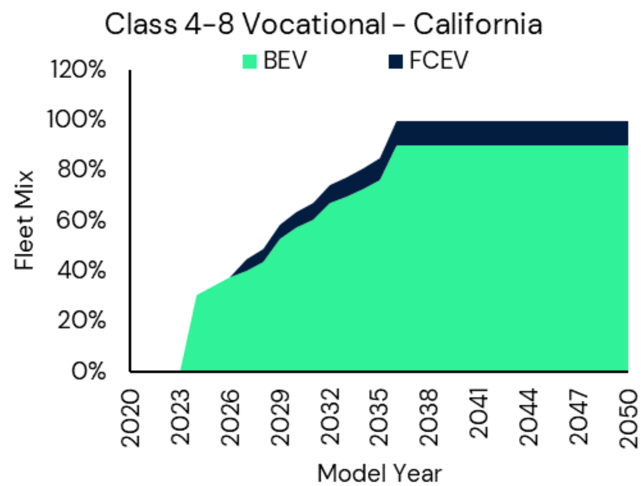
For non-Clean Car States, LD ZEV goals are in line with the proposed EPA standards for MY2027 and later that fleet average BEV penetration will reach 67% by 2032. Since the EPA proposed rule only considered BEV penetration, here we adjust technology mix to account for PHEV using California ACC II assumptions. Note that for states that do not need to meet 100% ZEV sales, shares of PHEV might be smaller than what ACCII assumed. In addition, ZEV sales might slowly ramp up between 2021 and 2026 despite no regulatory requirement until 2027.

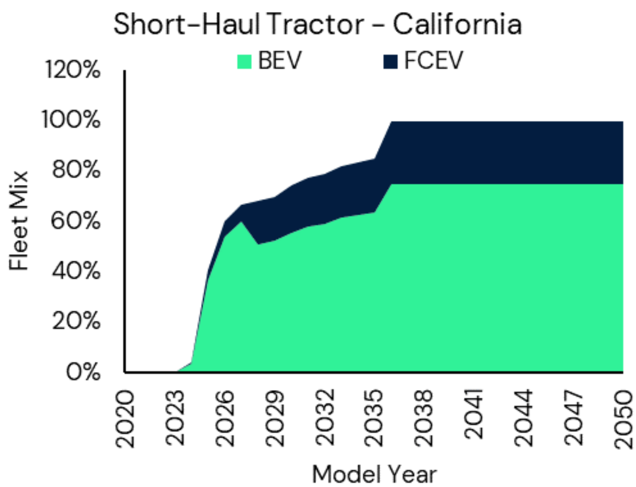


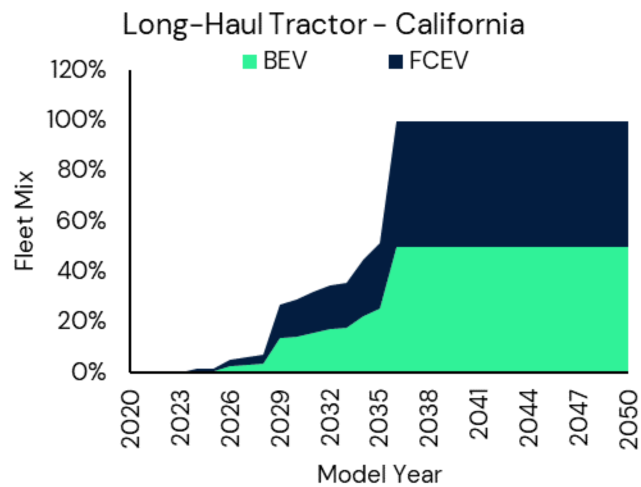


California is so far the only state that has set 100% sales target for medium- and heavy-duty truck sales through the recently adopted Advanced Clean Fleets (ACF) regulation. In addition, ACF has also established fleet purchase requirement that goes above and beyond the manufacturer sales targets that were originally set by the Advanced Clean Trucks regulation. Technology mix was kept consistent with ACF rule making assumptions as well. Note that ACF sales curves are not as smooth as others because of the non-linear fleet purchase requirements of the regulation.

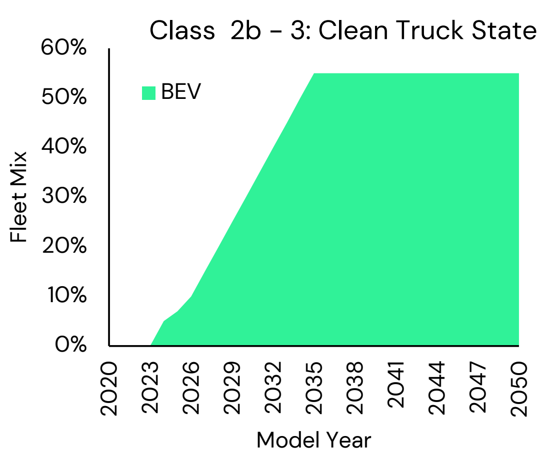


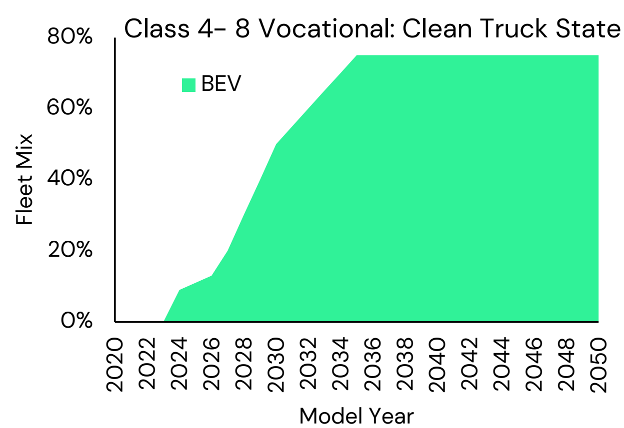


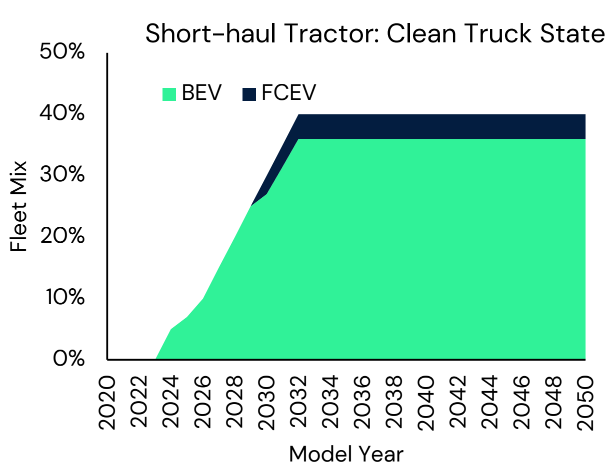


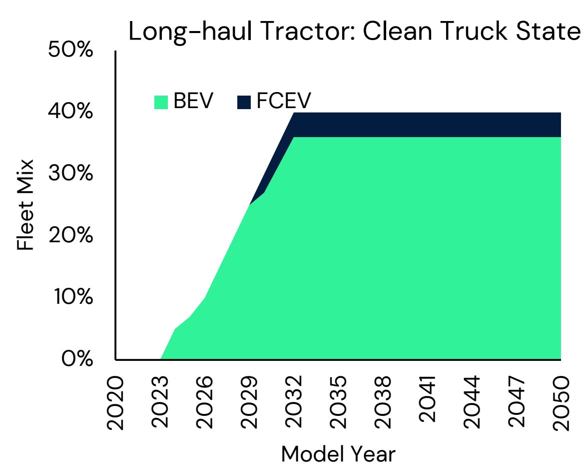


In July 2020, 15 states including CO, CT, DC, MA, MD, ME, NC, NJ, NY, OR, PA, RI, VT, WA, and HI, signed a Memorandum of Understanding (MOU), volunteering to achieve 30% zero-emission vehicle sales by 2030. MHD ZEV targets for these states were assumed to follow California's Advanced Clean Trucks regulation while technology mix assumptions were kept consistent with ACT (10% FCEV – 2030 phase in timeframe as stated in the EPA latest heavy-duty rule making document).

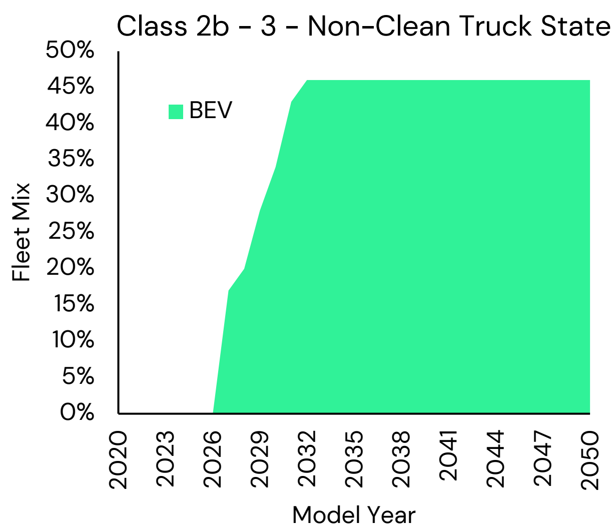


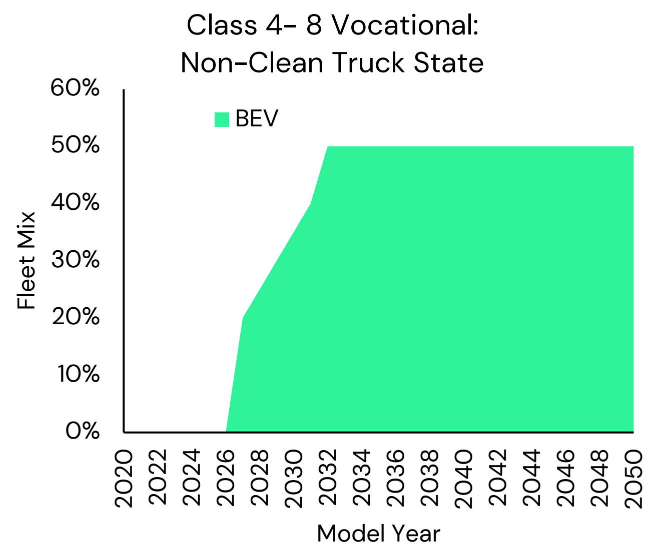


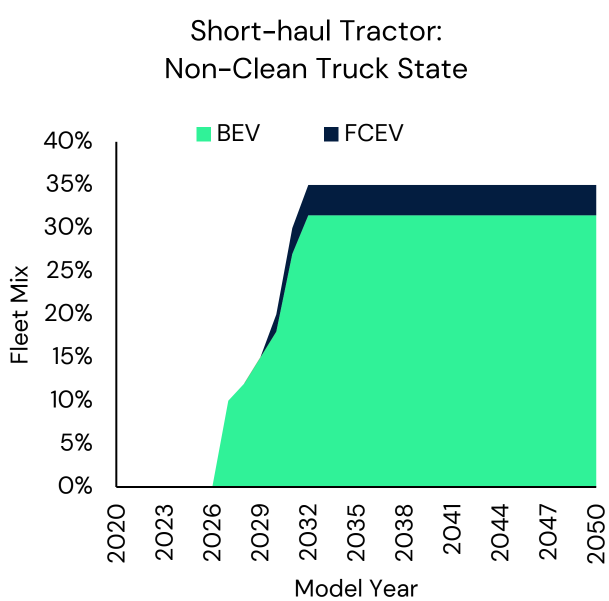


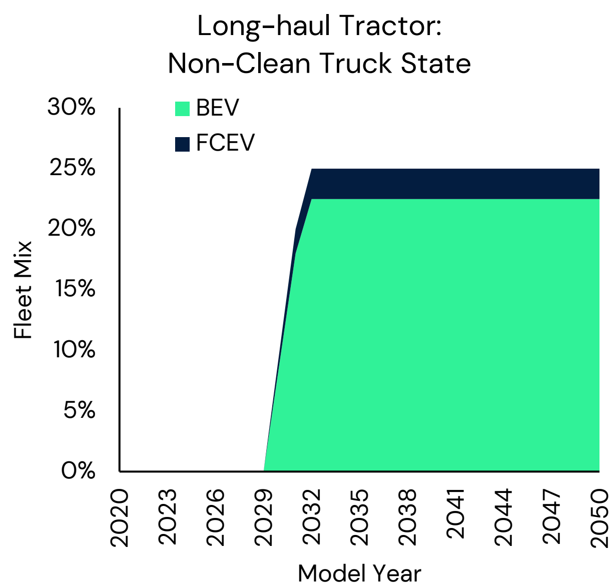


Class 2b-3 for non-ZEV states will follow the proposed EPA Multi-Pollutant Emissions Standards while Class 4 – 8 trucks will follow the EV penetration rates as proposed in the Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles—Phase 3. Technology mix assumptions were kept consistent with the ACT states.

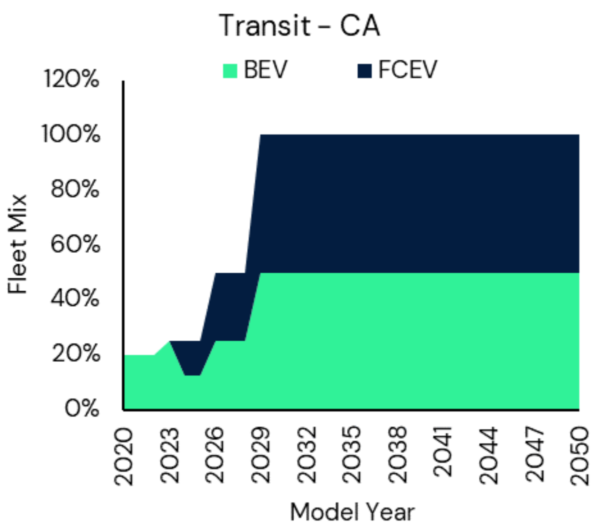


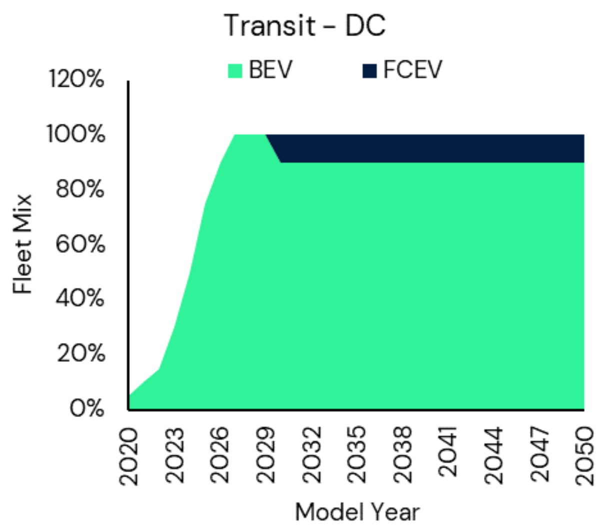


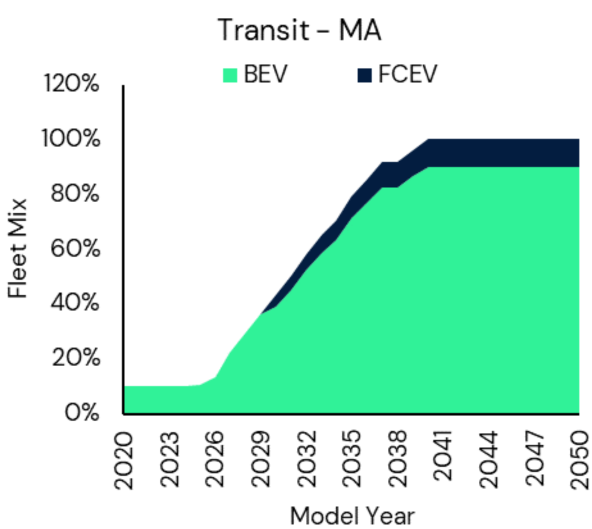


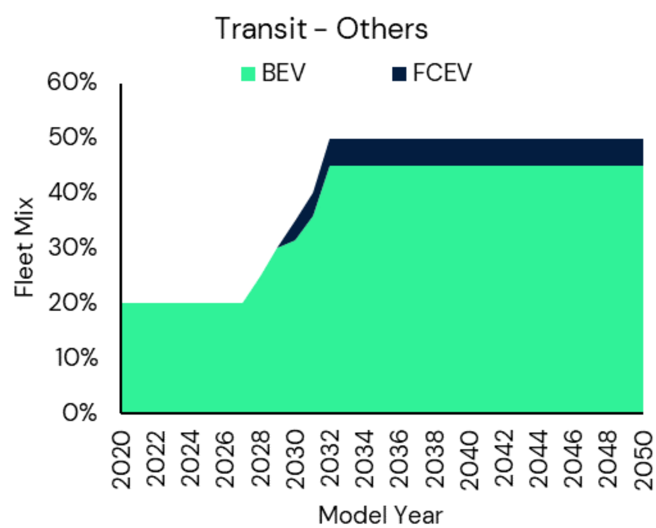


Technology mix assumptions for transit bus were kept consistent with ACF long-haul tractors for California and with ACT tractors for other states.









Appendix II: BEV and FCEV Vehicle Efficiency

Regulatory Class	Source Type	BEV (kWh/mile)	FCEV (g H2/mile)
Light Duty Vehicles	Passenger Car	0.28	14.4
Light Duty Trucks	Passenger Truck	0.42	17.2
Class 2b and 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	Passenger Truck	0.64	26.3
Light Duty Trucks	Light Commercial Truck	0.42	17.2
Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	Transit Bus	1.14	68.3
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Transit Bus	1.40	84.2
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Transit Bus	2.24	144.9
Urban Bus (see CFR Sec 86.091_2)	Transit Bus	2.24	144.9
Class 2b and 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	Light Commercial Truck	0.64	26.3
Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	Other Buses	1.14	68.3
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Other Buses	1.50	89.7
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Other Buses	2.82	169.1
Class 2b and 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	School Bus	0.64	26.3
Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	School Bus	0.94	56.4
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	School Bus	1.36	81.6
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	School Bus	1.40	84.0
Class 2b and 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	Refuse Truck	0.64	26.3
Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	Refuse Truck	0.96	57.6
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Refuse Truck	2.60	156.0
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Refuse Truck	3.18	200.0
Class 2b and 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	Single Unit Short-haul Truck	0.64	26.3
Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	Single Unit Short-haul Truck	0.91	54.6
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Single Unit Short-haul Truck	1.33	79.8
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Single Unit Short-haul Truck	1.80	108.0
Class 2b and 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	Single Unit Long-haul Truck	0.64	26.3
Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	Single Unit Long-haul Truck	0.91	54.6
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Single Unit Long-haul Truck	1.33	79.8
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Single Unit Long-haul Truck	1.80	108.0
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Combination Short-haul Truck	1.33	79.8
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Combination Short-haul Truck	2.35	137.0
Glider Vehicles (see EPA-420-F-15-904)	Combination Short-haul Truck	2.35	137.0
Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Combination Long-haul Truck	1.33	79.8
Class 8a and 8b Trucks (GVWR > 33,000 lbs)	Combination Long-haul Truck	2.35	137.0
Glider Vehicles (see EPA-420-F-15-904)	Combination Long-haul Truck	2.35	137.0

Appendix III: EVI-Pro and EVI-OnDemand Modeling Outputs

State-level L1 & L2 Port Count Summary

State	2025	2030	2035	2040	2045	2050
Alabama	180,121	698,626	1,329,246	1,767,946	1,928,434	2,085,949
Alaska	14,602	55,710	107,994	140,352	163,812	176,999
Arizona	184,676	715,925	1,383,589	1,825,450	2,133,941	2,157,120
Arkansas	109,319	415,313	803,052	995,543	1,161,830	1,255,545
California	1,548,487	4,289,662	8,164,674	11,134,288	12,154,276	13,477,506
Colorado	242,582	679,833	1,313,441	1,799,702	1,989,603	2,178,128
Connecticut	138,321	384,858	738,058	1,022,878	1,131,976	1,157,147
Delaware	29,673	115,017	222,716	293,317	343,002	347,291
Florida	557,316	2,134,920	4,117,063	5,400,782	6,298,319	6,338,701
Georgia	315,392	1,223,850	2,369,653	3,118,041	3,404,316	3,686,169
Hawaii	25,435	96,273	185,171	241,255	281,343	303,706
Idaho	48,151	185,568	357,105	465,595	541,515	583,933
Illinois	301,697	1,159,686	2,246,611	2,965,156	3,467,624	3,506,214
Indiana	202,786	785,812	1,520,572	1,998,656	2,182,086	2,362,191
Iowa	105,831	408,104	787,933	1,029,024	1,121,306	1,212,196
Kansas	94,660	365,633	695,139	925,627	1,009,346	1,092,361
Kentucky	140,199	542,007	1,047,650	1,372,628	1,497,830	1,621,092
Louisiana	147,967	562,832	1,089,902	1,448,635	1,578,660	1,707,286
Maine	67,023	191,363	369,248	479,350	571,766	589,564
Maryland	271,609	747,792	1,483,641	1,911,670	2,120,742	2,337,377
Massachusetts	265,506	733,576	1,409,076	1,957,002	2,170,863	2,222,644
Michigan	307,957	1,195,250	2,286,161	3,057,472	3,349,814	3,630,669
Minnesota	279,193	784,252	1,566,768	2,063,381	2,326,907	2,585,056
Mississippi	112,618	427,450	826,616	1,023,516	1,194,198	1,290,581
Missouri	193,276	748,342	1,428,481	1,904,925	2,081,217	2,253,221
Montana	37,184	142,775	270,220	364,428	395,481	428,677
Nebraska	62,895	242,702	469,003	612,124	713,677	721,139
Nevada	109,090	306,046	600,363	809,493	894,370	979,756
New Hampshire	40,283	153,775	297,099	390,417	455,793	459,978
New Jersey	321,945	890,661	1,706,580	2,369,900	2,626,463	2,687,227
New Mexico	115,488	324,912	636,166	813,856	896,132	983,447
New York	508,698	1,413,560	2,776,228	3,754,167	4,153,147	4,553,750
North Carolina	308,135	1,191,828	2,305,013	3,028,353	3,307,293	3,580,501
North Dakota	30,756	117,731	223,543	301,123	326,316	353,710
Ohio	317,306	1,229,497	2,377,842	3,131,783	3,660,186	3,701,765
Oklahoma	141,926	539,325	1,049,200	1,306,600	1,529,178	1,537,525
Oregon	168,317	479,100	933,323	1,269,615	1,410,771	1,548,592
Pennsylvania	285,507	1,101,867	2,128,341	2,811,482	3,288,558	3,557,948
Rhode Island	37,570	104,107	202,455	278,601	309,010	339,515
South Carolina	170,178	659,569	1,274,744	1,663,909	1,813,808	1,962,166
South Dakota	31,631	121,282	234,926	309,478	335,495	363,558
Tennessee	215,397	835,655	1,616,697	2,120,481	2,314,521	2,505,185
Texas	836,523	3,250,107	6,295,124	8,272,525	9,012,094	9,766,141
Utah	84,312	326,120	629,349	830,518	970,726	1,049,577
Vermont	32,780	91,343	178,019	226,686	247,408	271,296
Virginia	392,161	1,106,631	2,154,536	2,772,385	3,293,102	3,383,137
Washington	274,975	773,240	1,517,973	2,062,401	2,290,307	2,513,644
West Virginia	58,366	225,757	429,792	572,894	625,061	675,507
Wisconsin	197,704	762,284	1,450,675	1,938,051	2,115,356	2,292,618
Wyoming	26,686	101,193	195,697	243,152	283,534	283,358

State-level DCFC Port Count Summary (Passenger LD Only)

State	2025	2030	2035	2040	2045	2050
Alabama	1,816	6,485	11,777	18,819	24,647	28,912
Alaska	270	884	1,863	2,144	2,739	3,179
Arizona	1,571	6,203	12,771	18,921	24,510	28,646
Arkansas	1,271	3,931	6,355	10,374	13,645	16,041
California	8,628	24,648	55,057	89,202	124,222	147,265
Colorado	2,566	7,658	14,024	22,873	30,501	36,189
Connecticut	1,083	3,852	7,924	12,999	17,336	20,607
Delaware	107	442	1,091	1,672	2,295	2,746
Florida	4,606	18,284	37,236	54,292	69,872	81,419
Georgia	3,333	12,420	26,261	36,345	47,158	55,095
Hawaii	204	770	1,603	2,190	2,839	3,325
Idaho	625	2,031	4,365	5,355	6,897	8,039
Illinois	2,857	6,397	13,688	19,012	25,362	29,972
Indiana	2,219	7,825	16,452	21,992	28,598	33,486
Iowa	1,432	4,340	9,654	11,053	14,435	16,931
Kansas	1,083	3,213	4,901	8,116	10,701	12,589
Kentucky	1,542	4,841	10,931	13,144	17,363	20,459
Louisiana	1,332	4,789	8,701	13,812	18,090	21,206
Maine	682	1,797	3,450	5,919	8,106	9,647
Maryland	1,536	5,366	11,775	20,619	28,450	34,239
Massachusetts	2,021	4,853	10,048	17,292	23,637	28,394
Michigan	3,326	12,336	22,747	35,656	46,218	54,078
Minnesota	3,291	9,268	17,996	30,844	42,127	50,518
Mississippi	1,144	3,373	5,444	9,220	12,277	14,493
Missouri	2,836	10,013	17,385	26,739	34,425	40,192
Montana	584	1,560	2,075	3,374	4,529	5,330
Nebraska	950	2,847	6,069	6,786	8,766	10,213
Nevada	943	3,015	6,431	9,402	12,585	14,936
New Hampshire	264	959	2,135	2,998	3,996	4,731
New Jersey	930	3,007	7,894	15,110	21,512	26,274
New Mexico	1,161	2,877	5,295	9,094	12,408	14,828
New York	5,942	21,092	42,507	62,500	81,615	96,152
North Carolina	3,138	11,905	24,948	34,647	44,846	52,394
North Dakota	613	1,754	2,454	3,869	5,100	5,962
Ohio	3,412	13,008	26,355	36,979	47,665	55,694
Oklahoma	1,590	5,066	8,760	14,258	18,752	22,006
Oregon	1,409	4,396	9,695	14,608	19,738	23,530
Pennsylvania	3,402	13,224	26,185	37,320	47,710	55,511
Rhode Island	430	1,644	3,207	4,793	6,225	7,320
South Carolina	1,419	5,335	11,567	15,903	20,866	24,524
South Dakota	571	1,589	3,701	3,471	4,612	5,414
Tennessee	2,443	9,010	18,859	25,531	33,066	38,695
Texas	7,261	27,558	58,546	81,770	106,403	124,572
Utah	953	3,595	7,130	9,958	12,734	14,813
Vermont	383	864	1,503	2,639	3,643	4,332
Virginia	2,725	7,893	16,118	28,647	39,784	47,936
Washington	1,870	4,591	10,607	17,080	23,839	28,806
West Virginia	761	2,411	3,870	6,301	8,207	9,596
Wisconsin	2,077	7,413	13,515	21,240	27,610	32,394
Wyoming	360	1,000	1,484	2,450	3,220	3,763

Appendix IV: Available Federal Funding and Incentive Programs

Incentive Program	Description
Congestion Mitigation & Air Quality Improvement Program	The Congestion Mitigation & Air Quality Improvement Program (CMAQ) Program provides funding to state and local governments and agencies for projects and programs that help meet the requirements of the Clean Air Act by reducing mobile source emissions and regional congestion on transportation networks. Eligible activities include transit improvements, travel demand management strategies, congestion relief efforts (such as high occupancy vehicle lanes), diesel retrofit projects, alternative fuel vehicles and infrastructure, and medium- or heavy-duty zero emission vehicles and related charging equipment.
Electric Vehicle (EV) Charging and Clean Transportation Grants	The U.S. Department of Energy (DOE) provides grants for transportation decarbonization research projects. Eligible program includes planning and development of medium- and heavy-duty EV charging and hydrogen fueling corridors and advanced engine and fuel technologies to improve fuel economy and reduce greenhouse gas emissions.
National Electric Vehicle Infrastructure Program (NEVI)	The U.S. Department of Transportation's (DOT) Federal Highway Administration (FHWA) NEVI Formula Program will provide funding to states to strategically deploy electric vehicle (EV) charging stations and to establish an interconnected network to facilitate data collection, access, and reliability. Funding is available for up to 80% of eligible project costs, including: the acquisition, installation, and network connection of EV charging stations to facilitate data collection, access, and reliability; proper operation and maintenance of EV charging stations; and long-term EV charging station data sharing.
Charging and Fueling Infrastructure Grants	The FHWA Charging and Fueling Infrastructure Discretionary Grant Program (CFI Program) offers funding to strategically deploy publicly accessible electric vehicle charging infrastructure and other alternative fueling infrastructure. CFI Program offers two tracks of funding opportunities: the Community Charging and Fueling Grants (Community Program) and the Alternative Fuel Corridor Grants (Corridor Program). The Corridor Program aims to install infrastructure along designated alternative fuel corridors, while the Community Program includes locations such as public roads, schools, parks, and in publicly accessible parking facilities.
Alternative Fuel Infrastructure Tax Credit	Alternative Fueling equipment for various fuels can receive a tax credit of 30% of the cost up to $30,000 until December 31, 2022, and after that date, the credit is 30% or 6% for depreciable property up to $100,000, with specific requirements. Additionally, residential fueling equipment purchased between January 1, 2023, and December 31, 2032, can receive up to a $1,000 tax credit.
Heavy-Duty Zero Emission Vehicle (ZEV) and Infrastructure Grants	The Inflation Reduction Act (IRA) allocated $1 billion towards replacing polluting heavy-duty vehicles with clean, ZEVs, supporting ZEV infrastructure, and providing workforce development and training. Additionally, funds will be provided for planning and technical activities to promote the adoption and deployment of zero-emission vehicles. The EPA will distribute the funding between now and 2031, with $400 million going to communities in nonattainment areas.
Rebuilding American Infrastructure with Sustainability and Equity	The U.S. Department of Transportation (DOT) Rebuilding American Infrastructure with Sustainability and Equity (RAISE) grant program provides federal financial assistance to eligible transportation infrastructure projects that address climate

	change and environmental justice impacts, among other key objectives. Starting in FY21, RAISE has substantially increased program focus on ZEV infrastructure, including EV charging.
Port Infrastructure Development Program (PIDP)	The U.S. DOT Federal Highway Administration (FHWA) will establish the Port Infrastructure Development Program (PIDP) to fund projects that improve port resiliency to address sea-level rise, flooding, extreme weather events, earthquakes, and tsunami inundation, as well as projects that reduce or eliminate port-related criteria pollutant or greenhouse gas emissions, including EV charging or hydrogen fueling infrastructure.
Carbon Reduction Program (CRP)	The U.S. DOT will establish a carbon reduction formula program for states to reduce transportation emissions. Eligible activities include truck stop electrification, vehicle-to-infrastructure communications equipment, public transportation, port electrification, and deployment of alternative fuel vehicles, including charging or fueling infrastructure and the purchase or lease of zero emission vehicles.
National Multimodal Cooperative Freight Research Program	The U.S. DOT will establish a national cooperative freight transportation research program (Program), administered in collaboration with the National Academy of Sciences (NAS). NAS will establish an advisory committee to recommend a national research agenda on improvements in the efficiency and resiliency of freight movement, including adapting to future trends such as zero-emissions transportation. NAS may award research contracts or grants under the Program. Funding will be made available each fiscal year until November 15, 2026, and will remain available until expended for this Program.

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