Medium & Heavy-Duty Zero Emission Vehicle Blueprint
MD/HD ZEV Needs Assessment Report

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ABSTRACT

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EXECUTIVE SUMMARY

The intent of this report is to shed light on the needs for zero-emission (ZE) medium and heavy-duty (MD-HD) vehicles and infrastructure in the San Diego region (herein referred to as the region). The report starts with an overview of the existing regulations that are designed to accelerate the adoption of ZE MD-HD vehicles. The Advanced Clean Trucks (ACT) regulation sets scheduled sales requirements of ZEVs for OEMs to supply ZE MD-HD vehicles in California. The ACT regulation will be supplemented by the proposed Advanced Clean Fleets (ACF) regulation, which will create the demand for ZE MD-HD vehicle fleets. In addition to these regulations, the report highlights key incentive programs in California and the region that promote the adoption of ZE MD-HD vehicles. Incentive programs, such as Hybrid and Zero-Emission Truck and Bus Voucher Project (HVIP), Carl Moyer Program, and Clean Transportation program, offer funding opportunities for large commercial entities seeking to reduce emissions at freight facilities with ZE trucks and infrastructure. Local infrastructure make-readiness programs, such as those provided by the San Diego Gas & Electric Power Your Drive for Fleets program, help install make-ready charging infrastructure for MD-HD electric vehicles in the region. The report summarizes these incentive programs and provides an overview of their eligibility criteria as well as potential funding amount available through each program.

In addition to regulatory and incentive programs, this report also summarizes the current and projected state of technology for ZE MD-HD vehicles. To demonstrate the technology availability for MD-HD battery electric vehicles (BEVs), the project team relied on the data embedded within ICF's proprietary EV library, a comprehensive database of all available and "to be available" BEVs in the United States. Using this data, the project team illustrated the current availability, electric ranges, and potential vehicle price for various models of electric vehicles. Our assessment showed that while battery electric technology for transit buses is farther along in the market (closely followed by drayage, shuttle buses and delivery trucks), the technology is still under development for long-haul tractors. In addition to battery electric technology, the project team also explored the market readiness and availability of hydrogen fuel cell electric vehicles (FCEV). Leveraging the available (or soon to be available) fuel cell electric models in the CALSTART's Global Commercial Vehicle Drive to Zero Program, our project team demonstrated that hydrogen fuel cell transit buses are the only vehicle segment that is fully commercially available, but other MD-HD FCEVs are still being developed and vehicle manufacturer-announced models generally have later timeframes for release compared to BEVs.

Aside from vehicle technology, this report also provides an overview of the existing ZE infrastructure technology (both battery electric charging and hydrogen fueling infrastructure) and highlights some of the most recent development with respect to high power charging and hydrogen production/delivery. The report also provides estimates on the cost of equipment and installation for charging infrastructure based on data available through literature as well as those provided by the CEC. The project team also leveraged cost data from some of the most recent hydrogen fueling station projects funded through CEC's Clean Transportation Program, to shed light on potential cost of hydrogen infrastructure deployment.

In addition to discussing vehicle technology and infrastructure readiness and availability, this report also includes a review of the Total Cost of Ownership (TCO) analyses conducted by CARB as part of the ACF regulation to shed light on the potential economics of ZE MD-HD vehicles compared to conventional internal combustion engine (ICE) counterparts. These analyses reveal that upfront costs of ZE MD-HD vehicles are considerably higher than diesel and natural gas counterparts. However, ZE MD-HD vehicles offer high savings potential in operating costs, which can lead to lower lifetime TCO compared to diesel and natural gas options. Moreover, lower lifetime TCO for ZE MD-HD vehicles can be achieved when accounting for subsidies from the LCFS programs as well as other available incentive funding.

Following the policy and market assessment, the project team conducted fleet modeling and infrastructure analysis to determine the type and quantity of ZE MD-HD vehicles and infrastructure. To do so, the project team leveraged CARB's EMFAC2021 model, which provides the most recent vehicle and emissions inventory and projects future vehicle and emissions inventories. Using EMFAC2021, the project team conducted MD-HD fleet and emissions modeling based on the proposed ACF regulation, simulating accelerated ZE MD-HD vehicle adoption. The analysis accounts for all the region's vehicle categories, excluding light-duty vehicles, between years 2020 through 2040. The results indicate that by 2040, under the ACF scenario, the distribution of the region's total Class 2b through 8 vehicle population by fuel type is expected to be 40 percent battery electric, 32 percent diesel, 23 percent gasoline, 4 percent fuel cell electric, and less than 1 percent natural gas. The project team estimated the decrease in total emissions in the ACF scenario, showing that by 2040, NOx emissions decrease by 55 percent, PM2.5 emissions decrease by 47 percent, and GHG emissions decrease by 45 percent.

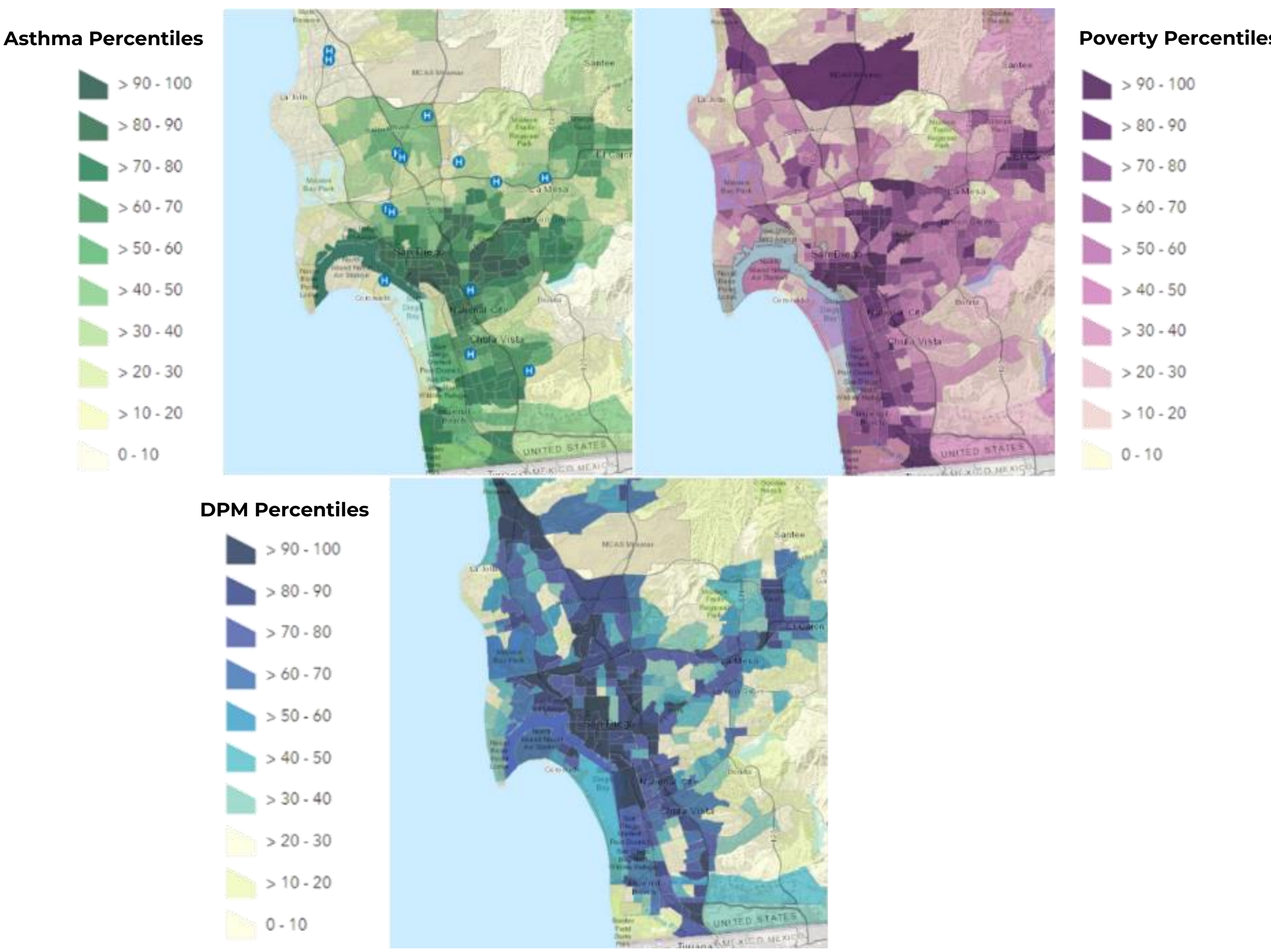
Using the quantity of ZE MD-HD vehicles that will likely be deployed in the region under the ACF scenario, the project team identified regional infrastructure goals by number and type. The region's charging and fueling infrastructure needs are based on a combination of energy use, vehicle operational characteristics, and duty cycle information. For charging infrastructure, the project team leveraged Lawrence Berkeley National Laboratory's (LBNL) HEVI-LOAD model to estimate the number and types of charger deployments using the ZE MD-HD vehicle population data that the project team estimated for the region. HEVI-LOAD does not estimate the number of chargers for Class 2b vehicles, so the project team leveraged the National Renewable Energy Laboratory's (NREL) EVI-Pro model, using the estimated Class 2b vehicle population as input to determine charger deployments. The results from HEVI-LOAD and EVI-Pro are combined to estimate the overall charging infrastructure needs for all MD-HD ZEVs anticipated to operate in the region.

The results from the regional infrastructure analysis showed that by 2040, there will be a need for almost 23,000 chargers with power levels ranging between 19 kW to 1,600 kW, providing a maximum of 3,800 MW of power to the battery-electric MD-HD vehicles (Class 2b – 8) operating within the region. Of these, the project team determined that 3,200 chargers will be public, with the following distribution: 350 will be megawatt chargers (i.e., > 1,000 kW), approximately 1,000 will be high power DC fast chargers (350 kW – 1,000 kW), and the rest (approximately 1,800) will be a combination of Level 2 and < 150 kW DC fast chargers. This analysis showed that while there is a significant need for charging infrastructure in the region, most of this infrastructure are assumed to be private chargers deployed in truck and bus depots, and only 14% of chargers are considered public. The project team also determined hydrogen fueling infrastructure, using estimates for the annual hydrogen fuel consumption expected across all region's fuel cell electric MD-HD vehicles. The results of this analysis showed that by 2040, approximately 5,800 fuel cell electric MD-HD vehicles will be served by 83 hydrogen fueling stations with a total daily hydrogen capacity of more than 65,000 kilograms per day. The results of this vehicle and infrastructure study demonstrated that although State and local ZE MD-HD goals and policies may pose some challenges, pathways towards vehicle electrification are continuing to develop via curated needs assessment analyses.

INTRODUCTION

For many decades, low-income and disadvantaged communities near California's major freight facilities have suffered from high levels of air pollution and local air quality issues. Despite significant improvement, there still exist many communities that are disproportionately impacted by air pollution from freight movement. For example, ***Figure 1*** shows a side-by-side comparison of asthma, poverty levels, and diesel particulate matter (DPM) concentrations based on the CalEnviroScreen 4.0[1] for San Diego County. ***Figure 1*** illustrates how regions with higher poverty levels, especially those surrounding ports and major freight facilities, are also burdened with high levels of DPM and asthma.

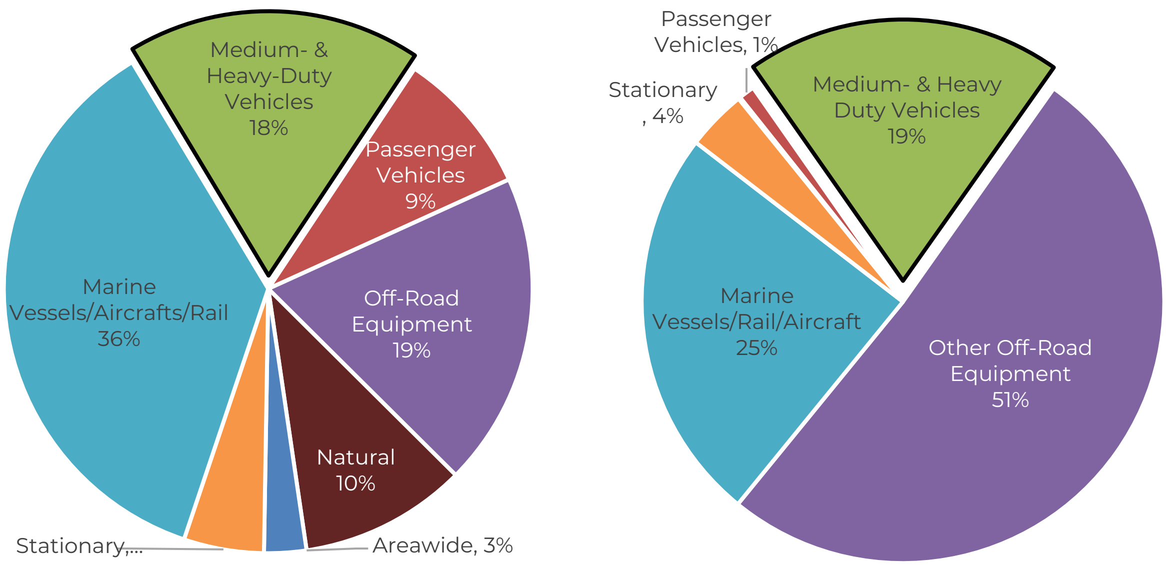
Figure 1. Asthma cases (top left), Poverty (top right), DPM levels (bottom) in San Diego County



[1] https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

Medium- and heavy-duty (MD-HD) vehicles – vehicles with Gross Vehicle Weight Rating (GVWR) above 8,500 lbs. – are one of the major sources of air quality issues in disadvantaged communities. MD-HD vehicles are significant sources of nitrogen oxides – a precursor to ozone – and DPM, a toxic pollutant with high inhalation cancer risk factor. In ***Figure 2***, results from California Emissions Projection Analysis Model (CEPAM) illustrate the contribution of MD-HD trucks and buses to NOx and DPM emissions in San Diego County in 2022[2]. Although only one-fifth of DPM and NOx emissions in San Diego County are associated with operation of these vehicles, these MD-HD vehicle emissions are localized near schools and residences, as these trucks operate within these zones. Their proximity to these communities makes these vehicles a significant contributor to air pollution exposure and public health risks. MD-HD vehicles are also a significant source of greenhouse gas (GHG) emissions, contributing to global climate change.

Figure 2. 2022 NOx (left) and Diesel PM (right) Emissions in San Diego County

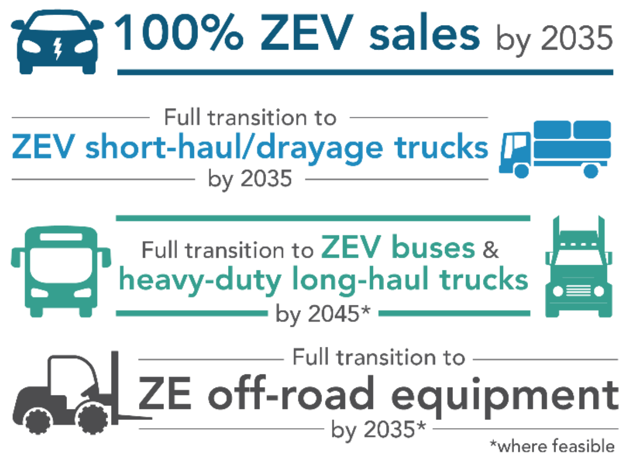


Source: 2019 California Emissions Projection Analysis Model (CEPAM) version 1.03

In response to the significant impact of MD-HD operation on air quality and environmental justice issues across California, the State has established numerous goals and has adopted various policies to accelerate the adoption of zero-emission vehicles (ZEV) across these sectors. For example, in September 2020, Governor Gavin Newsom signed Executive Order No. N-79-20, setting ambitious targets for the state to reach 100 percent ZE MD-HD vehicles in the State by 2045 for all operations where feasible, and 100 percent ZE drayage trucks by 2035. To achieve these ambitious targets, California Air Resources Board (CARB) has adopted multiple regulations, such as Innovative Clean Transit (ICT) and ACT regulations, to accelerate the adoption of ZE technologies in the MD-HD vehicle sector. CARB is also pursuing the new ACF and Zero-Emission Drayage Truck regulations, which would start in 2024 upon approval. The ACF regulation would require MD-HD vehicle fleets operating in California to transition to ZE

[2] CARB's 2019 California Emissions Projection Analysis Model v1.03. Link: https://ww2.arb.ca.gov/applications/cepam2019v103-standard-emission-tool

technologies, with the goal of transitioning all drayage trucks to ZE by 2035 and the rest of the MD-HD vehicles to ZE by 2045. Additionally, State agencies such as CARB and California Energy Commission (CEC) are currently offering a suite of different incentive programs within California providing funding towards the purchase of ZE trucks and buses, replacement of older diesel vehicles with cleaner technologies, and buildout of ZE infrastructure. For example, for the Fiscal Year (FY) 2022-2023 budget, Governor Newsom adopted a $6.1 billion ZEV package to accelerate the State's transition to ZEVs. This is in addition to the $3.9 billion multi-year investment that was allocated in 2021. A significant fraction of this package is earmarked for heavy-duty vehicles and their supporting infrastructure. Of the $6.1 billion, $935 million is allocated for the purchase of 1,000 ZE short-haul drayage trucks and 1,700 ZE transit buses. Another $1.5 billion is provided for the purchase of electric buses for school transportation programs. The package also provides $1.1 billion to assist with purchase of ZE trucks, buses, and off-road equipment (plus related fueling infrastructure), with $400 million to enable port electrification.



In addition to these State policies and legislations, there are multiple local and regional efforts underway to further accelerate the adoption of zero-emission MD-HD vehicles in the region. Among those is the San Diego Air Pollution Control District Board's (APCD) Community Emissions Reduction Plan (CERP) for Portside Environmental Justice Neighborhoods, which was approved in July 2021. The CERP calls for 100 percent emissions reduction from MD-HD vehicles servicing indirect sources 5 years in advance of regulatory requirements and to develop an electric truck charging needs assessment and strategy to support electric truck expansion beyond pilot programs. Additionally, the Port of San Diego adopted the Maritime Clean Air Strategy (MCAS) in October 2021. The MCAS includes ambitious goals to accelerate the conversion of diesel trucks which visit the Port's cargo terminals to zero emissions. The MCAS calls for 100% zero emission trucks by the end of 2030 with an interim goal to achieve 40 percent zero emission truck trips in 2026. In June of 2022, the Port released its Heavy-Duty Zero emission truck transition Plan[3], which outlines a strategy to make progress on these goals. According to the Port's assessment, charting a path to achieve the 2030 target will include more aggressive ZE policies and funding, advancement of battery technologies, and widespread deployment of public charging and fueling infrastructure for both battery and hydrogen – factors that are often outside of Port's control. However, the Port truck transition plan identifies a potential pathway for meeting the interim target of 40 percent ZE truck trips through battery-electric trucks. A key assumption for this pathway is that for trucks with daily mileages exceeding battery electric truck range, there will need to be wide access to publicly accessible opportunity charging (i.e., public fast charging) and overnight charging. In other words, the Port demonstrated that to achieve the 40 percent ZE truck trips in 2026, access to

[3] https://pantheonstorage.blob.core.windows.net/environment/Final-Zero-Emission-Truck-Transition-Plan.pdf

public opportunity charging will be necessary given the range of the duty cycles of vehicles visiting the Port. Additionally, included in the list of local and regional efforts is the development of Sustainable Freight Implementation Strategy, which is currently underway by SANDAG to guide the sustainable freight investments in the San Diego and Imperial Counties over the next 30 years.

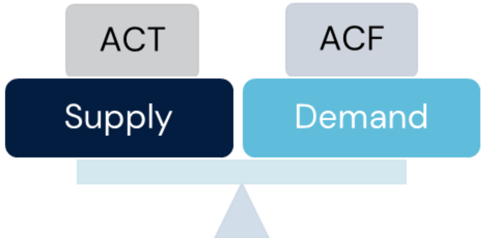
While there are multiple public agencies in the region developing ZE rollout plans for transit and freight vehicles, SANDAG is undertaking a new effort to develop a MD-HD ZEV blueprint that guides the transition of freight and transit vehicles to ZE technologies and highlight the challenges related to technology readiness, infrastructure availability, and cost. This Blueprint will develop a plan and related strategies for achieving ZE MD-HD vehicle goals.

This report is one of the first tasks in the development of SANDAG's MD-HD ZEV Blueprint. The major objective of this report is to provide a summary of State and local regulatory and incentive program landscape around zero-emission MD-HD vehicles, as well as the technology and infrastructure market readiness for these vehicles. As part of this report, the project team provides a discussion on the TCO of ZE MD-HD vehicles and highlights some of the lessons learned through the pilot and demonstration programs. In addition to market assessment, the report also provides details on the technical analysis that the project team has conducted to estimate the number of MD-HD ZEVs that the region could expect over the next 15 years as well as the number, type, and power level/capacity of ZEV infrastructure needed in the region to power these vehicles.

POLICY LANDSCAPE

State's Zero-Emission MD-HD Regulations

To accelerate adoption of ZE MD-HD vehicles in California, the State has adopted (or is in process of adoption) several regulations which require both the supplier of the MD-HD vehicles (i.e., manufacturers) to sell ZEVs in California and Californian consumers (i.e., fleets operating in California) to purchase those trucks. Therefore, these regulations are intended to both increase the supply of ZE trucks and induce consumer demand.



On the supply side, the ACT regulation is a manufacturers ZEV sales requirement which applies to vehicles with a GVWR greater than 8,500 lbs. (Classes 2b through 8) and manufacturers with greater than 500 annual California sales[4]. The regulation requires manufacturers to produce and deliver ZE trucks in California. By 2035, the regulations will require 55 percent of Class 2b-3, 75 percent of Class 4-8 vocational (i.e., any class 4-8 trucks excluding class 7-8 tractors), and 40 percent of Class 7-8 tractors sold in California to be ZE. CARB adopted the ACT regulation in June 2020 with the first sales requirement kicking in 2024. Upon the adoption of the ACT regulation in California, 15 states and the District of Columbia announced a joint memorandum of understanding (MOU), committing to working collaboratively to advance and accelerate the market, with the goal of reaching 100 percent of all new MD-HD vehicle sales to be ZEV by 2050, and with an interim target of 30 percent ZEV sales by 2030.

In the meantime, CARB is working on a complementary regulation to create consumer demand for ZE MD-HD vehicles in California. The ACF regulation, planned for board consideration in Spring 2023, seeks transition of fleets to ZEVs and will focus on setting two major ZEV requirements. The first is a ZEV purchase schedule for public fleets. The second is 100% ZEV requirements for drayage and high priority/federal fleets[5]. Beginning 2024, a large fraction of heavy-duty vehicles operating in California would be subject to the following requirements:

- **State and Local Government Fleets:** From 2024 through 2026, at least 50% of new public vehicle additions must be ZEV, and 100% of new purchases should be ZEV starting in 2027.

- **Drayage Fleets:** Beginning in calendar year 2024, new drayage trucks added to Port registries must be ZEV, and all drayage trucks must be ZEV by 2035. The ACF regulation notes that legacy drayage trucks (i.e., diesel and natural gas drayage trucks) may enter the Port registry prior to 2024 and operate to the extent of their useful life, but not past 2035.

[4] Manufacturers with less than 500 annual California sales are exempt but may opt-in to earn credits for selling ZEVs.
[5] draft2022aqmp.pdf (aqmd.gov)

- **High Priority and Federal Fleets:** California heavy-duty truck fleets are high-priority if: 1) the fleet has 50 or more vehicles under common ownership or control, or 2) the entity or the combination of entities operating under common ownership or control have $50 million or more in total gross annual revenue in the prior year– otherwise, the fleet is not subject to this regulation. Similar to drayage trucks, starting 2024, high priority fleets can only add ZEVs to their fleets and legacy ICE vehicles have until the end of their useful life to transition to ZEV. The proposed ACF regulation also provides another compliance option in which fleets are not restricted from procuring ICE vehicles after 2024 but are required to hit pre-established ZEV milestones each year.

According to CARB's estimates, by 2050, almost two-thirds of trucks operating in California are expected to be ZE. It is expected that the ACT and ACF regulations will drastically change the mix of MD-HD vehicle technologies in the region. Specifically, this regulation will not only impact large fleets with more than 50 trucks or $50 million in total gross annual revenue, but also it affects the vehicles that are under common ownership and control by these entities. For example, vehicles owned by different entities but operated using common or shared resources to manage the day-to-day operations using the same motor carrier number, displaying the same name or logo, or contractors whose services are under the day-to-day control of the hiring entity are under common ownership or control. The common ownership or control also includes relationships where the controlling party has the right to direct or control the vehicle as to the details of when, where, and how work is to be performed or where expenses for operating the vehicle, such as fuel or insurance, are shared. Of course, this requirement expands the applicability of the regulation to broader set of vehicles which could also impact some of the owner-operators that are common control of a larger entity.

While policy actions such as ACT and ACF regulations are key in accelerating the adoption of ZE trucks in California, the full transition of California's MD-HD vehicles to ZE technology will not be possible without financial incentives. As described, the current policy landscape primarily targets public, drayage, federal, and high priority fleets. Consequently, smaller fleets that do not fall into any of these categories may be left unregulated. Additionally, California's regulations are only focusing on vehicle adoption, despite an imminent need to prepare and build charging and fueling infrastructure. This is where incentive programs could play a significant role in facilitating this transition. Notably, California has already established several incentive programs that have been instrumental in facilitating the adoption of ZE vehicles. Many of these incentives have been developed and administered by local and state agencies, such as CARB, CEC, and San Diego APCD.

Incentive Programs

This section highlights incentive programs that support adoption of the MD-HD ZEVs and infrastructure throughout the State as well as the region. A complete list of these incentive programs is provided in Table 1.

Hybrid and Zero-Emission Truck and Bus Voucher Project (HVIP)

HVIP is a point-of-sale incentive program that provides a voucher up to $120,000 for zero-emission trucks. As of this report, the program has supported the purchase of 2,400 natural gas and 1,800 battery-electric trucks since 2010 (redeemed vouchers), and over half of all voucher requests have come from disadvantaged communities seeking DPM reductions. Although HVIP has provided much needed resources for adopting clean technologies, it is one of California's most oversubscribed programs, a key issue especially for smaller fleets that do not have the resources to quickly apply for these grants and use them to transition their trucks to clean technologies. Additionally, HVIP cannot be stacked with other State-funded incentives, such as Carl Moyer. In response to these limitations, in 2021, CARB proposed amendments to the HVIP program by introducing fleet size limits. Beginning on January 1, 2023, private fleets with more than a total of 100 trucks and buses will no longer be eligible for HVIP incentives. This limit would be reduced to 50 trucks and buses beginning on January 1, 2024. Public agencies, including public transit and public-school districts, public utilities, municipalities, and California Native American tribal governments, would not be subject to any fleet size limits. Additionally, in their 2021-22 funding plan, CARB proposed to set aside $25 million of pilot funding for incentives targeted at small trucking fleets and independent owner operators to implement new and innovative mechanisms including, but not limited to: flexible leases, peer to peer truck sharing, truck as a service, assistance with infrastructure, individual owner planning assistance, as well as other mechanisms. In addition to this, CARB also set aside $75 million in its 2021-22 funding plan for ZE drayage trucks that will be limited to HVIP-eligible Class 8 trucks purchased by fleets and owner-operators that are currently operating in drayage service. In total, CARB's 2021-22 funding plan allocated $569.5 million toward HVIP program. CARB is currently working on the 2022-23 funding plan.

Federal Tax Credits for Commercial Vehicles

In 2022, U.S. Federal government passed into law the Inflation Reduction Act (IRA), with several key goals. The IRA intends to mitigate inflation, invest in domestic energy production and manufacturing, and reduce carbon emissions by roughly 40 percent by 2030. As part of the IRA, beginning January 1, 2023, a tax credit will be available to businesses for the purchase of new BEVs and FCEVs. Vehicles with a GVWR below 14,000 pounds (lbs.) must have a battery capacity of at least seven kilowatt-hours (kWh) and vehicles with a GVWR above 14,000 lbs. must have a battery capacity of at least 15 kWh. The tax credit amount is equal to the lesser of the following amounts:

- 15% of the vehicle purchase price for plug-in hybrid electric vehicles
- 30% of the vehicle purchase price for EVs and FCEVs
- The incremental cost of the vehicle compared to an equivalent internal combustion engine vehicle

Maximum tax credits may not exceed $7,500 for vehicles under 14,000 lbs. and $40,000 for vehicles above 14,000 lbs. This is the first of kind federal tax credits being offered to commercial heavy-duty vehicles. Considering that this is a tax credit, fleets should be able to stack it with incentives they receive from the California HVIP program. A caveat here is that since this is a tax credit, a fleet may likely need to owe at least $40,000 to the U.S. Internal Revenue Service (IRS) to take the full advantage of the program. Otherwise, fleet tax credits will be limited to the amount they owe the Federal IRS.

Carl Moyer Program, Carl Moyer Voucher Incentive Program (VIP)

The Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program) provides incentives for cleaner-than-required on-road and off-road diesel engines and equipment. The program has focused on deploying the most advanced low-NOx and ZE technologies and generates surplus emission reductions through their vehicle scrappage requirement. The Carl Moyer Program is implemented as a partnership between the CARB and the 35 local air districts. Local air districts administer Carl Moyer Program grants, select the projects to fund, and report that information to CARB. To date, about $210 million has been allocated to on-road projects, which has resulted in replacement of 7,800 diesel engines across CA, eliminating more than 25,000 tons of NOx and VOC and 680 tons of DPM. As shown in Table 1, specific to San Diego region, between 2005 through 2020, the region has executed almost $70 million in Carl Moyer funding of which $11 million was allocated to on-road vehicles.

Table 1. Carl Moyer Program Statistics for San Diego APCD for Moyer Funding Years 8-22[6]

Source Category	Count	Lifetime NOx+ROG (tons)	Lifetime PM (tons)	Funds Executed
On-Road	376	592	10.3	$11,060,975
Off-Road Agriculture	76	272	14.9	$5,373,467
Off-Road Other	220	1,365	49	$22,491,633
Locomotive	10	974	22.5	$13,027,309
Marine Vessels	188	1,198	40.9	$13,876,817
Agricultural Pump	20	111	3.5	$543,990
Infrastructure	1	N/A	N/A	$500,000
Shore Power	2	156	2.9	$2,521,105
Total	**893**	**4668**	**144**	**$69,395,296**

[6] https://ww2.arb.ca.gov/sites/default/files/2022-03/2020%20Carl%20Moyer%20Statistics%2002152022.pdf

To calculate the amount of funding that can be allocated to a certain project, the Carl Moyer program considers cost-effectiveness of that project. Considering that conventional combustion trucks has become much cleaner over time, the lower emissions benefits have led to lower grant awards for on-road vehicle projects. Additionally, the scrappage requirement instills some aversion in fleet owners, especially small fleets, who may lack resources to apply for funding and would instead prefer to sell their old trucks.

In response to this issue, on November 19, 2021, CARB approved amendments to the Carl Moyer Program cost-effectiveness limits and funding caps for optional advanced technology and ZE replacement on-road projects. As part of these amendments, the cost effectiveness limit for ZE trucks increased from $100,000 per weighted ton to $500,000 per weighted ton. Aside from the updates to cost effectiveness limits, CARB also approved increasing the maximum funding amounts to ensure that those incremental costs can be covered by the program. Changes include increasing the cap for heavy duty ZE replacements from $200,000 to $410,000. Such amendments will ensure that the program will continue to focus on developing the most advanced zero- and low-emission technologies. Despite these changes, access to Carl Moyer funding remains difficult due to the scrappage requirements. For California to claim emissions reductions from the Carl Moyer program as part of its State Implementation Plan (SIP), U.S. Environmental Protection Agency (EPA) requires emission reductions be permanent, which requires scrapping a truck. While such requirements ensure that emission reductions resulting from the program are surplus, it impedes the use of funding to accelerate the adoption of advanced clean technologies.

Aside from Carl Moyer Program that provides funding to all eligible fleets, the Carl Moyer Voucher Incentive Program (VIP) offers a streamlined funding option directed exclusively to smaller fleets with 10 vehicles or less to purchase cleaner vehicle replacements. Similar to the Carl Moyer Program, ZE projects in the VIP are eligible for a cost-effectiveness limit of up to $500,000 per weighted ton.

Volkswagen Environmental Mitigation Trust for California

California VW Mitigation Trust

The Volkswagen (VW) Mitigation Trust provides capped funding opportunities to mitigate NOx emissions from heavy-duty trucks and support ZE truck transitions at the Ports. The VW Trust offers up to $200,000 for ZE trucks, including drayage trucks, waste haulers, dump trucks, and concrete mixers. Public and private fleets are subject to different eligibility criteria for replacement of current trucks for ZE vehicles. Additionally, the VW Trust requires scrappage of the existing vehicle, and does not permit stacking other State-level funds.

Truck Loan Assistance Program

The Truck Loan Assistance Program offers financing opportunities to qualified small-business truckers who fall below conventional lending criteria and are unable to qualify for traditional financing for cleaner trucks. The loans are accessible to smaller fleet owners – trucking fleets with 10 or fewer heavy-duty vehicles and with less than $10 million in annual revenue – to provide them with funding for low-NOx and zero-emission technologies in compliance with the Truck and Bus rule. Loans from this program can be used to finance either one or multiple technologies, and loans can be combined with other incentive programs. According to CARB's Draft 2022-2023 Funding Plan, as of May 13, 2022, about $203 million in Truck Loan Assistance Program funding had been expended to provide about $2.5 billion in financing to small business truckers for the purchase of over 39,500 cleaner trucks, exhaust retrofits, and trailers.

Clean Transportation Program

The CEC's fuel and transportation portfolio includes public and private infrastructure development funding, planning grants, and workforce training to prepare workers for the clean transportation economy. As of December 2021, the CEC has invested more than $1 billion in clean transportation projects, including charging and fueling infrastructure, advanced vehicle technologies, and workforce training. As part of the draft funding allocations for FY 2022–23, CEC has allocated more than $160 million to support medium- and heavy-duty ZEV infrastructure to address the need for rapid transition to ZE technologies across the state. Of this, $30 million will be allocated to medium- and heavy-duty ZEV and infrastructure (Level 2 and DCFC), $85 million is earmarked for drayage, $30 million for transit, and $15 million for school buses. Also in FY 2021-22, CEC allocated $390 million for MD-HD vehicles, of which $105 million was earmarked for drayage and infrastructure pilots, $28.5 million for transit, and $19 million for school buses.

To facilitate distribution of the Clean Transportation Program funds allocated to MD-HD vehicles, in March 2022 the CEC and CALSTART launched the $50 million EnergIIZE Commercial Vehicles block grant which will provide exclusive zero-emission infrastructure funding to support the transition of MD-HD vehicles to BEVs and FCEVs. In December 2021, CEC increased the project cap to $276 million which will be disbursed via CALSTART[7]. Participation in the EnergIIZE incentive project requires that the applicant or the funding recipient belong to one of the following categories: a) a business, organization, or individual responsible for the operation of a MD-HD ZEV (vehicle Class 2b and above) in the State, or b) a business, organization, or individual responsible for the engineering, construction, procurement, and completion of a ZE infrastructure site in the state of California which shall service MD-HD ZEVs Class 2b or above. EnergIIZE also establishes four "Funding Lanes" each with differing qualifications and incentive structures. These funding lanes include:

- **EV Fast-Track**: Targeting zero-emissions medium and heavy-duty fleets registered in California or have been purchased, funded, or otherwise incentivized through state/federal projects.

- **EV Jump Start:** Targeting small businesses[8], certified Minority Business Enterprise, Woman-Owned Small Business, Veteran-Owned Small Business, or LGBT-owned small business. This funding lane is also available for transit agencies, school districts, or commercial fleet whose infrastructure will be in a designated disadvantaged community. Additionally, the funding is available to California Federally Recognized

[7] https://efiling.energy.ca.gov/GetDocument.aspx?tn=240980&DocumentContentId=74829
[8] As recognized by the California State Legislative Code, Section 14837(d)

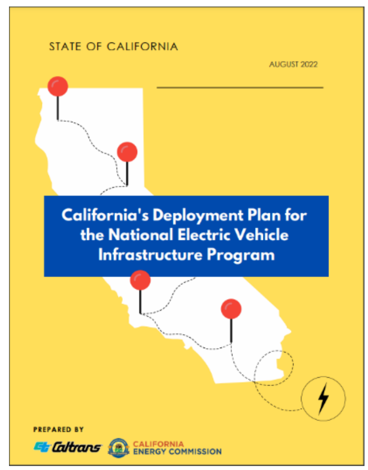
Tribes and California Tribal Organizations, or commercial fleets that are a 501(c)(3) non-profit organization.

- **Public Charging Station**: Available to public charging station developers, who can show documentation providing adequate utilization and throughput for the proposed public charging stations. The funding shall be used to install DC fast chargers at capacities of 150 kW or higher (level 2 chargers are not eligible).

- **Hydrogen Fueling**: Available for medium and heavy-duty hydrogen fueling infrastructure projects only.

National Electric Vehicle Infrastructure Formula (NEVI) Grant

On November 15, 2021, President Biden signed the Infrastructure Investment and Jobs Act/Bipartisan Infrastructure Law (IIJA/BIL), which allocated $7.5 Billion for the nationwide deployment of EV charging stations of which $5 billion is allocated to National Electric Vehicle Infrastructure (NEVI) Formula Program and $2.5B available for Competitive grant program to support communities and corridors. California's share of NEVI funding is estimated to include $384 million over the five-year period. The IIJA designates state Departments of Transportation to serve as the lead agency and requires close collaboration with state-level energy departments. The California Department of Transportation (Caltrans) and CEC are leading NEVI development in California.



The NEVI guidelines require development of the State Electric Vehicle Infrastructure Deployment Plan. Initially, NEVI funds can only be used on designated Alternative Fuel Corridors. After the corridors are built out, NEVI funding can be used on any public road or at a publicly accessible site that is open to the general public. NEVI requires that new DCFC stations be spaced no more than 50 miles apart within 1 mile of the freeway or highway corridor. The minimum technical requirements are for 4 x 150 kW connectors with a minimum station power capacity of 600 kW.

CEC in coordination with Caltrans released the final California's Deployment Plan for the National Electric Vehicle Infrastructure Program[9] as required by NEVI in August 2022. According to the plan, the initial deployment will focus on investments in light-duty vehicle charging infrastructure and will consider projects that can also accommodate MD-HD charging infrastructure. Therefore, at this point, the project team does not anticipate NEVI funds to play a critical role in development of charging infrastructure for Class 8 trucks.

Low Carbon Fuel Standard (LCFS)

The LCFS is a California regulation that creates a market mechanism that incentivizes low carbon fuels. The regulation requires the carbon intensity of California's transportation fuels to

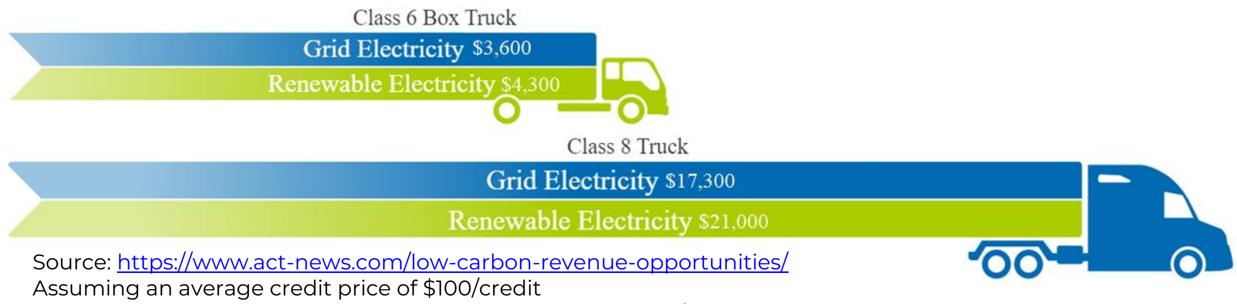
[9] https://dot.ca.gov/-/media/dot-media/programs/sustainability/documents/nevi/2022-ca-nevi-deployment-plan-a11y.pdf

decrease by 20 percent through the 2030 timeframe and maintains the standard afterwards. While LCFS is a regulatory program, it offers incentives and subsidies toward deployment and operation of non-residential EV charging and hydrogen fueling stations. This is mainly because EV chargers deliver a low-carbon fuel to transportation vehicles and therefore, owners of Level 2 and DC fast chargers are eligible to apply for the generation of LCFS credits based on the amount of fuel (electricity) dispensed. Additionally, LCFS provides credit options for deployment of DC fast chargers as well as H2 fueling station based on their capacity (called capacity credit). The number of credits that a fleet generates is based on the amount of electricity used to charge and the carbon intensity of that electricity. Fleets that strategically use renewable electricity for charging, or purchase renewable energy certificates (RECs), can further increase their LCFS revenue streams. With renewable electricity, the LCFS credits could increase by 20% as illustrated in ***Figure 3***. It is noteworthy to mention that owners of public charging infrastructure can also generate and sell credits, including incremental credits, for EV charging. Specific to public ZEV infrastructure, these sites are not only eligible for regular LCFS credits (i.e., credits earned through dispensing of fuel), but the eligible hydrogen station, or DC fast charger sites can generate infrastructure credits based on the capacity of the station or charger minus the quantity of dispensed fuel. Such credit will incentivize initial build-out of ZEV refueling infrastructure by providing credits when fuel demand is low in early years. As more ZEVs use the station and the station utilization increases, the site will generate more LCFS fuel credits and fewer infrastructure credits. Currently stations intended for light duty vehicles (<1,200 kg/day for hydrogen stations and <350 kW per charger for charging stations) are eligible for the capacity credits. Although the program does not preclude a heavy-duty vehicle from utilizing the sites, the regulation limits the design of sites for light duty use (based on the capacity constraints provided earlier). This is certainly one of the limitations of the LCFS program in promoting adoption of public charging and fueling infrastructure for medium and heavy-duty vehicles. More details on ZEV infrastructure capacity credits are provided at: *LCFS ZEV Infrastructure Crediting*. In its July 7, 2022 workshop[10], CARB staff included a discussion on the opportunity for extending these capacity credits to medium and heavy-duty vehicle stations as part of the next amendments to the LCFS program.

Credits earned through the LCFS program may be sold by a registered broker, and the value of the credits are generally required to be reinvested in electric vehicle infrastructure or services. This could include services such as EV purchases and maintenance, charging infrastructure purchases and maintenance, electricity costs, and administrative fees. The value of the LCFS credits for any one EV charging site is influenced by many factors including but not limited to: the number of EV chargers in operation, the type of EV chargers installed, the amount of fuel dispensed, and the value of the credit when sold, etc.

[10] https://ww2.arb.ca.gov/sites/default/files/2022-07/LCFSWorkshop_Presentation.pdf

Figure 3. An example of annual revenues generated using LCFS



Source: https://www.act-news.com/low-carbon-revenue-opportunities/
Assuming an average credit price of $100/credit
Assumes Class 6 truck with 20,000 annual miles and 1.3 kWh/mi electricity consumption rate
Assumes Class 8 truck with 60,000 annual miles and 2.1 kWh/mi electricity consumption rate

San Diego Gas & Electric Power Your Drive for Fleets

San Diego Gas & Electric (SDG&E) through its Power Your Drive for Fleets program offers two options for assisting fleets with their charging infrastructure. In the first option, SDG&E pays for, constructs, owns, and maintains all infrastructure up to the charging station whereas, the customer pays for, constructs, owns, and maintains charging stations. In the second option, SDG&E pays for, constructs, owns, and maintains all infrastructure up to the meter, whereas customer pays for, constructs, owns, and maintains “customer-side infrastructure” and charging stations. Under this option, SDG&E provides a rebate of up to 80% of the cost of “customer-side infrastructure.”. With this summary on regulatory and incentive programs encouraging ZEV adoption in California and specifically in San Diego County, the next section will discuss the technology readiness of ZE MD-HD vehicles.

A summary of all the above-mentioned incentive programs is provided in ***Table 2***.

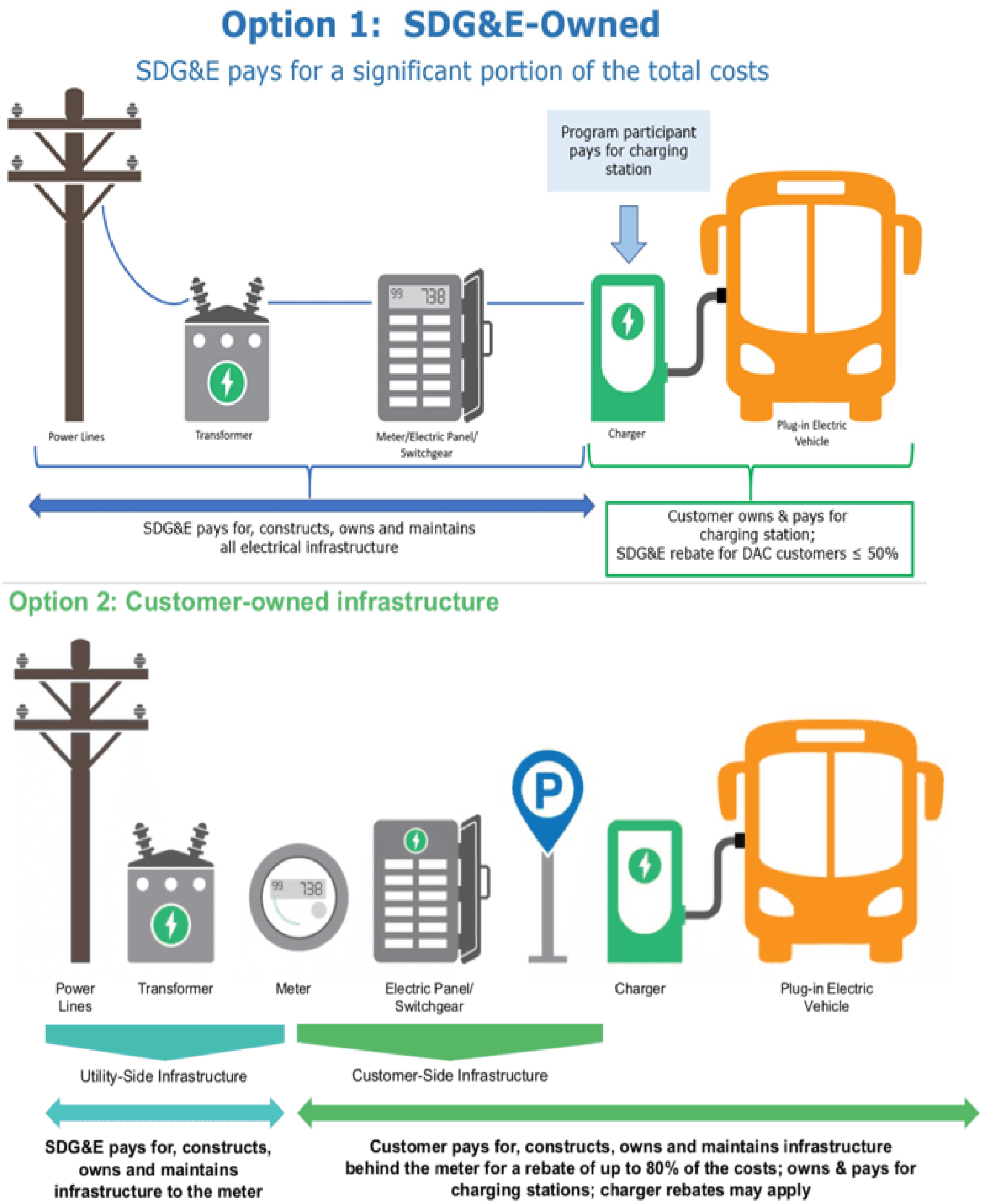


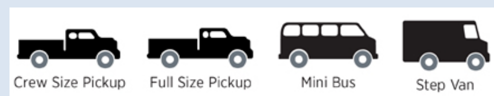
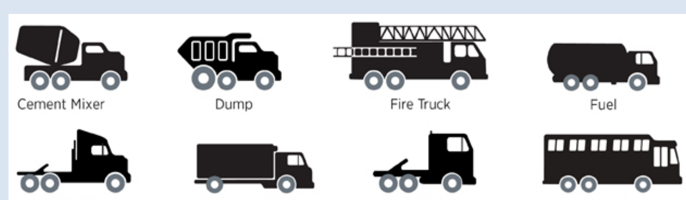
Table 2. Summary of Incentive Programs for Class 8 Trucks

Program	Incentive Structure	Eligibility	Funding Amount
HVIP	Point-of-sale	Zero-emission or 0.01 g/bhp-hr engines	$120,000 (Base)
Inflation Reduction Act	Tax rebates	Zero emissions commercial MD/HD vehicles above 14,000 lbs.	30% of the vehicle purchase price up to $40,000
Carl Moyer	Cost-effectiveness limit	Clean combustion and Zero-emissions Requires scrappage	Up to $410,000 for ZE trucks
Carl Moyer VIP	First come first served	Fleets of 10 or fewer vehicles that have been operating at least 75% (mileage-based) in California during the previous 24 months	Up to $410,000 for ZE trucks
VW Mitigation Trust	First come first served	Class 8 Freight Trucks (including drayage trucks, waste haulers, dump trucks, and concrete mixers) – Public and private	Up to $200,000 for zero-emission trucks
Truck Loan Assistance	Financing Assistance	Trucking fleets with 10 or fewer heavy-duty vehicles that are also designated as small business	Varies
Clean Transportation Program	Competitive solicitation, Block Grants, First come first served	Public and private fleets of medium and heavy-duty vehicles as well as public charging and hydrogen fueling station developers	Between 50 – 75 percent of the project cost
LCFS	Credit based program	Non-residential EV charging and H2 fueling stations	Number of credits earned x Credit price
San Diego Gas & Electric Power Your Drive for Fleets	Make-Ready Rebates	• Demonstrate commitment to procure a minimum of 2 electric fleet vehicles • Demonstrate long-term electrification growth plan and schedule of load increase • Provide data related to charger usage for a minimum of 5 years • Own or lease the property where chargers are installed within SDG&E's service area and operate and maintain vehicles and chargers for a minimum of 10 years	Provide low-to no-cost electrical system upgrades. Rebates up to 80% of the cost of customer-side infrastructure.

TECHNOLOGY READINESS & AVAILABILITY

MD-HD are considered Class 2b through 8 vehicles (above 8,500 lbs. GVWR), which cover the transportation needs for essentially all commercial activity. MD-HD vehicles range between full size pickup trucks used for low payload hauling and towing, step- and walk-in vans used for package delivery, drayage trucks, and day cab or sleeper trucks used for freight transport. The classification of Class 2b through 8 vehicles is done through the weight of the vehicle as shown in ***Table 3***.

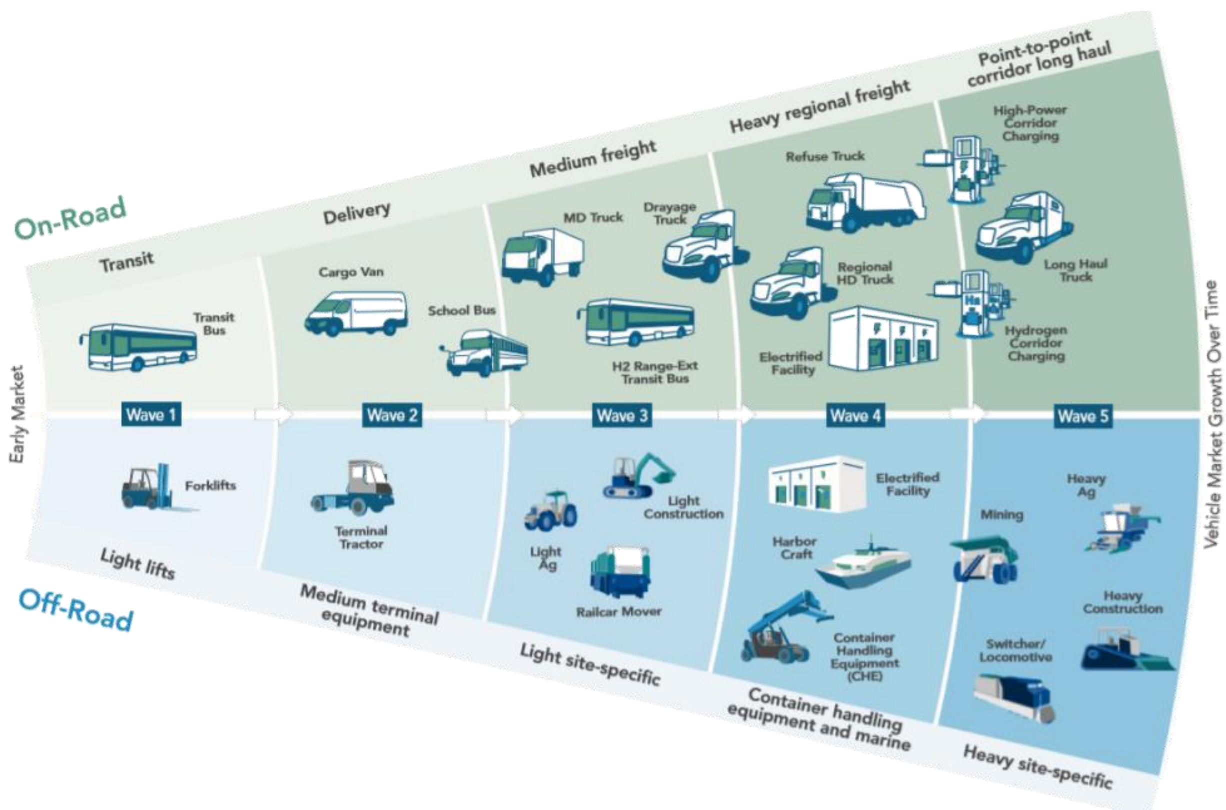
Table 3. Medium- and Heavy-Duty Vehicle Classifications by GVWR

Vehicle Class	Classification	GVRW	Vehicle Examples
Class 2b		8,501 to 10,000 lbs.	
Class 3		10,001 to 14,000 lbs.	
Class 4	Medium Duty	14,001 to 16,000 lbs.	
Class 5		16,001 to 19,500 lbs.	
Class 6		19,501 to 26,000 lbs.	
Class 7	Heavy Duty	26,001 to 33,000 lbs.	
Class 8		Over 33,000 lbs.	

Broadly speaking, there are two types of ZEVs: BEVs and FCEVs. The rest of this section will explore the ZE technology readiness and availability for each vehicle class and what the outlook is for ZE powertrain technology adoption.

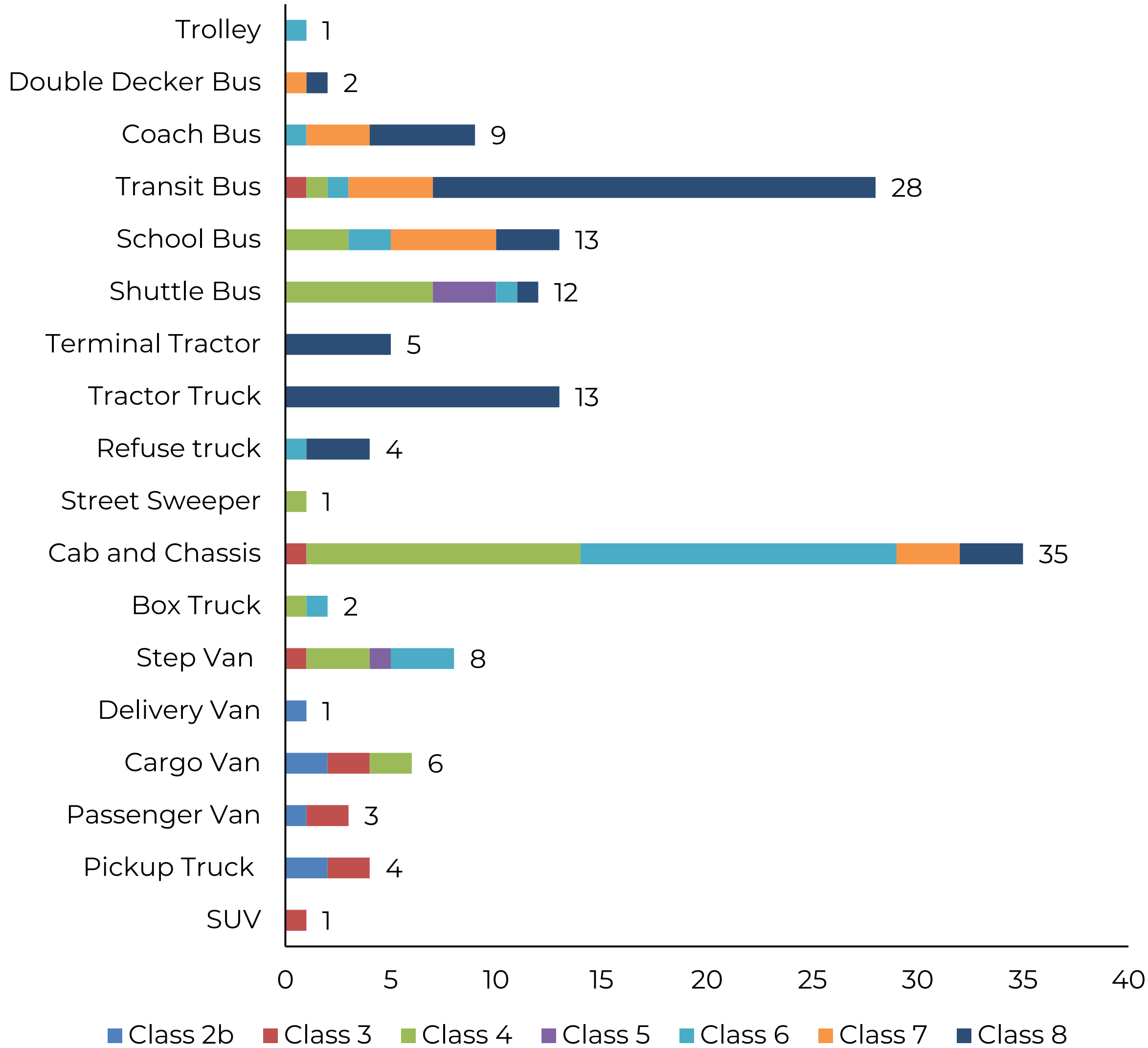
In general, technology readiness will vary not only by the vehicle class, but also duty cycle. For example, Class 8 BEVs may be better suited for short haul duty cycle compared to long-haul duty cycles. With that said, the ZEV market has expanded significantly in the past few years, and it is expected that BEVs and FCEVs will commercialize systematically, with vehicles operating on predictable and shorter routes succeeding first, particularly those with access to overnight charging depots. Following these use cases, technology is expected to develop to serve longer and more complicated applications over time. CARB calls this projection of commercialization the Beachhead Strategy shown graphically in ***Figure 4***.

Figure 4. CARB Zero-Emission Beachhead



Despite ZE technologies to be in the early stages of commercialization, over the last three years, there have been many announcements by major truck manufacturers on development and production of ZE MD-HD vehicles. According to CARB staff, there are 148 models where manufacturers are either accepting orders or preorders in North America. As can be seen in ***Figure 5***, there is a wide range of ZEVs, with cap and chassis, transit buses, tractor trucks, and school buses with the most available models as of August 2022. See ***Appendix A***: Commercially Available ZE Trucks, for a comprehensive list of available ZEV models.

Figure 5. Number of Commercially Available ZEVs[11]



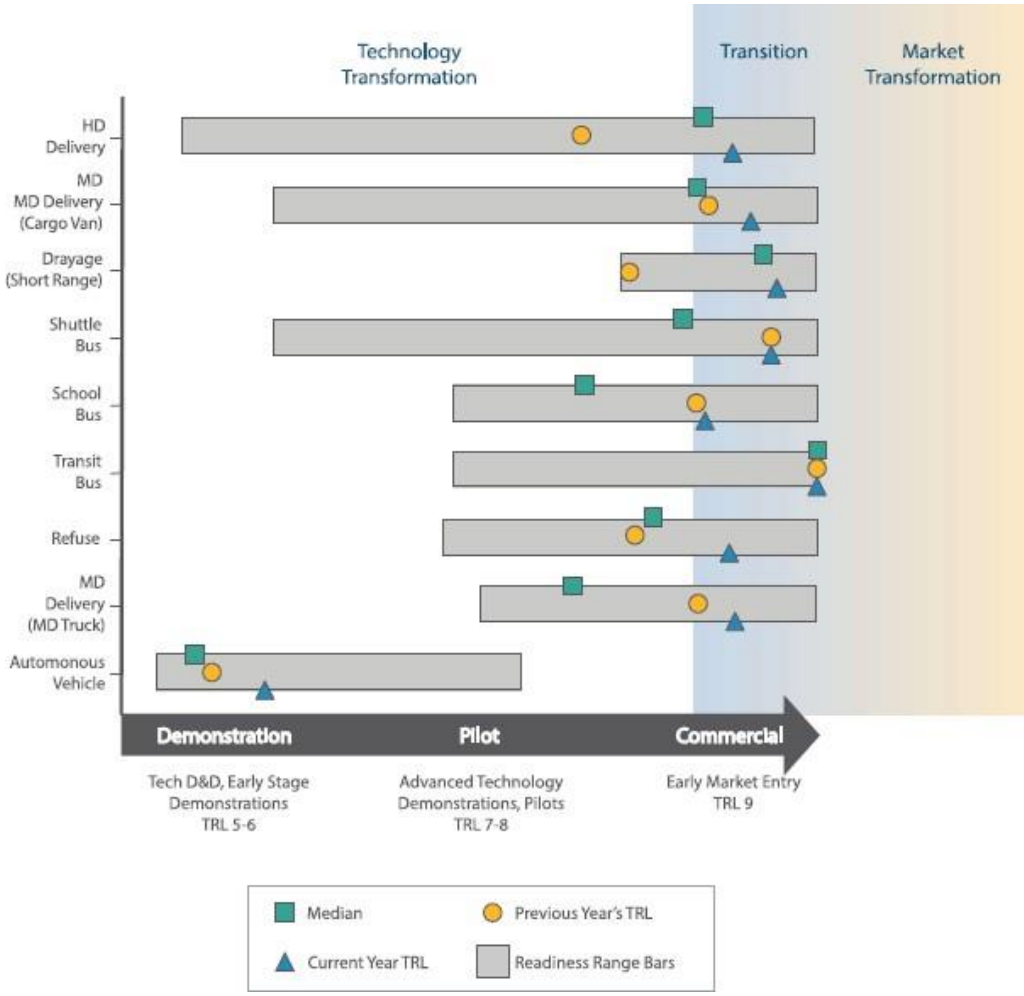
Battery Electric Vehicles

The technological readiness of Class 2b through 8 varies depending on the vehicle class and duty cycle, range requirements, and general application. Transit buses are farther along in the market followed closely by drayage, shuttle buses and delivery trucks. However, the technology is still under development for long-haul tractors. Due to shorter trip distance, and more predictable routes, transit buses, refuse trucks, and to some extent drayage trucks are suitable candidates for early deployment electric vehicles. On one hand, these vocations do not need electric vehicles with significantly high ranges, and on the other hand, the return to base and local operations of these vehicles make the charging infrastructure deployment less complicated as compared to line haul and more energy intensive applications. CARB's

[11] Proposed Advanced Clean Fleets Regulation Staff Report: Initial Statement of Reasons (ca.gov)

estimate for the technology readiness of battery electric trucks is shown in ***Figure 6***. According to this graph, all MD-HD vehicles are in the early market entry stage of commercialization.

Figure 6. On-road Battery Electric Vehicles Technology Status Snapshot[12, 13]



While demonstrations and pilots of these technologies do continue, the technology has developed to a point in which multiple manufacturers are now offering these vehicles for commercial sale. Over the last three years, there have been numerous announcements by major truck manufacturers on development and production of ZE MD-HD vehicles. According to ICF's EV Library[14], there are approximately 240 models of electric MD-HD vehicles that are either available today or planned to be available in the next two years. Note this number include vehicles within the same model that are offered with different battery capacities and electric ranges. It is also noteworthy to mention that while there are many industry announcements for availability of ZE MD-HD vehicles in the next couple of years, production of these vehicles may have been delayed due to supply chain issues caused by the COVID-19

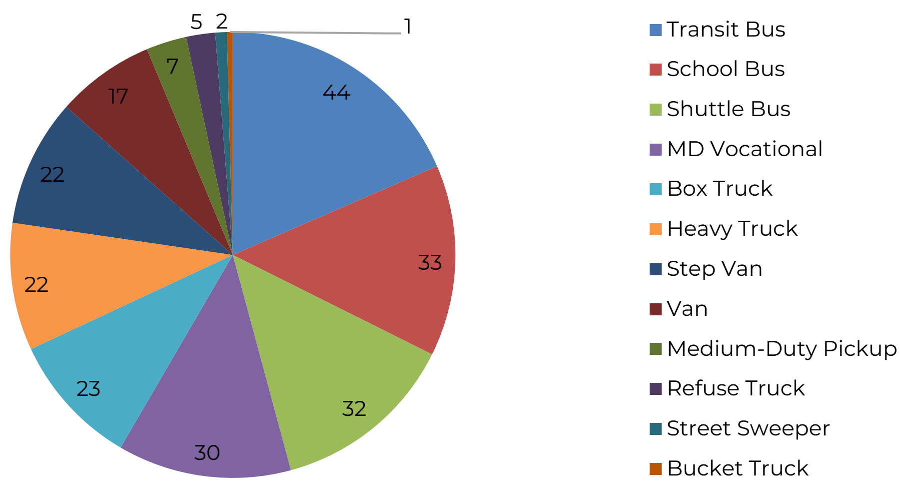
[12] CARB. (2020). Long-Term Heavy-Duty Investment Strategy. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2020-11/appd_hd_invest_strat.pdf

[13] Technology Readiness Level (TRL) is a numerical scale indicating where the technology falls on a spectrum from demonstration phases to commercialization

[14] ICF's Electric Vehicle Library is a regularly updated database of EV makes and models along with key information about their specifications and estimated year of commercial availability

pandemic or for other issues faced by the manufacturers. Therefore, there are certainly significant uncertainties involved with when these vehicles can be delivered by manufacturers.

Figure 7. Number of Available (or planned to be available) MD-HD Electric Vehicle Models in U.S. (from ICF EV Library)



The all-electric ranges of these battery electric trucks vary from as low as 60 miles for BYD 8R Refuse Truck to as high as 500 miles for Tesla Semi LR (expected to be available in 2023). ***Figure 8*** provides a graphical illustration of all electric ranges of these 240 models based on data embedded in the ICF EV Library. While typical ranges of MD-HD battery electric trucks is between 100 – 300 miles, there exists (or projected to be available) models that have electric ranges significantly above 300 miles. Aside from the all-electric range, the project team also illustrated the range of vehicle prices for these models in ***Figure 9***. As shown, while there is a wide price range for transit buses, most of the medium duty vehicles have price ranges between \$100,000 – \$230,000 (25^{th} – 75^{th} percentile). For heavy duty vehicles (excluding transit), the price range is between \$350,000 to \$480,000 (25^{th} – 75^{th} percentile).

Figure 8. All Electric Range (miles) of Battery Electric MD-HD Vehicles (ICF EV Library)

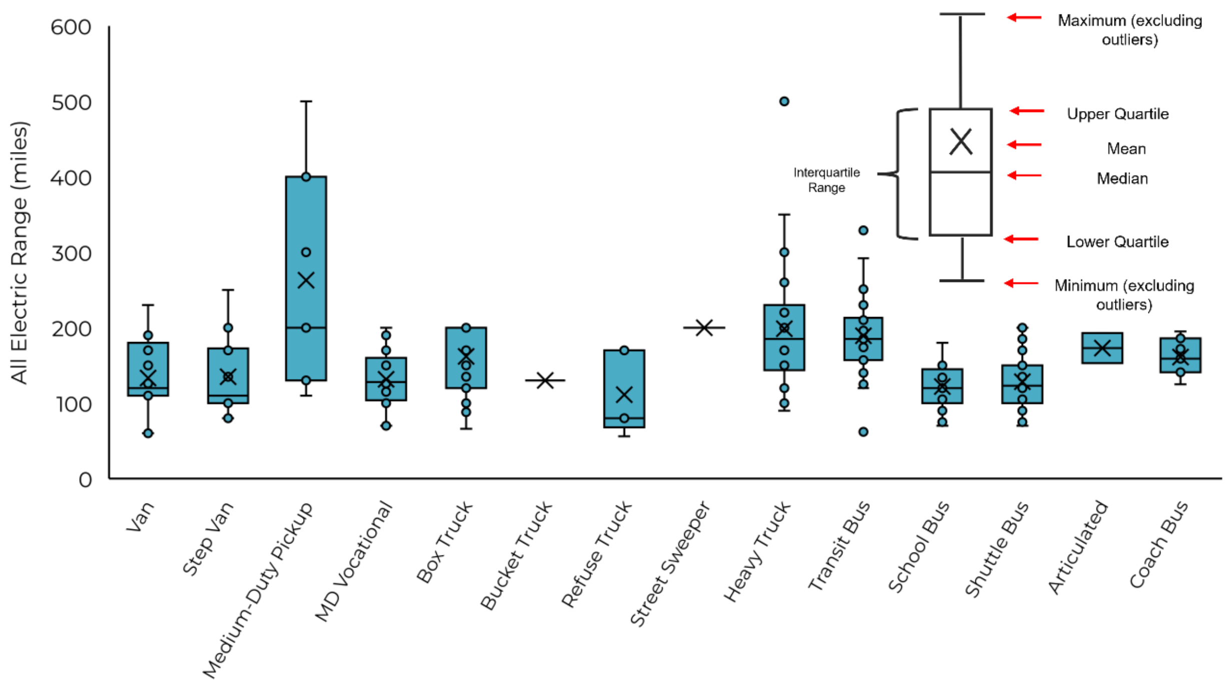
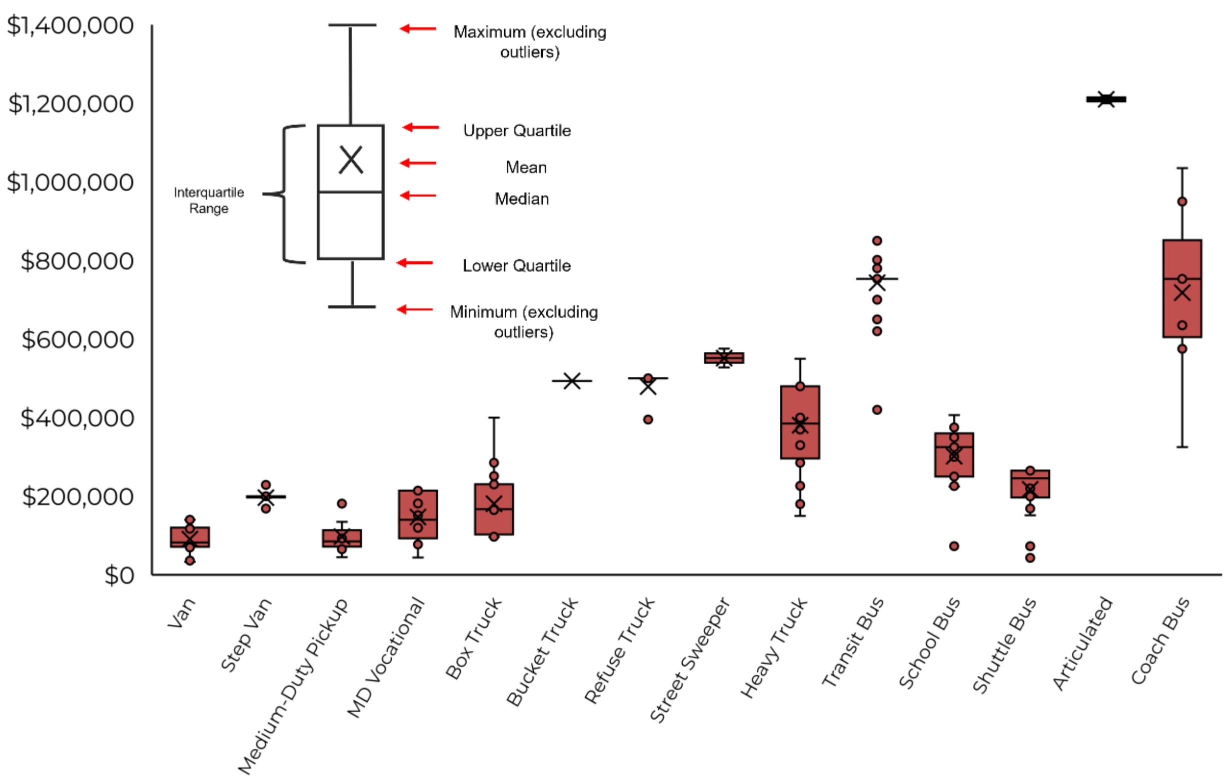


Figure 9. Actual/Projected Vehicle Price of Battery Electric MD-HD Vehicles (ICF EV Library)



Another positive development that helps illustrate the pace of market development is the prevalence of manufacturer announcements outlining their commitment toward zero-emission products as outlined in ***Table 4***. Today, there are 21 manufacturers that have announced to either fully or partially transition their vehicle offering to zero-emission technology.

Table 4. MD-HDV Manufacturer Commitments to ZEV Sales and Carbon Neutrality (as of December 2021) [15]

Manufacturer	Commitment	Date
Scania	At least 90% of zero-emission vehicle sales worldwide, with remainder powered by 100% fossil-free energy	2040
GM group	100% carbon neutral in global products and operations	2040
Stellantis	70% low-emission vehicle sales in Europe, and 40% in the US	2030
Ford Group	100% fossil free new vehicle sales	2040
Daimler Group	100% carbon neutral in driving operation in Europe, North America, and Japan	2039
Toyota Group	100% carbon neutral in lifecycle by 2050	2050
Changan	100% electric vehicle sales	2025
Great Wall Motor	100% carbon neutral with interim target of 80% new vehicle sales by 2025	2025
Mahindra & Mahindra	100% carbon neutral in operations	2040
VW Group	100% carbon neutral in operations	2050
Renault	100% carbon neutral worldwide, with interim target of 100% CO2 neutral in Europe by 2040	2050
Nissan	100% carbon neutral across operations and product lifecycle	2050
Mitsubishi	100% carbon neutral, with 50% EV sales by 2030	2050
Isuzu	100% carbon neutral in vehicle operation and plants sheet	2050
Paccar	100% fossil free new vehicle sales	2040
Suzuki	90% reduction in CO_2 emissions in driving operation	2050
Volvo Trucks Group	100% fossil free new vehicle sales	2040
CNH Industrial	100% fossil free new vehicle sales	2040
Honda	100% battery-electric and fuel cell electric vehicle sales in North America, with interim targets of 40% by 2030 and 80% by 2035	2040
Mazda	90% reduction in CO_2 emissions in driving operation and energy production	2050
Hyundai Kia	100% carbon neutral in all operations	2050

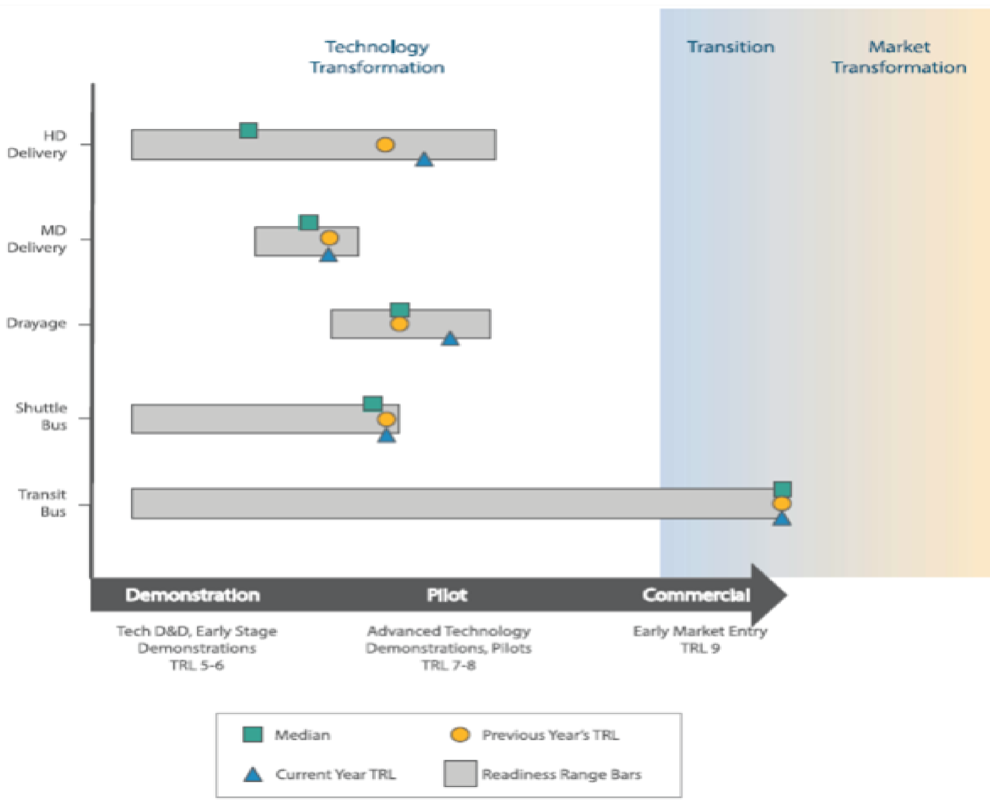
MD-HDV manufacturers continue to set ambitious targets to increase ZE heavy-duty vehicle offerings over the next 20 years. While most manufacturer targets commit to fossil-free vehicles without prescribing to a specific technology, it is likely that manufacturers will provide more BEV offerings than hydrogen due to the size of the current and expected near-term BEV market in comparison to the hydrogen vehicle market. With their competitive advantage and as BEV technology advances to increase efficiency, maximize range, and decrease the weight of the battery, manufacturers are likely to increase their BEV offerings to reach their climate targets.

[15] CALSTART. Review of Commitments for Zero-Emission Medium- and Heavy-Duty Vehicles. Retrieved May 24, 2022, from https://globaldrivetozero.org/site/wp-content/uploads/2021/12/Review-of-Commitments-for-Zero-Emission-Medium-and-Heavy-Duty-Vehicles_Dec_2021_Final-.pdf

Hydrogen

Hydrogen FCEVs are largely still in technology development stages, with demonstrations and pilots still ongoing. Currently, fuel cell electric transit buses are the only vehicle segment that are fully commercially available. For example, in California, many transit agencies are planning to transition their fleets to fuel cell electric buses (e.g., North County Transit District, Sunline Transit, Fresno Area Express, Golden Empire Transit). However, for other MD-HD hydrogen vehicles, fuel cell electric technology is still under development and automaker-announced models generally have later timeframes for release compared to battery electric vehicles. ***Figure 10*** shows CARB's estimate for the technology readiness of hydrogen powered vehicles in various vehicle classes and truck vocations. As noted, transit buses are the only hydrogen application in the MD-HD sector that has reached early market entry.

Figure 10. On-Road Fuel Cell Electric Vehicle Technology Status Snapshot[16]



Through their Global Commercial Vehicle Drive to Zero Program, CALSTART has collected information on hydrogen fuel cell MD-HD vehicles that are currently available and expected to be available within the next few years. A comprehensive list of available hydrogen powered trucks is provided in ***Table 5***. As shown there currently exists (or projected to be available) four medium-duty step vans, two shuttle buses, 8 heavy-duty trucks, and five heavy-duty busses

[16] CARB. (2020). Long-Term Heavy-Duty Investment Strategy. Retrieved from https://ww2.arb.ca.gov/sites/default/files/2020-11/appd_hd_invest_strat.pdf

are either currently available or will be available within a couple years. Note that the market for hydrogen fuel cell vehicles is still young and so price data is somewhat tentative.

Table 5. Hydrogen Fuel Cell Electric Vehicles (per the Global Commercial Vehicle Drive to Zero Program) [17]

Vehicle Type	Manufacturer	Model	Estimated Range (miles)	Reported Availability Year	Estimated Cost Information
MD Van	Unique Electric Solutions	FCCC MT-55 FC	140	2021	Unavailable
MD Van	Unique Electric Solutions	Ford F-59 FC	140	2021	Unavailable
MD Van	Unique Electric Solutions	International 1652 FC	150	2020	Unavailable
MD Van	US Hybrid	H2Cargo	125	2019	Unavailable
Shuttle Bus	US Hybrid	H2 Ride 30 ft	125	2019	Unavailable
Shuttle Bus	US Hybrid	H2 Ride 32 ft	200	2019	Unavailable
HD Truck	Hyundai	HDC-6 NEPTUNE	800	2023	Unavailable
HD Truck	Hyundai	Xcient	249	2023	$500,000[18]
HD Truck	Hyzon	FCET 8	500	2021	Unavailable
HD Truck	Hyzon	FCET 6	350	2021	Unavailable
HD Truck	Kenworth	T680	150	2023	Unavailable
HD Truck	Nikola	Tre FCEV	500	2023	$268,782[19]
HD Truck	Nikola	Two FCEV	900	2024	Unavailable
HD Truck	Toyota	Beta	300	2023	Unavailable
HD Bus	ElDorado National	Axess FC 35 ft	260	2020	Unavailable
HD Bus	ElDorado National	Axess FC 40 ft	260	2020	$1,200,000[20]
HD Bus	Hyzon	High-Floor Coach	250	2021	Unavailable
HD Bus	New Flyer	Xcelsior CHARGE H2 – 40 ft	350	2020	Unavailable
HD Bus	New Flyer	Xcelsior CHARGE H2 – 60 ft	350	2020	$850,000[21]

Additionally, out of the 21 manufacturers with listed commitments in ***Table 4***, 18 companies did not limit the technologies they will produce to reach their ZE goals. This provides manufacturers the flexibility to increase investments in future FCEV offerings as well as BEV offerings. Due to their on-board hydrogen storage, hydrogen fuel cell trucks have greater range flexibility (similar to conventional diesel), requiring fewer stops on long routes, refilling time is relatively fast, and have less risk of lost cargo capacity. This makes them a suitable option for heavier and longer-range vehicles, which explains why there are no Class 2b or 3

[17] CALSTART. Zero-Emission Technology Inventory. Retrieved March 14, 2022, from https://globaldrivetozero.org/tools/zero-emission-technology-inventory/.
[18] https://asia.nikkei.com/Business/Transportation/Hyundai-hydrogen-fueled-trucks-making-inroads-in-Europe
[19] https://cleantechnica.com/2020/08/06/head-to-head-nikolas-hydrogen-fuel-cell-trucks-vs-the-tesla-semi/
[20] https://atlaspolicy.com/wp-content/uploads/2019/07/Electric-Buses-and-Trucks-Overview.pdf
[21] https://atlaspolicy.com/wp-content/uploads/2019/07/Electric-Buses-and-Trucks-Overview.pdf

vehicles in the table above. It should be noted that there is limited availability of hydrogen fueling station in the region, requiring expansion alongside the commercialization of FCEVs.

Total Cost of Ownership

The TCO framework is a useful financial analysis methodology. Rather than simply comparing the initial purchase price of two potential vehicles, a TCO analysis compares the total costs to own and operate each vehicle. The TCO inputs include:

- Vehicle purchase price, including the state sales tax and use tax, and where applicable the federal excise tax,
- Fuel cost,
- Maintenance cost, and
- Infrastructure cost.

The TCO is particularly valuable at this juncture given the need for ZEVs, coupled with the purchase price disparity between ICE and ZE vehicles. The price of ZEVs has begun to decrease and is expected to continue through this decade and beyond. For Class 2b through 8 BEVs, price reductions are largely due to battery pack price reductions. According to CARB's ACF TCO Discussion Document [22], Class 2b and 3 BEVs will experience a 2-year delay behind light-duty BEV battery prices, while Class 4 – 8 will experience a 5-year delay.

In the short- and mid-term, until ZE vehicles reach price parity with ICE vehicles, the TCO can provide fleets with the full financial picture and capture the fuel and maintenance savings experienced by ZEVs. It is important to note, however, that TCO studies make several assumptions that influence the final results. For example, the projected price reduction for ZE models as well as projected energy prices (e.g., diesel, hydrogen, and electricity prices) are some of the key assumptions that could influence the overall conclusions from the TCO analysis. In addition, the TCO is highly dependent on several factors, including the type of vehicle purchased, daily mileage, fuel economy, fuel prices, and general operational characteristics for each vehicle.

In the following section, results from CARB's ACF TCO analysis are summarized. In this study, diesel and natural gas vehicles are compared to BEVs and FCEVs for a Class 2b cargo van, Class 5 walk-in van, Class 6 bucket truck, Class 8 refuse packer, Class 8 day cab[23], and a Class 8 sleeper cab[24]. Additional TCO studies were reviewed, including from NREL[25], CALETC[26], and CARB's Advanced Clean Trucks TCO discussion document[27]; however, it was concluded that CARB's ACF had the most up-to-date and accurate cost assumptions.

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[22] California Air Resources Board. (August 30, 2022). Advanced Clean Fleets Total Cost of Ownership Discussion Document. Retrieved from https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/appg.pdf

[23] "Day cab tractor" means an on-road tractor without a berth designed for resting or sleeping at the back of the cab and is not a yard tractor.

[24] "Sleeper cab tractor" means a tractor with a berth designed for resting or sleeping at the back of the cab.

[25] NREL. (2021, September). Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks. Retrieved from https://www.nrel.gov/docs/fy21osti/71796.pdf

[26] ICF. (2019, December). Comparison of Medium- and Heavy-Duty Technologies in California. Retrieved from https://caletc.aodesignsolutions.com/assets/files/ICF-Truck-Report_Final_December-2019.pdf

[27] CARB. (2019, February 22). Appendix H Draft Advanced Clean Trucks Total Cost of Ownership Discussion Document. Retrieved from https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/apph.pdf

CARB's ACF conducted TCOs for the vehicle classes listed above for model years 2025, 2030, and 2035.[28] This analysis assumes the useful life of diesel engines are 15 years or 270,000 miles for Class 4-5, 12 years or 350,000 for Class 6-7, and 12 years or 800,000 miles for Class 8 vehicles. Midlife costs are included in this analysis and account for the costs of replacing major components due to deterioration. For diesel and natural gas vehicles this typically involves an engine rebuild and is assumed to occur at 300,000 miles and is estimated to cost 25 percent of the total vehicle price minus vehicle body costs. BEV midlife costs account for the cost to replace a battery due to battery degradation overtime and assumed this occurs at 300,000 miles until model year 2030 and increases to 500,000 miles after model year 2030 due to battery durability innovations. Battery costs were calculated by multiplying the battery size (kWh) by the battery price per kWh at the time of replacement. Although the understanding of FCEV midlife costs is limited, the study stated that a fuel cell stack refurbishment will be necessary every seven years and is estimated to cost 33 percent of the original fuel cell stack cost at the time of refurbishment.

Diesel vehicle prices are projected to increase moderately for all vehicle classes through 2030, with a leveling off for model years 2030 and 2035. Natural gas vehicle price remains relatively steady for all vehicle classes and model years, with no substantial increase or decrease. All classes of BEVs and FCEVs are projected to decrease in price for each model year but remains marginally more expensive than diesel for 2035 model years. ***Table 6*** shows the purchase price for all vehicle classes, powertrain type, and model year. Note that this TCO does not include rebates or grants but does include revenue generated from California's LCFS fuel credits. The authors stated that incentives were intentionally omitted in order to show the true costs across powertrains without the impact of subsidies. With respect to LCFS credits, CARB staff projected an LCFS credit price of $200 until 2030, then declining linearly to $25 in 2045 and remaining constant thereafter. Using this assumption, in 2025, an electric Class 2b-3 vehicle will earn $0.147/kWh using grid electricity while an electric Class 4-8 vehicle will earn roughly $0.249/kWh at $200 credit price[29]. Note that at the time of developing this report, an average LCFS credit is being traded at $87 per credit, significantly lower than that assumed by CARB's TCO analysis.

Table 6. Initial Purchase Price Forecast by Model Year and Vehicle Class

Vehicle	2025 MY	2030 MY	2035 MY
Class 2b Cargo Van – Diesel	$39,963	$40,364	$40,364
Class 2b Cargo Van – Gasoline	$35,963	$36,364	$36,364
Class 2b Cargo Van – Battery-Electric	$52,447	$48,001	$47,174
Class 2b Cargo Van – Fuel Cell Electric	$79,405	$67,592	$67,489
Class 5 Walk-in Van – Diesel	$90,709	$94,403	$95,703
Class 5 Walk-in Van – Natural Gas	$107,028	$107,983	$108,177
Class 5 Walk-in Van – Battery-Electric	$113,571	$105,167	$105,167
Class 5 Walk-in Van – Fuel Cell Electric	$129,422	$119,397	$119,397
Class 6 Bucket Truck – Diesel	$130,491	$134,725	$135,585
Class 6 Bucket Truck – Battery-Electric	$156,349	$144,073	$139,903
Class 6 Bucket Truck – Fuel Cell Electric	$176,695	$161,317	$157,147

[28] No 2025 analysis is included for sleeper cab tractors since they do not face a requirement in the current Advanced Clean Fleets proposal until 2030.
[29] Note that the difference between Class 2b-3 and Class 4-8 is mainly because of different Energy Economy Ratio (EER) assumptions.

Vehicle	2025 MY	2030 MY	2035 MY
Class 8 Refuse Packer – Diesel	$231,783	$236,085	$237,140
Class 8 Refuse Packer – Natural Gas	$258,823	$259,778	$259,972
Class 8 Refuse Packer – Battery-Electric	$299,932	$276,029	$266,929
Class 8 Refuse Packer – Fuel Cell Electric	$316,578	$294,380	$285,280
Class 8 Day Cab – Diesel	$143,862	$149,865	$150,920
Class 8 Day Cab – Natural Gas	$195,607	$198,263	$198,457
Class 8 Day Cab – Battery-Electric	$201,999	$176,028	$176,028
Class 8 Day Cab – Fuel Cell Electric	$212,353	$190,155	$190,155
Class 8 Sleeper Cab – Diesel	$153,862	$159,865	$160,920
Class 8 Sleeper Cab – Natural Gas	$240,607	$243,263	$243,457
Class 8 Sleeper Cab – Battery-Electric	$304,629	$247,638	$247,638
Class 8 Sleeper Cab – Fuel Cell Electric	$251,403	$226,272	$226,272

For this analysis it is assumed that diesel and natural gas trucks have the same maintenance costs per mile. Battery electric and hydrogen trucks are also assumed to have the same maintenance costs per mile. In general, higher daily and annual VMT results in lower maintenance costs, which are reflected in the table below where sleeper cab and day cab are assumed to have the lowest maintenance costs due to higher VMT (***Table 7***).

Table 7. Vehicle Maintenance Costs per Mile

Vehicle	Maintenance Cost ($/mi.)
Class 2b Cargo Van – Diesel	$0.34
Class 2b Cargo Van – Gasoline	$0.34
Class 2b Cargo Van – Battery-Electric	$0.25
Class 2b Cargo Van – Fuel Cell Electric	$0.25
Class 5 Walk-in Van – Diesel	$0.21
Class 5 Walk-in Van – Natural Gas	$0.21
Class 5 Walk-in Van – Battery-Electric	$0.16
Class 5 Walk-in Van – Fuel Cell Electric	$0.16
Class 6 Bucket Truck – Diesel	$0.70
Class 6 Bucket Truck – Battery-Electric	$0.53
Class 6 Bucket Truck – Fuel Cell Electric	$0.53
Class 8 Refuse Packer – Diesel	$0.94
Class 8 Refuse Packer – Natural Gas	$0.94
Class 8 Refuse Packer – Battery-Electric	$0.71
Class 8 Refuse Packer – Fuel Cell Electric	$0.71
Class 8 Day Cab – Diesel	$0.20
Class 8 Day Cab – Natural Gas	$0.20
Class 8 Day Cab – Battery-Electric	$0.15
Class 8 Day Cab – Fuel Cell Electric	$0.15
Class 8 Sleeper Cab – Diesel	$0.16
Class 8 Sleeper Cab – Natural Gas	$0.16
Class 8 Sleeper Cab – Battery-Electric	$0.12
Class 8 Sleeper Cab – Fuel Cell Electric	$0.12

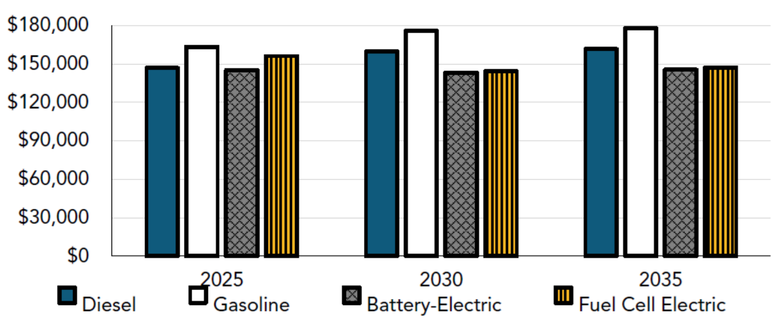
This analysis accounts for infrastructure costs differently for each powertrain technology. For diesel and hydrogen vehicles it is assumed that these vehicles will either use existing infrastructure or publicly accessible stations, thus there are no infrastructure costs included for diesel and FCEVs. Natural gas vehicle infrastructure costs were obtained from two sources. For Class 8 vehicles, costs are assumed to be $40,000 per vehicle, which was taken from the ICT rulemaking, where 100 bus refueling stations cost $4,000,000. For class 4-7 vehicles, NREL's VICE 2.0 CNG model was used and assumes $18,000 per vehicle. For BEVs, all vehicles except Class 8 sleeper cabs are assumed to use depot charging, which is reflected in each TCO (see ***Table 8***). Class 8 sleeper cabs on the other hand are assumed to use public opportunity charging stations.

Table 8. Charger Power Ratings and Infrastructure Costs per Vehicle

Vehicle	Charger Power (kW)	Charger Cost	Infrastructure Upgrade Cost
Class 2b Cargo Van	19	$5,000	$25,000
Class 5 Walk-in Van	19	$5,000	$25,000
Class 6 Bucket Truck	50	$25,000	$44,000
Class 8 Refuse Packer	150 kW for 2 vehicles	$37,500	$44,000
Class 7-8 Day Cab Tractor	150 kW	$75,000	$88,000

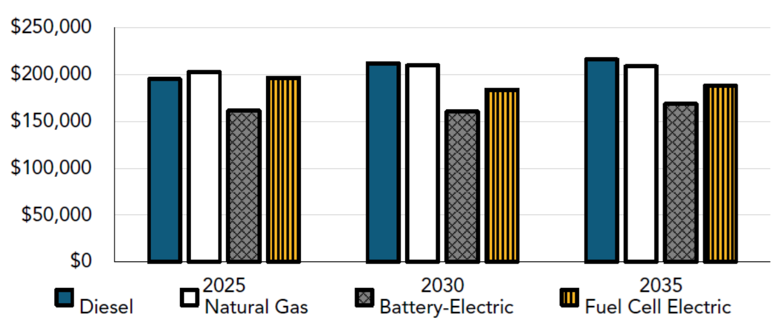
The TCO results from this analysis showed that in general BEVs achieved TCO cost savings through a combination of lower operational costs and revenue from LCFS credits. TCO cost competitiveness for FCEVs occurs later than BEVs, around 2030 – depending on the vehicle class. Additionally, because this analysis assumed all vehicles were financed, although upfront costs were higher compared to diesel vehicles, that operational savings would accrue before substantial cashflow would be required. ***Figure 11*** through ***Figure 16*** present the TCO results for all vehicle classes.

Figure 11. Class 2b Cargo Van TCO



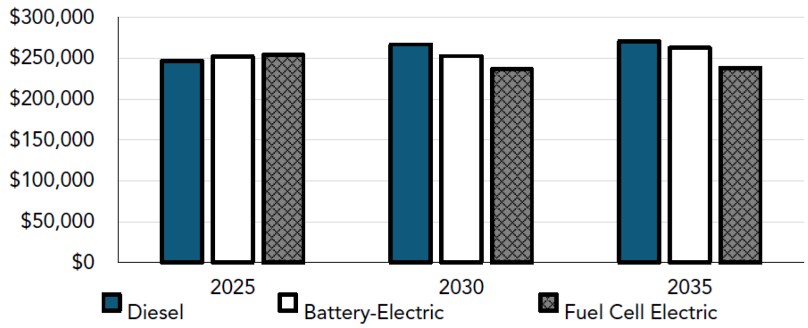
BEV cargo vans achieve a slightly favorable TCO for all model years. FCEVs achieve a favorable TCO, comparable to BEVs for model years 2030 and 2035, while model year 2025 remains moderately more expensive.

Figure 12. Class 5 Walk-in Van TCO



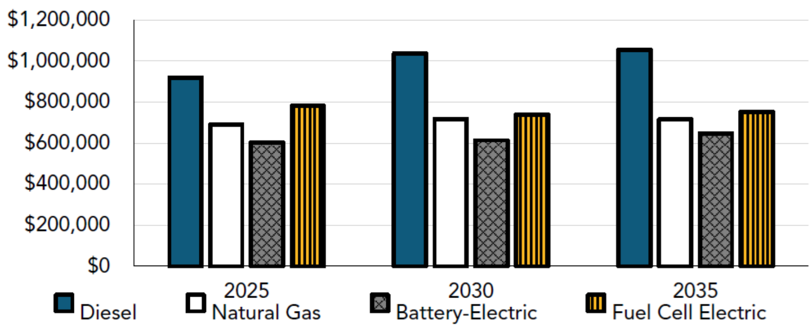
BEV walk-in vans achieve a favorable TCO for all model years, while FCEVs achieve a favorable TCO for model years 2030 and 2035 – and achieve TCO price parity for model year 2025.

Figure 13. Class 6 Bucket Truck TCO Comparison



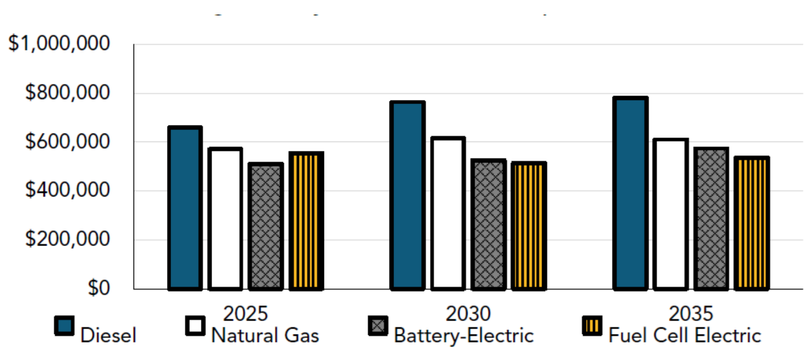
BEV and FCEV bucket trucks achieve a favorable TCO for all 2030+ model years. Specific to bucket trucks, fuel cell electric trucks show a more favorable TCO than battery electric options for future model years.

Figure 14. Class 8 Refuse Truck TCO



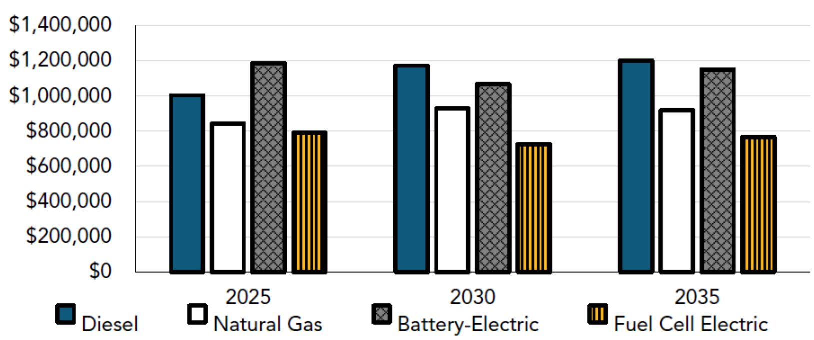
BEV and FCEV refuse trucks are substantially less expensive for all model years. favorable TCO for all model years.

Figure 15. Day Cab Tractor TCO Comparison



Day Cab tractor with a short haul travel pattern show BEV and FCEVs achieving a favorable TCO for all model years.

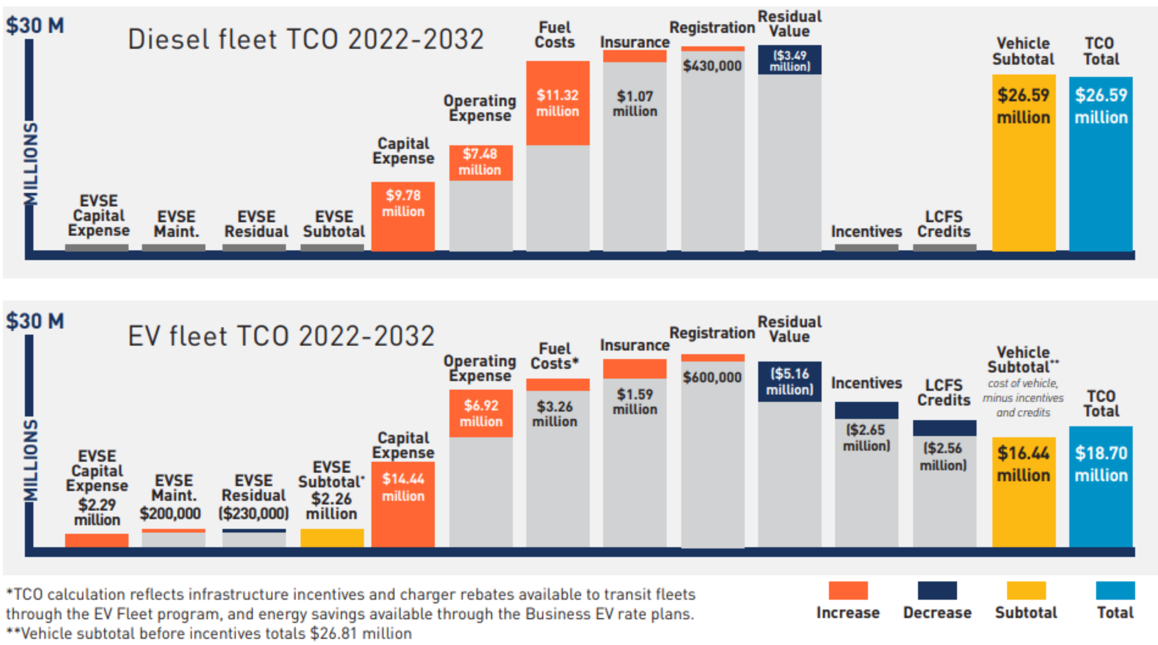
Figure 16. Sleeper Cab Tractor TCO



For a sleeper cab tractor, FCEVs exhibit a favorable TCO for all model years, while BEVs remain more expensive for 2025 model

It is noteworthy to mention that while the TCO analysis presented in this section is focused on medium- and heavy-duty trucks, there are other studies conducted by various utilities and public agencies on the TCO of battery electric, hydrogen, and internal combustion engines (diesel, and CNG) transit buses. For example, ***Figure 17*** provides a TCO analysis conducted by Pacific Gas & Electric (PG&E) comparing the TCO of a 20-vehicle transit fleet operating on diesel versus electricity. More on TCO analysis for transit buses can be found at CARB's ICT Rollout Plan webpage[30] where transit agencies such as the San Diego Metropolitan Transit System has provided their plan (including cost estimates) for transitioning to ZE buses.

Figure 17. TCO to Transition a 20-vehicle Transit Fleet from Diesel to Electric[31]



[30] https://www.pge.com/pge_global/common/pdfs/solar-and-vehicles/your-options/clean-vehicles/charging-stations/ev-fleet-program/transit-tco.pdf
[31] https://www.pge.com/pge_global/common/pdfs/solar-and-vehicles/your-options/clean-vehicles/charging-stations/ev-fleet-program/transit-tco.pdf

CHARGING & FUELING INFRASTRUCTURE STATUS

Charging and fueling infrastructure for both BEVs and FCEVs can be organized into public stations, which will require fast charging and refill rates and private or semi-public depot facilities which typically utilize overnight charging and thus require less power level EVSE for BEVs. According to CEC's Zero-Emission Vehicle and Infrastructure Statistics[32], there are currently 428 direct current fast charging (DCFC) stations ports, and 9,633 Level 2 chargers in the region. The majority of these chargers were constructed to only serve light duty vehicles. In terms of hydrogen stations, currently, there is one operational public hydrogen fueling infrastructure for light duty vehicles, and 5 other stations planned to be deployed of which one of them will be for transit buses.

Class 2b through 8 BEVs will require a range of charging options to accommodate the diversity of vehicle operations. As a simple example, Class 8 trucks that operate solely in California and those that operate across state borders will travel different distances daily and annually; charging needs for trucks that stay within California will also vary greatly depending on their duty-cycle. Level 2 chargers are more suitable for medium-duty BEVs and have a power level between 2.5 and 19.2 kW. Direct current fast chargers (DCFC) are more likely to be needed for Class 7 and 8 trucks and lower vehicle classes when fast charging is necessitated due to daily range requirements. DCFCs can currently operate at power levels between roughly 20 kilowatts (kW) and 360 kW, offering a significantly faster charge than Level 2 chargers. For example, a 150 kW and 350 kW DCFC can charge an electric truck in 1.2 hours and 0.5 hour, respectively (assuming a battery capacity of 175 kilowatt-hours (kWh)). In contrast, the same truck would take 8 to 10 hours to charge using a Level 2 charger. A more recent development within the industry is megawatt (MW) charging technology, which has the potential to significantly reduce charging dwell times. Leading the development of a Megawatt Charging System (MCS) is the member-based Charging Interface Initiative (CharIN). The MCS is designed to provide a maximum of 3.75 MW of charging power (***Figure 18***). It is expected that CharIN will publish the final MCS standard in 2024.[33]

Figure 18. The Megawatt Charging System (MCS) Connector

[32] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics
[33] Inside EVs. (2022, June 15). CharIN Officially Launches The Megawatt Charging System (MCS). Retrieved from https://insideevs.com/news/592360/megawatt-charging-system-mcs-launch/

Connector standardization is also important to the success of MD-HD vehicle electrification. While interoperability in charging infrastructure is improving over time, there remains a lack of standardization for charger connectors. Importantly, interoperability goes beyond connector standards; it also includes the software and communications connections between EVSE and charging networks. ***Table 9*** shows existing and upcoming charging connector standards relevant to MD-HD electric vehicles. As you can see, Level 1 and 2 chargers simply use the SAE J1772, while DCFC spans several connector standards.

Table 9. Existing and Upcoming Charging Connector Standards[34]

Diagram	Connector Standard	Maximum Output Power	Application Notes
	SAE J1772	19.2 kW AC	Used for Level 1 and Level 2 charging in North America. Commonly found on home, workplace, and public chargers.
	CCS[35]	450 kW DC	Used for DC fast charging most vehicle models in North America. Generally installed at public charging stations.[36]
	CHAdeMO	400 kW DC	Used for DC fast charging select vehicles models in North America. Generally installed at public charging stations[37].
	Tesla	22 kW AC 250 kW DC	Used for both AC and DC fast charging for Tesla models only.
	SAE J2954	22 kW light-duty, 200 kW MD/HD	Wireless power transfer. The standard for MD/HD vehicles is under development.
	SAE J3068	133 kW to 166 kW DC	Developed for three-phase charging, which the SAE J1772 and J1772 combo could only accommodate single-phase charging.
	SAE J3105	>1 MW	Automated connection device to charge MD/HD vehicles. Variants include pantograph "up" or "down" and pin-and-socket. LA Metro has already deployed this technology on the G/Orange Line,
	CharIN Megawatt Charging System	4 MW	Conductive MW-level charging for MD/HD road vehicles, ships and planes. The technical specification is expected in 2024.

[34] California Energy Commission. (2021, July). Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment Analyzing Charging Needs to Support ZEVs in 2030. Retrieved from https://efiling.energy.ca.gov/getdocument.aspx?tn=238853

[35] North American CCS standard is referred to as Type 1, CCS 2.0 is typically found in Europe.

[36] Incentive funding provided by the federal government via the National EV Infrastructure (NEVI) Formula Program is contingent upon certain requirements including that the chargers must include at least four 150kW plugs with CCS ports. This requirement, however, is only to receive federal funding through the NEVI program. Anyone can deploy CHAdeMO charger ports if they want, they just won't qualify for federal NEVI funding. See NEVI funding guidelines here: https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/90d_nevi_formula_program_guidance.pdf

[37] It is noteworthy to mention many of the zero emission vehicle manufacturers are moving aways from the CHAdeMO and shifting their products to be compatible with CCS.

Over the past three years, there have been multiple studies conducted by various non-profit organizations such as International Council on Clean Transportation[38] (ICCT), National Renewable Energy Laboratory[39] (NREL), Rocky Mountain Institute[40] (RMI), Environmental Defense Fund[41] (EDF) to estimate the cost of EV charging infrastructure deployment including the cost of equipment, installation, as well as the needed utility upgrades (e.g., grid interconnections). Considering the known challenges with EV infrastructure deployment, it was no surprise to see a significant cost variability across these studies. While these studies provided similar estimates for the equipment costs, the installation and utility upgrade costs varied significantly. A list of estimates provided by these studies are shown in ***Table 10*** below.

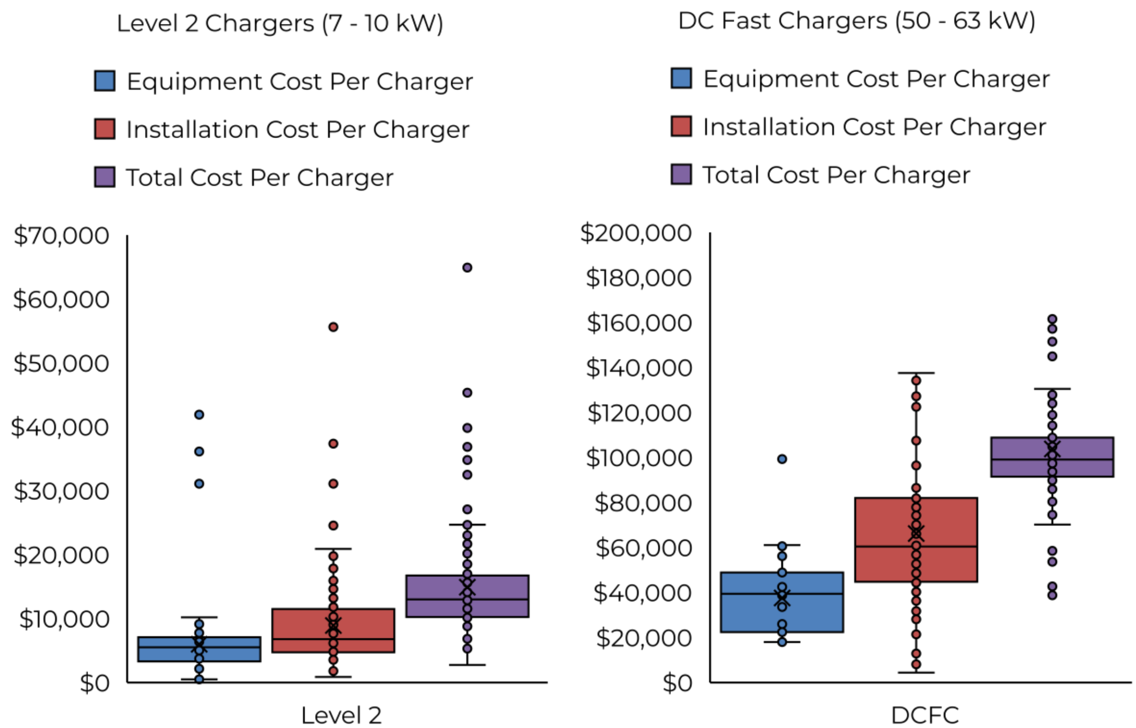
Table 10. Equipment and Installation Cost Data Reported in the Literature for Standard Level 2 and DCFC Chargers

Cost Elements	Study	Level 2	DCFC			
			50 kW	150 kW	350 kW	800 kW
Equipment Cost	ICCT (2019)	$3k	$28k	$75k	$140k	
	NREL (2020)	$3.5k	$38k	$90k		
	RMI (2020)	$2.5k - $4.9k	$20k - $36k	$76k - $100k	$128k - $150k	
	EDF & GNA (2021)			$137k		$481k
Installation Cost	ICCT (2019)	$3k - $4k	$18k - $46k	$19k - $48k	$26k - $66k	
	NREL (2020)	$2.5k	$20k	$60k		
	RMI (2020)	$7k	$63k	$76k	$138k	
	EDF & GNA (2021)			$35k		$175k

To further elaborate on the variability of EV infrastructure cost, ICF recently acquired EV charging infrastructure cost data associated with projects funded by the California Energy Commission[42] through the California Electric Vehicle Infrastructure Project (CALeVIP). The CALeVIP, implemented by the Center for Sustainable Energy (CSE), provides incentives for EV charger installations, and works with local partners on projects that support regional EV needs for Level 2 and DC fast charging units. Between December 2017 and October 2021, the program has funded 244 projects to deploy more than 500 Level 2 chargers with charging capacities ranging from 7 to 10 kW and approximately 300 DC fast chargers with charging capacities ranging from 50 to 63 kW. A summary of the cost data from CALeVIP projects are illustrated in the two whisker-box plots shown in ***Figure 19***. While on average, the equipment and installation cost for both Level 2 and DC Fast Chargers lines up with the recent published studies, this dataset clearly shows the significant variability across different projects. For Level 2 chargers, the total cost of EV charger deployment can vary between $2,700 - $24,000 per charger (excluding outliers), and for DC Fast Charger, it can range from $70,000 to $130,000. It is apparent that while there are some level variabilities across the equipment cost, the cost of installation is what mainly drives the variability for the total cost of deployment. For example, for the DC fast chargers, while the equipment cost varies from $18,000 to $61,000 (excluding outliers), the installations costs range from as low as $4,000 to as high as $137,000.

[38] https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf
[39] https://www.sciencedirect.com/science/article/pii/S2542435120302312
[40] https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf
[41] http://blogs.edf.org/energyexchange/files/2021/03/EDF-GNA-Final-March-2021.pdf
[42] https://www.energy.ca.gov/

Figure 19. CALeVIP Charging Infrastructure Cost Data



The installation cost variability is an inherent challenge to EV charging infrastructure deployment. This is mainly because there are several different variables involved in determining the total cost of installing a charger including the number of chargers per site, permitting/code requirements, site preparation cost, availability of grid interconnection, grid capacity, utility upgrades (e.g., transformers/switchgears), parking availability, and the level of construction needed.

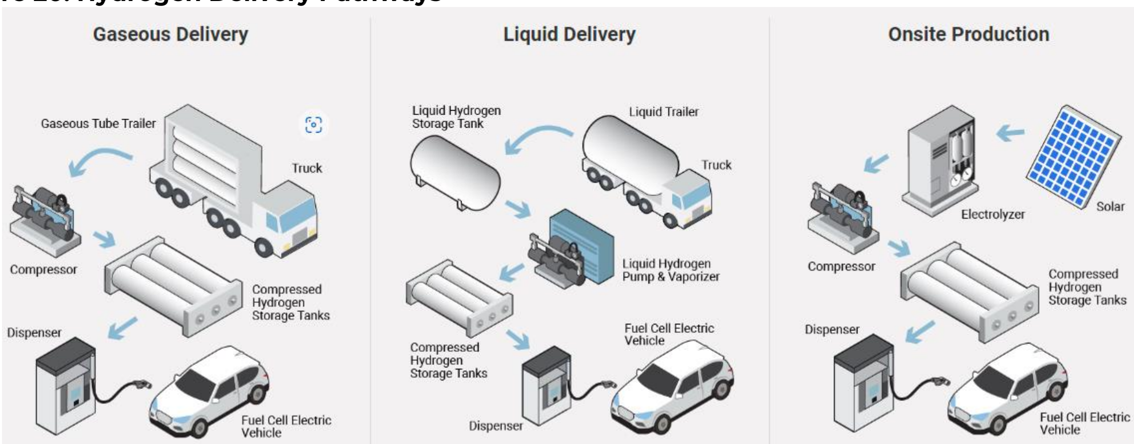
Hydrogen fueling infrastructure deployment is still in its infancy, with only 48 open retail stations in the United States as of mid-2021. With that said, the industry is taking steps to expand hydrogen fueling infrastructure. For instance, there are currently at least 60 retail stations in different stages of planning or construction, predominantly in California.[43]

Current hydrogen delivery systems include gaseous hydrogen delivery, liquid hydrogen delivery, and on-site hydrogen production and storage. Gaseous hydrogen delivery entails compressing hydrogen prior to transport, which is then delivered by truck or pipeline to the customer. 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. One of the advantages of this delivery pathway is that it can be more economical than trucking gaseous hydrogen over long distances. Hydrogen may also be produced on-site using several processes. 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

[43] AFDC. (n.d.). Hydrogen Fueling Infrastructure Deployment. Retrieved from https://afdc.energy.gov/fuels/hydrogen_infrastructure.html

hydrogen is not feasible, with one example being fuel cell electric buses deployed at Sunline Transit in the Coachella Valley. ***Figure 20*** depicts the three types of hydrogen delivery pathways.

Figure 20. Hydrogen Delivery Pathways[44]



As described earlier, through the Clean Transportation Program, the CEC invests in charging as well as hydrogen fueling infrastructure. ***Table 11*** below provides a list of MD-HD hydrogen fuel stations that are funded through this program. The funding for these projects covers direct and indirect labor for designing, engineering, and building the stations along with the equipment and shipping of the equipment. Data from the 6 hydrogen infrastructure projects funded under this program suggest that on average a MD-HD hydrogen fueling station would cost around $4,978 per kg/day which is very close to what CARB also suggested as part of its self-sufficiency report[45].

Table 11. Cost of H2 Fueling Station - CEC Clean Transportation Program

Recipient Name	Purpose	Capacity	Capital Cost
Equilon Enterprises LLC	Renewable hydrogen fueling station for freight at the Port of Long Beach	1,000 kg/day	$8,000,000
North County Transit District	North County Transit District Next Generation Hydrogen Fueling Infrastructure Project	Under Development	$6,000,000
Sunline Transit Agency	Liquid hydrogen refueling infrastructure for transit buses	1,680 kg/day	$4,986,250
Alameda Contra-Costa Transit District	Division 4 Hydrogen Fueling Infrastructure Upgrade	Under Development	$4,565,975
Center for Transportation and the Environment	NorCAL Drayage Truck Project	1,600 kg/day	$9,898,218
Equilon Enterprises LLC	Shell Multi-Modal Hydrogen Refueling Station (at the Port of West Sacramento for Sierra Northern Hydrogen Locomotive Project)	1,450 kg/day	$4,000,000

[44] California Fuel Cell Partnership. (n.d.). Costs and Financing. Retrieved from https://h2stationmaps.com/costs-and-financing
[45] https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf

LESSONS LEARNED FROM PILOT ZE PROJECTS

To successfully rollout of ZEVs and the accompanying fueling and charging infrastructure, the State has prioritized investment in pilot projects to better understand what challenges fleets are experiencing when transitioning to ZEVs. Ongoing BEV pilot projects are primarily interested in testing ZE technologies for heavy-duty weight classes and vehicles with more complex daily operations that may pose challenges, particularly for BEVs. As part of a statewide program that is funded by revenue from California's cap-and-trade program, the California Climate Investments seeks to reduce transportation sector greenhouse gas emissions through its Moving California Program. The remainder of this section outlines lessons learned from some of these pilot projects.

Class 6: Green On-Road Linen Delivery Project

This project focuses on the deployment of 21 battery-electric Class 6 walk-in vans to be used exclusively in linen delivery in San Joaquin Valley Air Pollution Control District. The vehicles were powered by Motiv propulsion systems, built on Ford F-59 chassis. This project was completed in the Spring of 2020 and achieved an average fleet up time of 98 percent with cumulative fleet mileage of 231,000 as of Q1 2020.

Lessons Learned

- **Successful driver training** is critical for maximum fleet performance
- Successful **EVSE infrastructure implementation is a fully collaborative activity** between site managers, utilities, and technology providers

Source: https://ww2.arb.ca.gov/lcti-green-road-linen-delivery-project

Class 7 & 8: Volvo Low Impact Green Heavy Transportation Solutions

Through a partnership between South Coast AQMD and Volvo Group North America, a project to assess the commercialization of heavy-duty BEVs in the Port of Long Beach. This project put into place a zero-emission goods movement system that connected the Ports of Long Beach and Los Angeles with four freight handling facilities. In total, the project deployed 59 pre-commercial and commercial Class 8 BEVs as well as 56 Level 2 and DCFC (ranging from 50 to 150 kW).

Lessons Learned

- **Pivoted to CCS1 connector** based on customer needs for faster charging, more drayage trips/day
- **Infrastructure deployment lead times longer**, challenging to align with equipment delivery
- **Challenges in utility interconnection approvals** for integrated solar/energy storage at fleets due to different requirements

Source:https://ww2.arb.ca.gov/lcti-sustainable-terminals-accelerating-regional-transformation-start-project-phase-1

Class 8: Sacramento Regional Zero-Emission School Bus Deployment Project

This project, which deployed 28 battery electric school buses, is aiming to show the financial, environmental, and performance benefits of transitioning to zero-emission school buses in the Sacramento area. In addition to the buses, 29 charging ports will be installed on school property. This project is still ongoing and transporting students daily.

Lessons Learned

- **Time delays due to unintended consequences** in planning on scope of work for the project, incorrect assumptions regarding infrastructure completion steps
- **Delays in construction of infrastructure,** due to requirements, regulations, inspections
- **Develop improved communication and collaboration** with our facilities department, for more understanding and acceptance of new technology. Breakthrough resistance to change
- **Stricter management of invoicing** and payment

Source:https://ww2.arb.ca.gov/lcti-sacramento-regional-zero-emission-school-bus-deployment-project

VEHICLE AND INFRASTRUCTURE STUDY

Following the policy landscape and technology readiness evaluations for ZE MD-HD vehicles, the project team conducted a vehicle and infrastructure study to identify the potential type and quantity of MD-HD ZEVs and infrastructure for the region. The region's MD-HD vehicle technology portfolio and supporting infrastructure is informed by State regulations and regional electrification strategies. To determine the number of ZEVs, including ZE trucks and buses, the project team conducted MD-HD vehicle fleet modeling using CARB's EMFAC2021 model. EMFAC2021 estimates the number of ZE MD-HD vehicles that will be deployed within the region based on State policies, such as the ACT and ICT regulations. Additionally, the project team considered the impact of the proposed ACF regulation on regional ZE MD-HD vehicle deployment. Detailed vehicle population and energy consumption data for ZE MD-HD vehicles by type, as well as the number and characteristics of regional infrastructure deployments (e.g., L2, DCFC, Hydrogen) are examined. The projected ZE MD-HD vehicle and infrastructure deployments between 2020 through 2040 for the region are consolidated into this Vehicle and Infrastructure Study, which is organized into the following sections:

- **San Diego Region Vehicle Study:** This section describes how the project team used the CARB EMFAC2021 model to develop the region's MD-HD Vehicle Study. The CARB EMFAC2021 model provides the current and projected MD-HD vehicle population under "Baseline" conditions (i.e., ACT, ICT). Subsequently, the "ACF Scenario" is modeled, simulating accelerated ZEV adoption requirements for Class 2b through 8 vehicles. The project team determined the fraction of the region's vehicle population affected by the proposed ACF regulation requirements. This study illustrated the difference between Baseline and ACF scenarios, and the distribution of MD-HD vehicles by fuel type are tabulated. Additionally, the project team provided the region's emissions inventory under Baseline and ACF scenarios. Finally, NOx, PM2.5, and GHG emissions reductions resulting from fleet transition to ZE technology are assessed.

- **San Diego Region Infrastructure Study:** This section discusses charging and infrastructure goals by type (e.g., L2, DCFC, Hydrogen) based on the MD-HD Vehicle Study. The basis for determining the necessary charging and fueling infrastructure is vehicle type and distribution of BEVs and FCEVs. The project team estimated electricity and hydrogen fuel consumption for the ZE MD-HD fleet using EMFAC2021 data as well as selected energy efficiency ratios (EER) for each vehicle category extracted from Argonne National Laboratory's GREET model. Lawrence Berkeley National Laboratory's (LBNL) Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operations, and Deployment (HEVI-LOAD) tool is used to determine charging infrastructure consistent with the State's SIP Strategy (SSS) that CARB modeled for ACT and ACF regulations. Hydrogen fueling infrastructure is determined using methodology consistent with AB 8 and CARB's Hydrogen Station Self-Sufficiency Report to estimate the number and capacity of hydrogen fueling stations needed.

Vehicle Study

Baseline Scenario

The project team leveraged CARB's EMFAC2021 (v1.0.2) model to estimate the region's current MD-HD vehicle population. Note that although all vehicle categories, model years, and fuel types are available, this report focused on the region's MD-HD vehicle population. A summary of the region's MD-HD vehicle population by category for calendar year 2022 is shown in ***Figure 21***. Class 2b through 3 vehicles (e.g., pickup trucks, vans, local delivery trucks) reflect 61 percent of the MD-HD vehicle population. Class 4 through 8 vehicles (e.g., utility trucks, refrigerated trucks, tractor trucks) combined represent 25 percent of the MD-HD vehicle population. Buses, such as city transport and school buses, account for 14 percent of the MD-HD vehicle population. Overall, it is estimated that roughly 147,000 MD-HD vehicles operate within the region on a typical day. A numerical breakdown of the MD-HD vehicle population in the region by category is shown in ***Table 12***.

Figure 21. MD/HD Vehicle Population Operating in the San Diego Region, 2022[46]

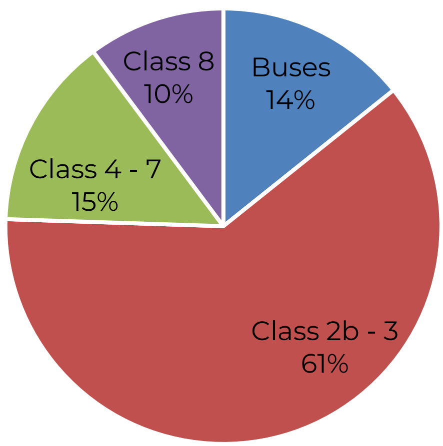


Table 12. MD/HD Vehicle Population for San Diego Region, 2022 (Numerical Breakdown)

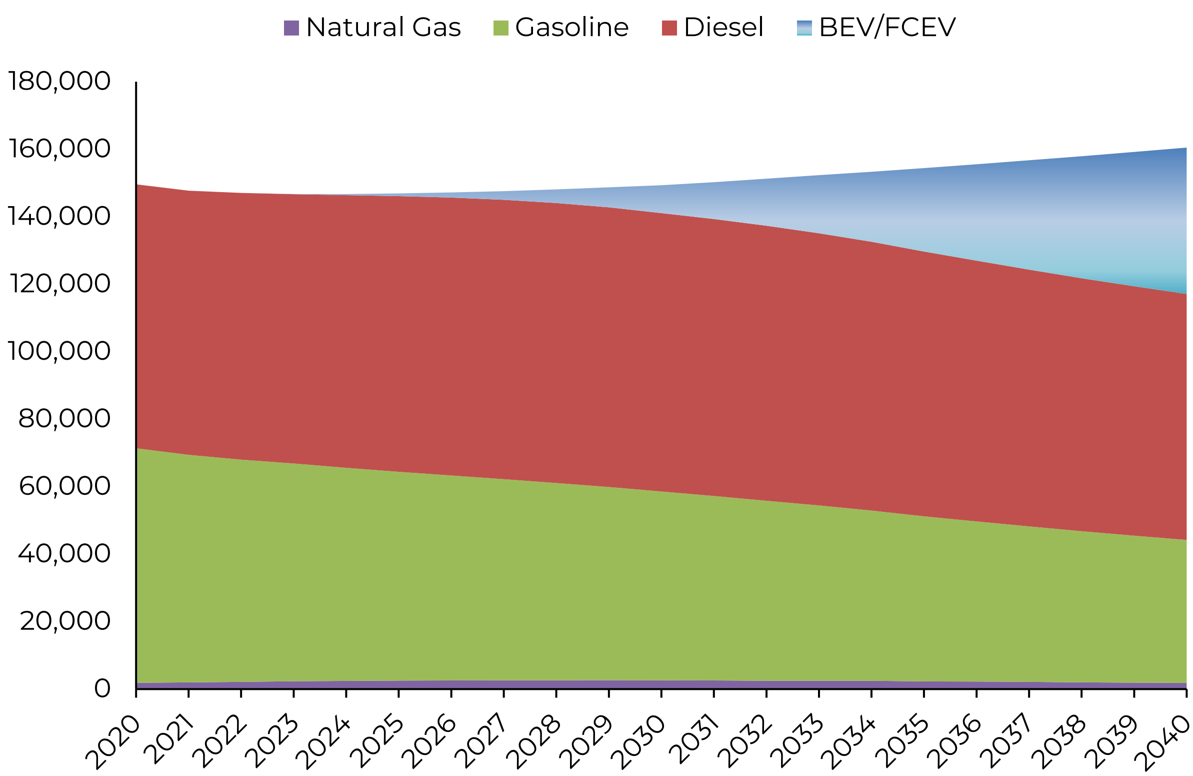
	Buses	Class 2b – 3	Class 4 – 7	Class 8
Population	21,000	90,000	21,000	15,000

The EMFAC2021 model also forecasts the population of Class 2b through 8 vehicles using national projections of vehicle sales from the Annual Energy Outlook as well as the California freight travel demand projections from the California Statewide Travel Demand Model (CSTDM). The projected growth in Class 2b through 8 vehicle population (under Baseline conditions) by fuel type between 2020 through 2040 is shown in ***Figure 22***. In 2022, the shares of the region's MD-HD vehicle population by fuel type consists of 54 percent diesel, 45 percent gasoline, and approximately 1 percent natural gas. Important to note is that by default, EMFAC2021 groups BEVs and FCEVs into one fuel technology group called "Electricity" fuel

[46] It is important to note that this population distribution reflects the number of MD-HD vehicles that operate on San Diego County roadways on a typical day; this data is not suitable to describe MD-HD vehicles domiciled to the region.

type; the project team renamed the EMFAC2021 “Electricity” category to BEV/FCEV. By 2040, under Baseline conditions, the distribution of the region’s total vehicle population by fuel type is expected to be 45 percent diesel, 27 percent BEV/FCEV, 27 percent gasoline, and 1 percent natural gas. As previously stated, the projected growth in ZE MD-HD vehicles under Baseline conditions considers various State adopted regulations (e.g., ICT, and ACT) that will increase ZE vehicle adoption and operation.

Figure 22. San Diego Region's Baseline Class 2b - 8 Vehicle Population by Fuel Type



The project team also relied on EMFAC2021’s emissions inventory to assess the region’s current and projected emissions from its Class 2b through 8 vehicle population. Data for on-road, mobile emissions sources (i.e., tailpipe emissions) is provided in tons per day for NOx, PM2.5, and diesel PM (DPM). GHG emissions are calculated using methane (CH4), nitrous oxide (N2O), and carbon dioxide (CO2) emissions. A summary of the region’s MD-HD NOx and PM2.5 emissions by vehicle category for calendar year 2022 is shown in ***Figure 23***. The region’s Class 2b through 3 vehicles reflect 33 percent and 52 percent of NOx and PM2.5 emissions, respectively. Class 4 through 8 vehicles combined reflect 60 percent and 42 percent of NOx and PM2.5 emissions, respectively. Overall, the region’s MD-HD vehicle population generates over 15 tons of NOx per day and approximately 0.17 tons of exhaust PM2.5 per day, the numerical breakdown of these quantities by vehicle category is shown in ***Table 13***.

The projected NOx, PM2.5, and GHG emissions for the region’s MD-HD vehicle population (under Baseline conditions) between 2020 through 2040 are shown in ***Figure 24***. Overall, the region is projected to achieve significant NOx, PM2.5, and GHG emission reductions because of adopted State regulations. By 2040, NOx emissions decrease by 50 percent, PM2.5 emissions decrease by 37 percent, and GHG emissions decrease by almost 20 percent, from 2022 baseline levels, respectively.

Figure 23. (Left to Right) San Diego Region's (NOx, PM2.5) Class 2b-8 Vehicle Exhaust Emissions, 2022

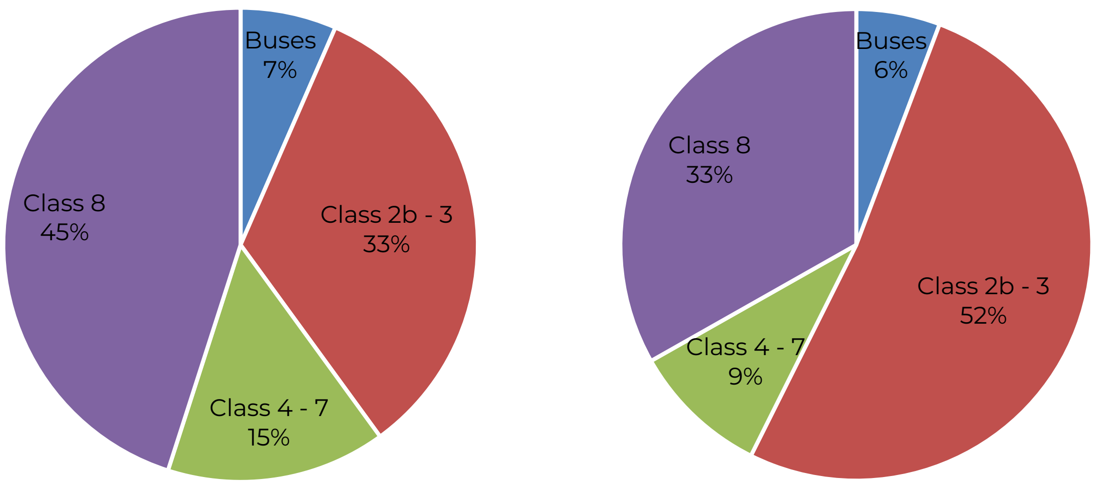
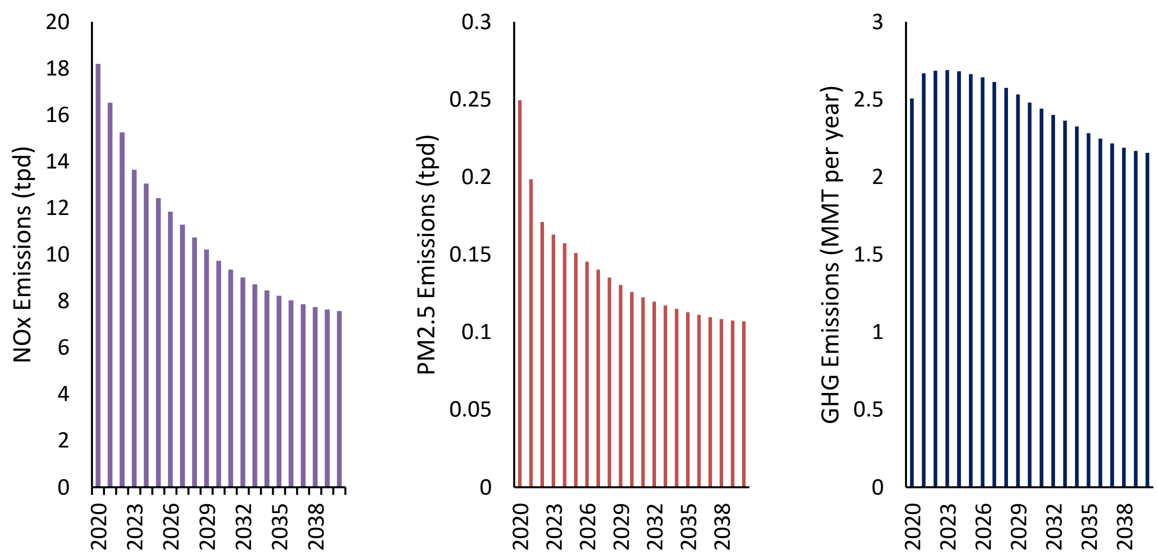


Table 13. MD/HD Vehicle Emissions for San Diego Region, 2022 (Numerical Breakdown)

Emission (tpd)	Buses	Class 2b – 3	Class 4 -7	Class 8
NOx	0.990	5.058	2.263	6.813
PM2.5	0.010	0.088	0.016	0.057

Figure 24. (Left to Right) San Diego Region's (NOx, PM2.5, GHG) Baseline Class 2b-8 Vehicle Emissions



Advanced Clean Fleets Scenario

To remain consistent with the regulatory language and requirements, EMFAC2021 vehicle categories are aligned with the three main ACF fleet categories: State and Local fleets, Drayage Fleets, and High-Priority/Federal Fleets. Recall that the proposed ACF regulation sets requirements specific to these three fleet categories. For State and Local fleets, 50 percent ZEV purchase requirement between 2024 through 2026 and 100 percent ZEV purchase requirement in 2027 and beyond. For Drayage fleets, 100 percent ZEV purchase requirement beginning in 2024 and 100 percent ZEVs fleetwide by 2035. For High-Priority fleets, 100 percent ZEV purchase requirement beginning in 2024. The project team contacted CARB to obtain the most recent percent population estimates of every EMFAC2021 vehicle category as they are considered under the proposed ACF regulation. For example, although Class 8 truck tractors are subject to the proposed ACF regulation, 12 percent are considered drayage vehicles, 49 percent are considered high-priority vehicles, and 39 percent are considered unregulated vehicles[47]. ***Table 17*** in ***Appendix B***: EMFAC Vehicle Category and Vehicle Alignment shows a complete breakdown of EMFAC2021 vehicle categories by their respective percent ACF population estimates.

Recall that EMFAC2021 originally aggregates BEVs and FCEVs into a homogenous "Electricity" category. Similarly, the proposed ACF regulation refers to BEVs and FCEVs as ZEVs. It is important to note that the ACF regulation outlines percent ZEV expectations: the actual BEV and FCEV distributions are left to interpretation. This gap in granularity makes it challenging to determine the necessary charging and fueling needs. Therefore, to determine the charging and fueling infrastructure goals for the region, the project team established percent BEV and FCEV allocation assumptions by vehicle category. ***Table 14*** summarizes the project team's assumptions about each vehicle category's BEV and FCEV adoption split.

Table 14. Percent BEV and FCEV Allocation Assumptions to Complement ACF ZEV Requirements

Type	Model Year	BEV % Allocation	FCEV % Allocation
Interstate Trucks	2024 and beyond	50%	50%
Intrastate Trucks	2024 – 2026	90%	10%
	2027 and beyond	75%	25%
Drayage Trucks	2024 – 2026	90%	10%
	2027 and beyond	75%	25%
All Other Vehicles	2027 and beyond	90%	10%
Class 2b-3 Vehicles	2024 and beyond	100%	0%

The values in ***Table 14*** complement the percent ZEV requirements of the proposed ACF regulation. For example, between 2024 through 2026, the proposed ACF regulation requires at least 50% of new State and Local government vehicle additions to be ZEVs; this 50% of ZEVs

[47] Unregulated vehicles are vehicles that are not affected by the ACF regulation. Any growth in the ZEV population of unregulated fleets is the result of other regulations or policies associated with Baseline conditions.

is then further broken down, into a 90% BEV and 10% FCEV split, to disaggregate ZEVs into distinct BEV and FCEV populations. These resultant BEV and FCEV populations are later used to determine charging and hydrogen fueling infrastructure needs. A detailed breakdown of EMFAC2021 vehicle categories by their assumed BEV and FCEV allocations is available in ***Table 18*** of ***Appendix B***: EMFAC Vehicle Category and Vehicle Alignment**.**

Class 2b through 8 Vehicle Population

The Class 2b through 8 vehicle population in the ACF scenario for the region between 2020 through 2040 is shown in ***Figure 25***. The results for the overall Class 2b through 8 vehicle population in the ACF scenario show significant increases in the ZE MD-HD vehicle population as compared to the Baseline scenario. In calendar year 2024 of the ACF scenario, when the proposed ACF regulation would take effect, there would be 5,282 new ZE MD-HD vehicles added to the region's roadways – a quantity over 16 times greater than the approximately 319 ZE MD-HD vehicles projected in the Baseline. Rapid adoption of BEV MD-HD vehicles in place of diesel, gasoline, and natural gas options from the Baseline can be observed, and MD-HD FCEV vehicles eventually outnumber natural gas counterparts. By 2040, under the ACF scenario, the distribution of the region's total Class 2b through 8 vehicle population by fuel type is expected to be 40 percent BEV, 32 percent diesel, 23 percent gasoline, 5 percent FCEV, and less than 1 percent natural gas. A numerical breakdown of the overall Baseline and ACF scenario vehicle populations by fuel type for select years is shown in

Table 15.

Figure 25. San Diego Region's Class 2b-8 Vehicle Population by Fuel Type (ACF Scenario)

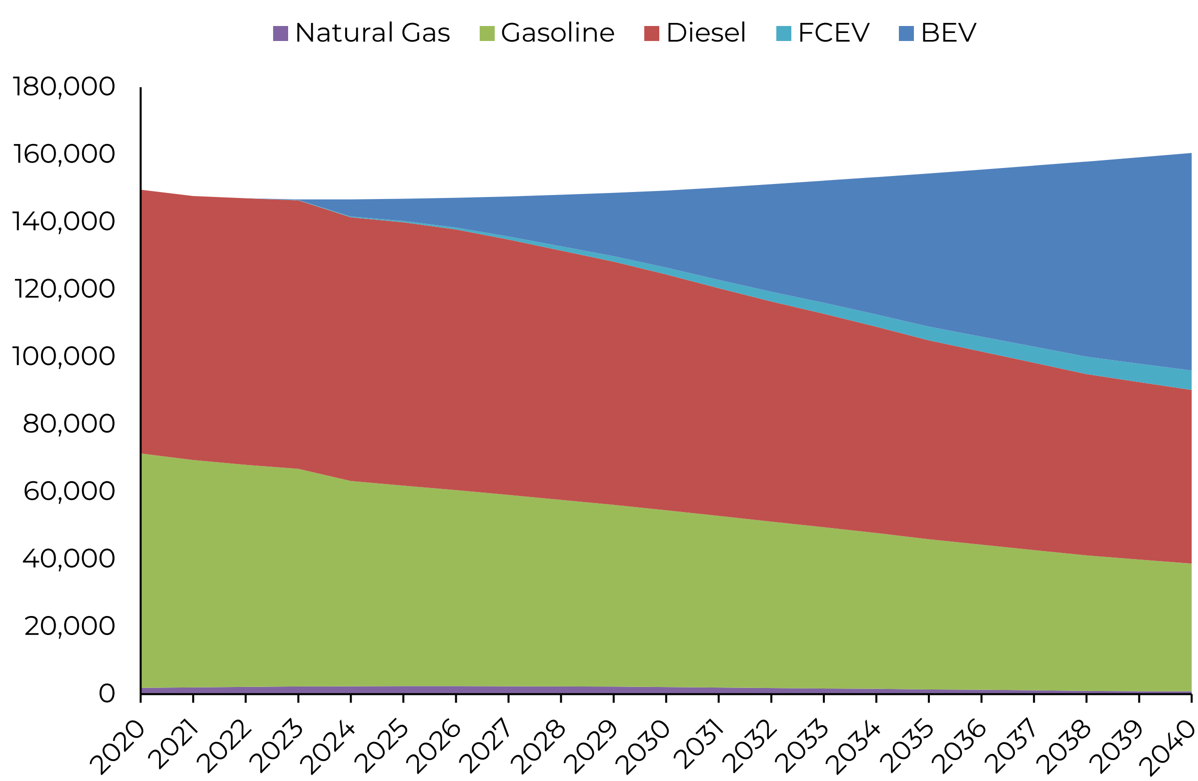


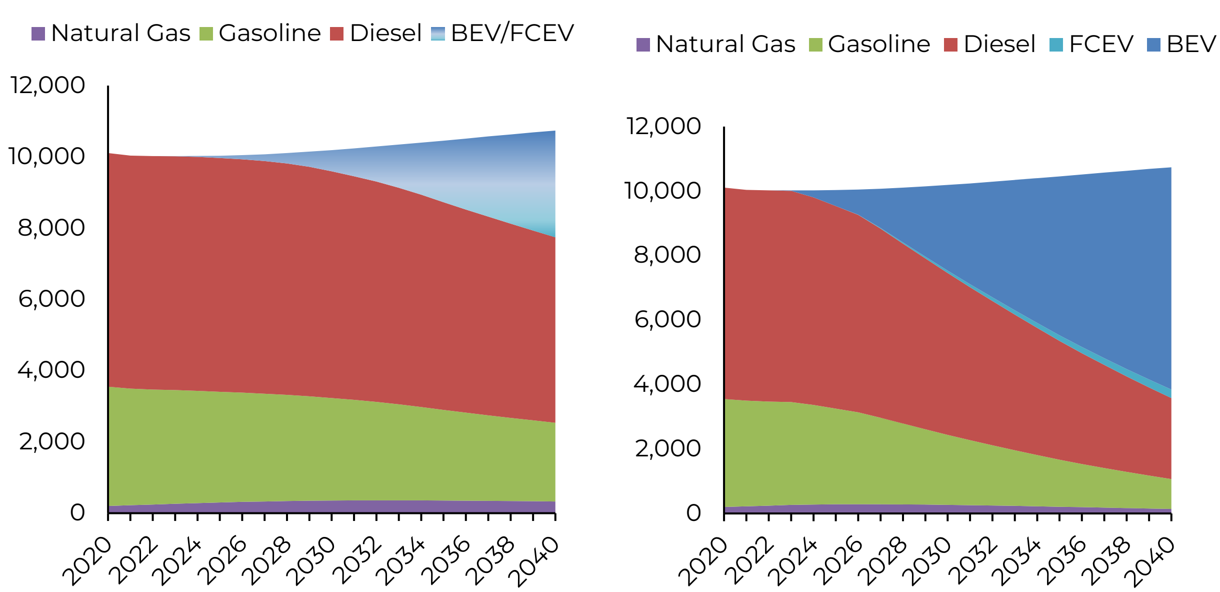
Table 15. San Diego Region's Class 2b-8 Vehicle Population by Fuel Type (Numerical Breakdown)

Scenario	Fuel Technology	2022	2025	2030	2035	2040
Baseline	Diesel	79,046	81,678	82,519	78,499	72,919
	CNG	2,153	2,507	2,605	2,3032	1,828
	Gasoline	65,870	61,897	55,965	48,882	42,372
	BEV/FCEV	-	820	8,224	24,706	43,371
with ACF	Diesel	79,046	78,084	69,923	58,969	51,511
	CNG	2,153	2,366	2,089	1,390	824
	Gasoline	65,870	59,471	52,444	44,556	37,881
	BEV	-	6,608	22,820	45,396	64,499
	FCEV	-	374	2,037	4,078	5,774

State and Local Fleets

The state and local fleet populations for the region between 2020 through 2040 under both the Baseline and the ACF scenario are shown in ***Figure 26***. In 2040, under Baseline conditions, the region's state and local population is expected to be comprised of 49 percent diesel, 27 percent ZE, 21 percent gasoline, and 3 percent natural gas. In 2040, under the ACF scenario, a marked difference can be observed, where the region's state and local fleet distribution by fuel type is 64 percent battery electric, 23 percent diesel, 9 percent gasoline, 3 percent fuel cell electric, and 1 percent natural gas.

Figure 26. (Left to Right) San Diego Region's (Baseline, ACF) State and Local Fleet Population by Fuel Type

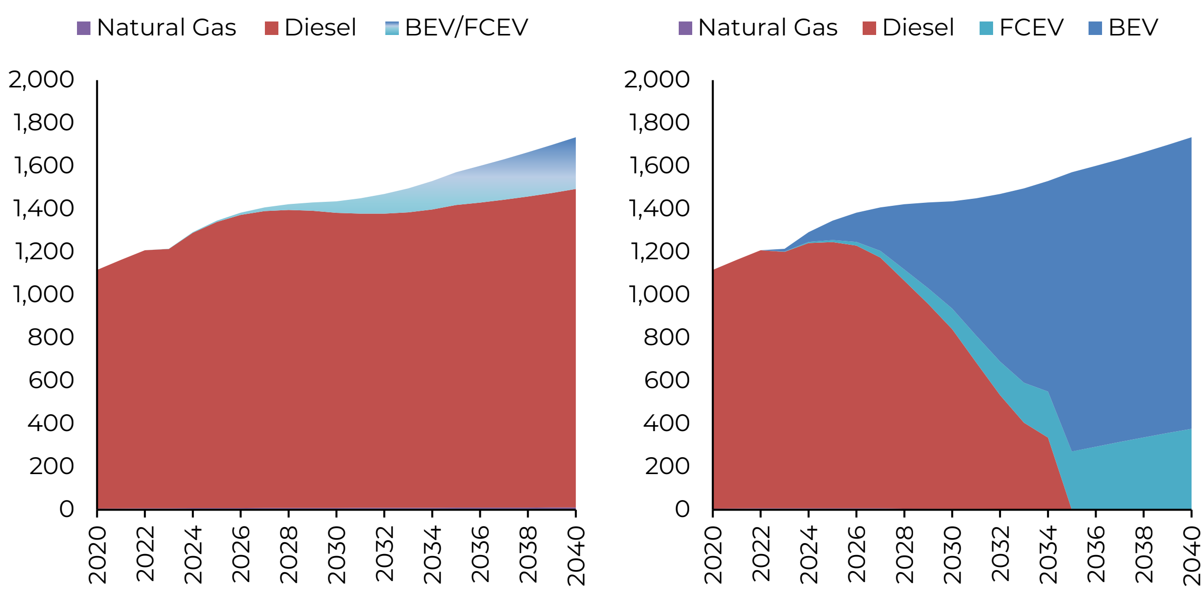


Drayage Fleets

The Baseline and ACF scenario drayage fleet populations for the region between 2020 through 2040 by fuel type are shown in ***Figure 27***. Under Baseline conditions, the region's drayage fleet population maintains a diesel fuel majority between 2020 through 2040. It can also be observed that ZE drayage truck additions would have increased over time. By 2040, under Baseline conditions, almost 14 percent of the region's drayage trucks would be ZEV, whereas 85 percent of the region's drayage trucks are diesel. Less than 1 percent of the region's drayage trucks are assumed to be powered by natural gas.

In the ACF scenario, the region's drayage truck population dramatically shifts to ZE technologies because of the proposed ACF regulation. Acquisition of diesel and natural gas trucks begin to taper off at the start of 2024, and conventional ICE drayage trucks registered at the Ports are assumed to operate for 15 years before retiring. It should be noted, however, that regardless of the remaining useful life, conventional drayage trucks will not be allowed to operate at the ports and intermodal railyard facilities after 2035. The proposed ACF regulation would require the Ports and intermodal railyard facilities to remove non-ZEV trucks from the CARB Drayage Truck Registry. Consequently, there is an abrupt decrease in diesel and natural gas drayage trucks in 2035, as only ZE drayage trucks are allowed to operate at the Ports thereafter.

Figure 27. (Left to Right) San Diego Region's (Baseline, ACF) Drayage Fleet Population by Fuel Type



High-Priority and Unregulated Fleets

The Baseline and ACF scenario high-priority fleet populations for the region between 2020 through 2040 by fuel type are shown in ***Figure 28***. In 2040, under Baseline conditions, the region's high-priority fleet population is comprised of 61 percent diesel, 25 percent ZE, 11 percent gasoline, and 3 percent natural gas. In the ACF scenario, a dramatic shift in the high-priority vehicle portfolio can be observed, beginning in 2024 and eventually reaching 100 percent ZEVs by 2038. Unlike drayage fleets, high-priority fleets are not required to be 100 percent ZE by a certain year, though the same 100 percent ZEV purchase requirement is held. Assuming a 15-year useful life, the last conventional high-priority fleets are expected to retire by 2038, assuming they are purchased right before the start of the 100 percent ZEV purchase requirement.

Any vehicle fleets which do not qualify as high-priority fleets because the vehicle fleets are smaller than 50 vehicles and company's gross revenue is less than $50 million, or the vehicles are exempt from the ACF regulation, are considered unregulated for the purpose of this vehicle study. Of course, some of those vehicles such as urban transit buses are subject to other regulations, such as the ICT regulation. Light-duty vehicles are considered exempt, but they are excluded from the total unregulated fleets assessed in this work, as this work focused the region's MD-HD vehicle population. The Baseline and ACF scenario unregulated fleet populations for the region between 2020 through 2040 by fuel type are shown in ***Figure 29***. Unregulated fleets are not required to accelerate ZE MD-HD vehicle adoption, nor are they required to retire or transition conventionally fueled vehicles early in lieu of cleaner vehicle options. Despite this, the distribution of the region's unregulated fleets by fuel type are simulated, based on the assumptions outlined in ***Table 18*** of ***Appendix B***: EMFAC Vehicle Category and Vehicle Alignment.

Figure 28. (Left to Right) San Diego Region's (Baseline, ACF) High-Priority Fleet Population by Fuel Type

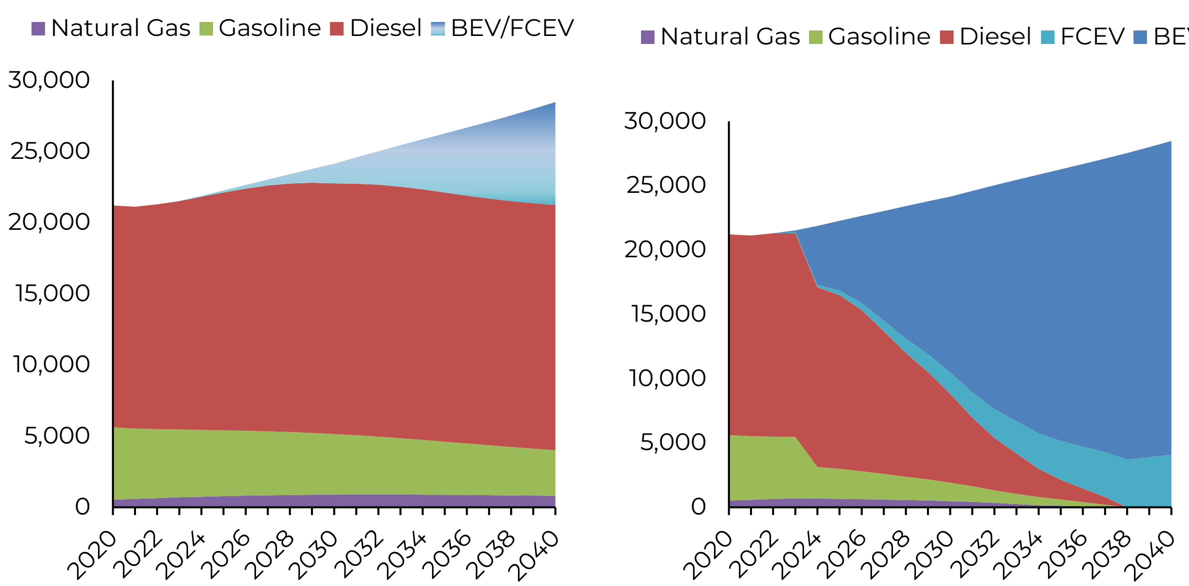
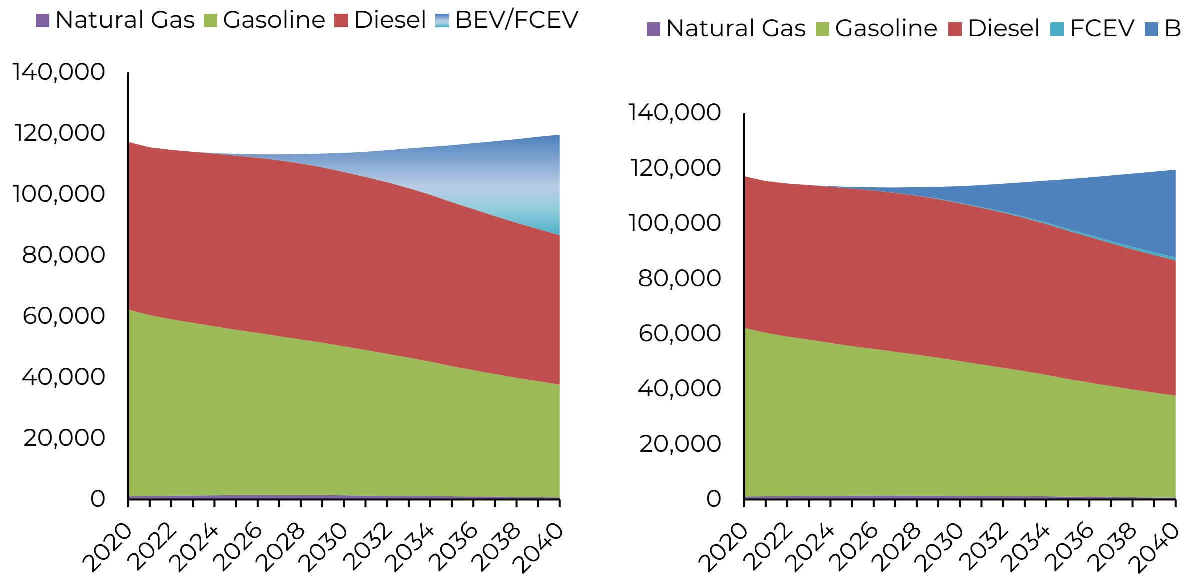


Figure 29. (Left to Right) San Diego Region's (Baseline, ACF) Unregulated Fleet Population by Fuel Type

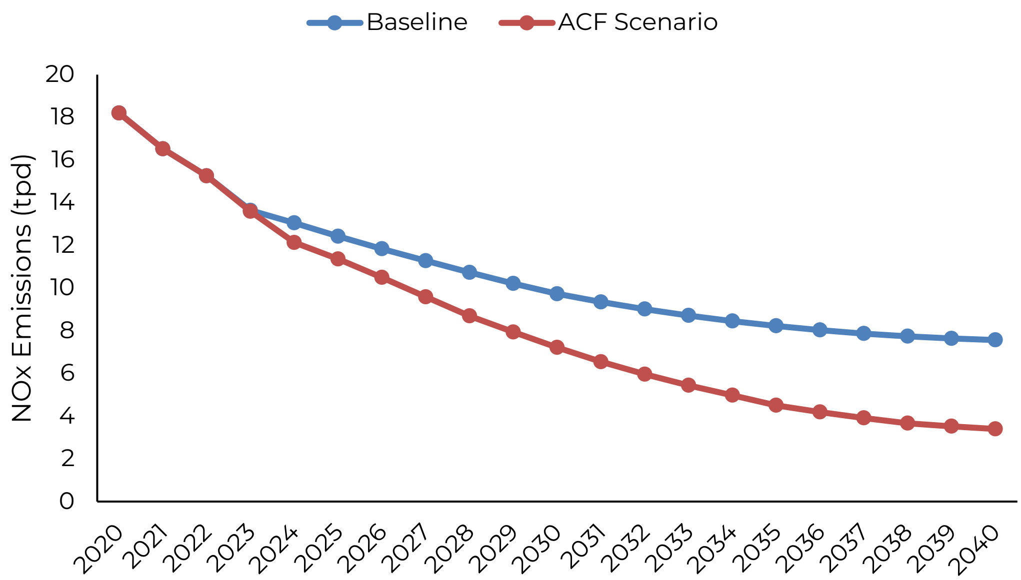


NOx, PM2.5, and GHG Emissions

The region's total emission trajectories are estimated based o the number of ZE MD-HD vehicle additions for the region under the ACF scenario. As shown previously in ***Figure 23***, Class 2b through 3 vehicles represent significant shares of total NOx and PM2.5 emissions in the region, and Class 8 vehicles are disproportionately significant contributors of total NOx and PM2.5 emissions relative to the total vehicle population. The proposed ACF regulation is expected to achieve considerable emission reductions via its MD-HD fleet electrification requirements. The analysis assumed that emission reductions are proportional to decreases in the internal combustion engine (ICE) MD-HD vehicle population. For example, if 50 percent of new trucks are required to be ZE in a given year, there is a subsequent 50 percent reduction in NOx, PM2.5, and GHG emissions from the Baseline year.

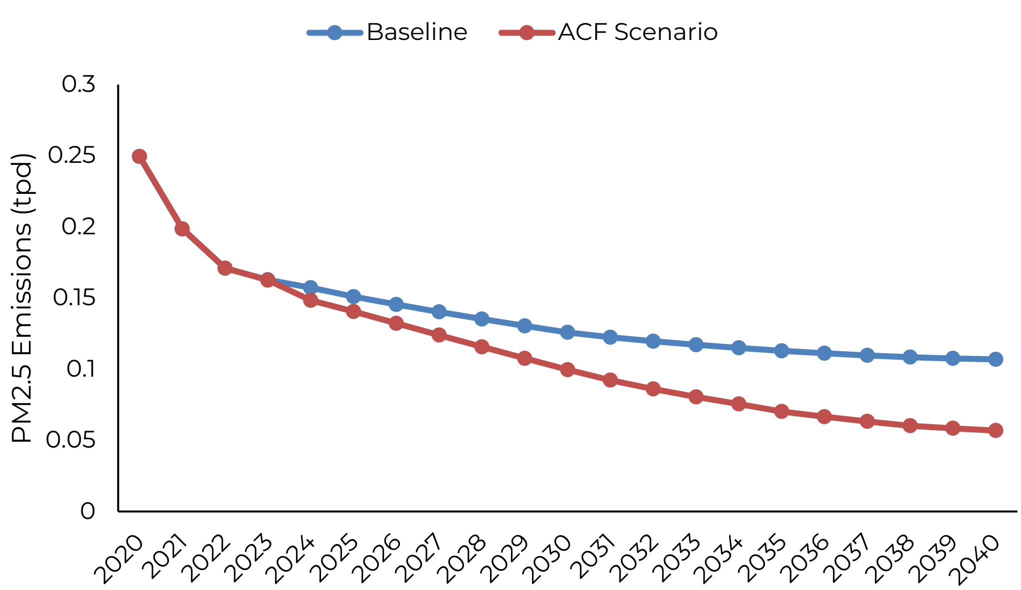
The Baseline and ACF scenario NOx emission projections for the region between 2020 through 2040 are shown in ***Figure 30***. In 2024, under the ACF scenario, emission benefits are immediately realized, resulting in 7 percent less NOx emissions as compared to Baseline conditions. By 2040, NOx emissions across all Class 2b through 8 vehicles will decrease by over 55 percent from Baseline levels. The remainder of the region's MD-HD ICE vehicles will produce approximately 3.4 tons of NOx per day in 2040, down from 7.6 tons of NOx per day in the Baseline.

Figure 30. Comparison of Baseline and ACF Scenario NOx Emissions for San Diego Region



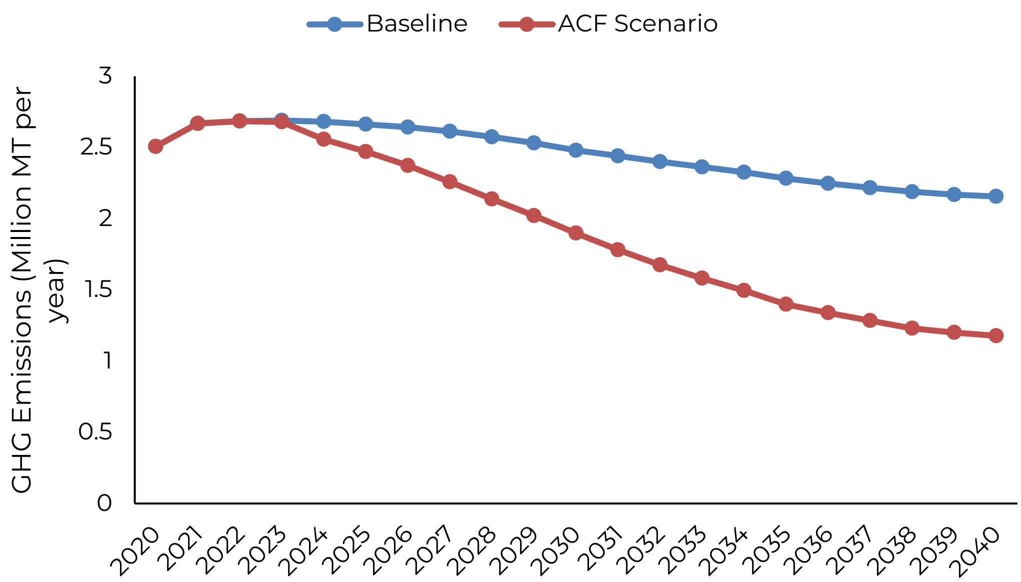
The Baseline and ACF scenario PM2.5 emission projections for the region between 2020 through 2040 are shown in ***Figure 31***. In 2024, under the ACF scenario, emission benefits are immediately realized, resulting in 6 percent less PM2.5 emissions as compared to Baseline conditions. By 2040, in the ACF scenario, PM2.5 emissions across all Class 2b through 8 vehicles will decrease by nearly 47 percent from Baseline levels. The remainder of the region's on-road, mobile PM2.5 emissions sources will produce approximately 0.06 tons of PM2.5 per day in 2040, down from 0.11 tons of PM2.5 per day in the Baseline.

Figure 31. Comparison of Baseline and ACF Scenario PM2.5 Emissions for San Diego Region



The Baseline and ACF scenario GHG emission projections for the region between 2020 through 2040 are shown in ***Figure 32***. In 2024, in the ACF scenario, GHG emissions decrease by nearly 5 percent as compared to Baseline conditions. By 2040, in the ACF scenario, GHG emissions across all Class 2b through 8 vehicles will decrease by over 45 percent from Baseline levels. The remainder of the region's on-road, mobile sources GHG emissions will produce approximately 1.2 million metric tons of GHG emissions per year in 2040, down from 2.2 million metric tons of GHG emissions per year in the Baseline.

Figure 32. Comparison of Baseline and ACF Scenario GHG Emissions for San Diego Region



ZEV Infrastructure Study

Projected Electricity and Hydrogen Fuel Consumption

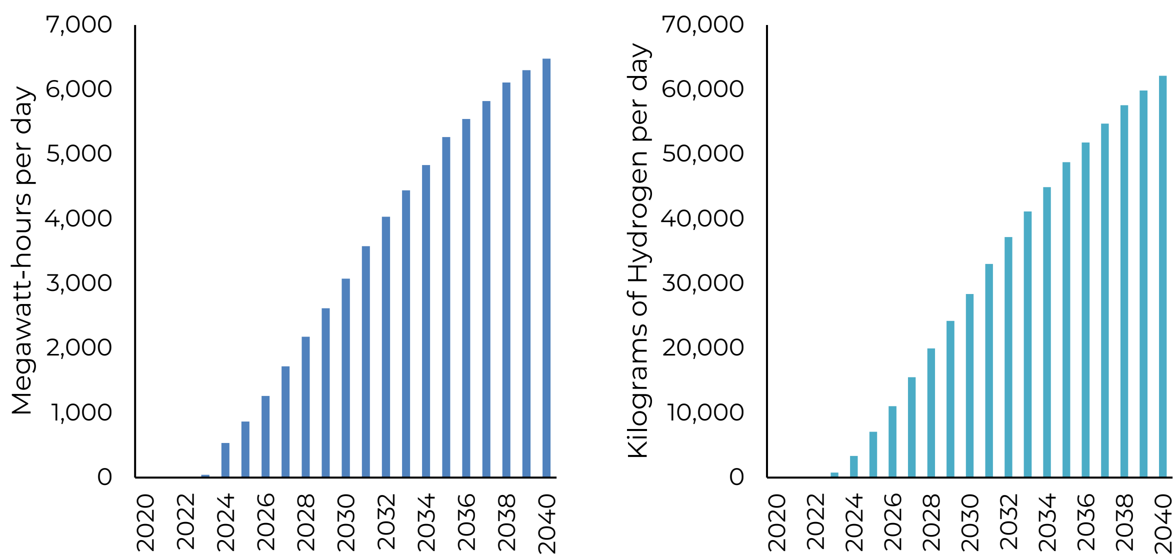
To determine regional infrastructure goals by type (e.g., L2, DCFC, Hydrogen), the project team estimated the energy consumption of the proposed Class 2b-8 vehicle population in ***Figure 25***. Then, the project team used methodologies consistent with the Assembly Bill (AB) 2127 assessment[48] and CARB Hydrogen Self Sufficiency Report[49] to transform energy consumption estimates into EV and hydrogen infrastructure recommendations.

First, electricity and hydrogen fuel consumption are estimated using fuel consumption data reported by EMFAC2021. The EMFAC2021 model outputs energy use in units of diesel gallon equivalent (DGE) for diesel and natural gas vehicles, or in units of kilowatt-hours (kWh) for BEV/FCEV vehicles. The project team's calculation for energy use in terms of DGE is initially unadjusted for ZEVs' energy efficiency ratios (EER). The EER is a comparison of the distance traveled by a ZEV compared to a conventional ICE vehicle using the same amount of energy. Then, the project team established assumptions for EERs based on known BEV and FCEV

[48] https://efiling.energy.ca.gov/getdocument.aspx?tn=238853
[49] https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf

performance metrics to transform the unadjusted DGE values into either kWh of electricity or kilograms of hydrogen that would have been consumed by the BEV or FCEV. Since BEVs and FCEVs are more efficient than diesel, natural gas, and gasoline counterparts, their effective energy consumption is lower. The results for the region's ZE MD-HD vehicle fleet energy consumption in the ACF scenario is shown in ***Figure 33***.

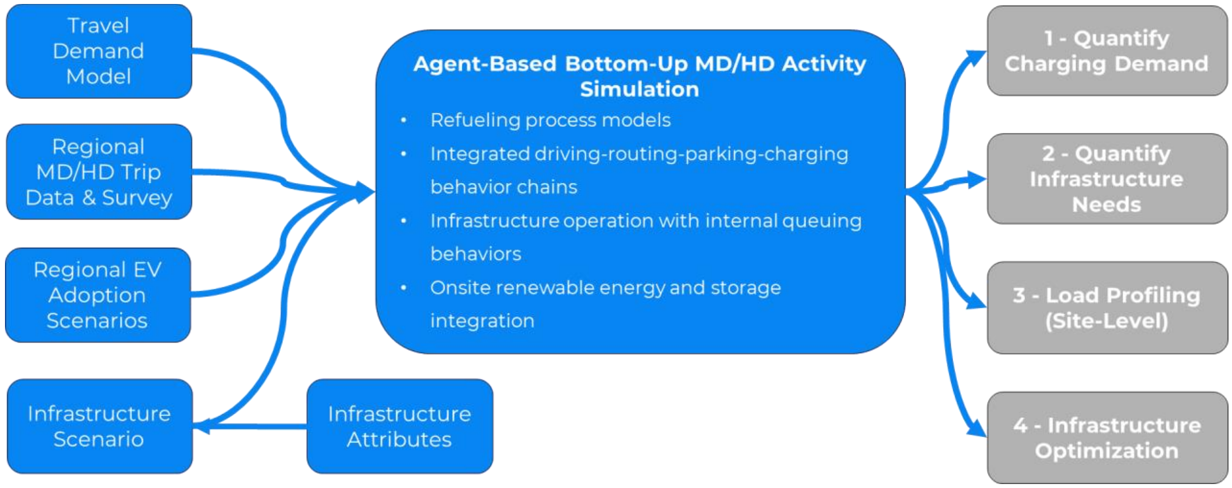
Figure 33. (Left to Right) San Diego Region's (BEV, FCEV) Daily Electricity and Hydrogen Fuel Consumption



In ***Figure 33***, the charts for electricity and hydrogen fuel consumption across all Class 2b through 8 vehicles show the continuous increase in energy that will be consumed by the San Diego region's MD-HD ZEVs. In 2024, electricity demand will be approximately 534 MWh per day, and hydrogen fuel demand will be approximately 3,342 kilograms of hydrogen per day across all ZE MD-HD vehicles in the region. Based on the trend, every year the daily electricity demand is expected to increase by approximately 377 MWh per day, and hydrogen fuel demand is expected to increase by approximately 3,576 kg per day. This means that by 2040, nearly 6.5 GWh per day of electricity and 62.5 metric tons per day of hydrogen will be consumed by the region's ZE MD-HD vehicle population.

To determine the charging infrastructure needed for MD-HD BEVs, the project team leveraged the LBNL HEVI-LOAD tool to determine the number and types of charger deployments based on power levels and MD-HD duty cycles. HEVI-LOAD was the primary tool that California used in development of its MD-HD charging infrastructure plan (AB 2127 Report). HEVI-LOAD's capability to project the quantity, and type of charging stations at the county, state, and regional levels, makes it a versatile tool for electric infrastructure planning and deployment across the state.

Figure 34. HEVI-LOAD Simulation Workflow



HEVI-LOAD has undergone significant methodological improvements since the July 2021 publication of the inaugural AB 2127 assessment. The HEVI-LOAD model is an agent-based, bottom-up model that can take the type and number of MD-HD BEVs per year as input (as determined in our Vehicle Study) to quantify charging demand and infrastructure needs. Additionally, HEVI-LOAD integrates simulated low-level MD-HD vehicle operations to provide optimized infrastructure recommendations.

The project team determined the required hydrogen fueling infrastructure needed for MD-HD FCEVs using a similar methodology developed by CARB in the Hydrogen Station Self-Sufficiency Report[50]. As part of this methodology, the project team used the hydrogen demand along with an assumed schedule for station capacity growth to determine the number and capacity of hydrogen fueling stations needed. As station capacities increase, it is likely that the cost of station development will reduce on a per-kg per day fueling capacity. Utilizing this schedule, the project team determined an optimized number of hydrogen stations by capacity needed for the region to meet its transportation-related hydrogen demand. Utilizing the hydrogen fuel cell electric truck population estimated, the project team assumed potential scaled capacity growth of existing stations, and expansion of hydrogen station numbers. For example, in the early years, most new stations are likely to be in the low-capacity range of 200-600 kg/day, while in the long-term, high-capacity stations (i.e., 2000 kg/day) would be more favorable.

Charging Infrastructure

In collaboration with the California Energy Commission and LBNL, the project team determined the number of chargers by power level that will likely be needed in the region to support Class 3 through 8 ZE MD-HD vehicles. Currently, the HEVI-LOAD model does not treat Class 2b as heavy-duty vehicles, and therefore does not generate the number of chargers for those vehicles. The reason why is that Class 2b vehicles can use home chargers and therefore could have similar considerations as light-duty vehicles. To estimate the number of chargers for Class 2b, the project team leveraged the National Renewable Energy Laboratory (NREL)

[50] https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf

EVI-Pro model[51], which is designed to estimate the number of public and workplace chargers for light-duty vehicles. The EVI-Pro model takes the number of vehicles as input and outputs the number of Level 2 and DC fast chargers. The project team combines the results from the LBNL HEVI-LOAD and NREL's EVI Pro model by assuming that all Level 2 chargers from the EVI-Pro model are 19 kW chargers, and DCFC chargers are equally split between 25 kW and 50 kW chargers.

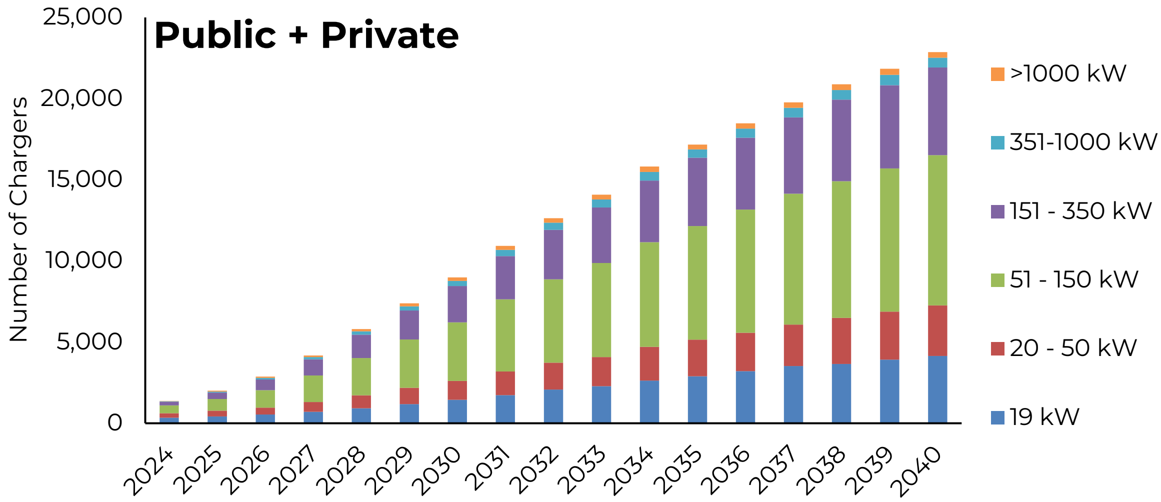
MD-HD EVs use two primary charging models: depot charging and on-route charging. Return to base duty cycles (e.g., delivery vehicles) often utilize depot charging, whereas more intensive interregional freight trucks that go longer distances often requires on-route charging. Chargers for these MD-HD vehicles tend to be in the following areas:

a) A central home base (e.g., warehouse, distribution center, or headquarters)
b) A customer's site that allows return-to-base vehicles with long routes to charge, usually while unloading, so that vehicles can return to base to finish charging
c) A major freight corridor, using public charging infrastructure

The benefit of using the HEVI-LOAD model in this project is the ability to separately estimate depot vs. public charging infrastructure. HEVI-LOAD model leverages the duty cycle data for various EMFAC vehicle categories to determine the number of vehicles and hence chargers that will need to access public charging infrastructure versus those that could solely rely on depot charging. The total number of chargers estimated by HEVI-LOAD based on the battery electric vehicle population projected for the region is shown in ***Figure 35***. The model estimated that by 2040, the region will need almost 23,000 chargers, combined, providing a maximum of 3,800 MW of power to the battery-electric MD-HD vehicles (Class 2b – 8) operating within the region[52]. To compare the number of charging stations needed against the existing gasoline and diesel fueling stations in the region, the project team extracted data from the most recent California Retail Fuel Outlet Annual Reporting[53] (CEC-A15). According to CEC-A15 report, in 2021, CEC estimated a total of 753 retail fuel station (gasoline and diesel) operating in San Diego County.

[51] https://www.nrel.gov/transportation/evi-pro.html
[52] The 3,800 MW is assuming a scenario where all 23,000 chargers are being used at their maximum capacity at the same time. This is a very unlikely scenario and only represent the maximum possible load that these chargers could put on the grid.
[53] https://www.energy.ca.gov/data-reports/energy-almanac/transportation-energy/california-retail-fuel-outlet-annual-reporting

Figure 35. Number of Charger Deployments (Public and Depot) in San Diego Region by Power Level for Class 2b – 8 Vehicles



The results suggest that in early years, chargers with lower power capacities serve the on-set demand by battery electric MD-HD vehicles, and in later years, average charger power capacity increases such that overall power capacity increases without excess installation of lower-power chargers. For example, the preliminary results show that between the years 2024 through 2027, 80 percent of the chargers serving the region will have power levels ≤ 150 kW, whereas in post-2030, that fraction will reduce to 70 percent as the number of > 150 kW chargers increased rapidly. Note that today, most of the DCFC are below 150 kW while there are stations being offered at 350 kW[54]. As discussed earlier, the > 1 MW chargers are still under development, and it is expected that CharIN will publish the final MCS standard in 2024. Also, it is important to note that for trucks to use these chargers, their batteries should be able to accept such high power levels. According to project team's research, most of the battery Class 8 tractor trucks available today can only accept up to 300 kW of charge, however, it is expected there will be trucks available (e.g., Tesla Semi) with Megawatt charging capability in near future.

The results from the HEVI-LOAD model also separated the number of public versus depot charging infrastructure. ***Figure 36*** illustrates the number of public charging infrastructure needed in the region whereas ***Figure 37*** present the number of depot chargers.

[54] https://new.abb.com/ev-charging/high-power-charging

Figure 36. Number of Public Charger Deployments in San Diego Region by Power Level for Class 2b – 8 Vehicles

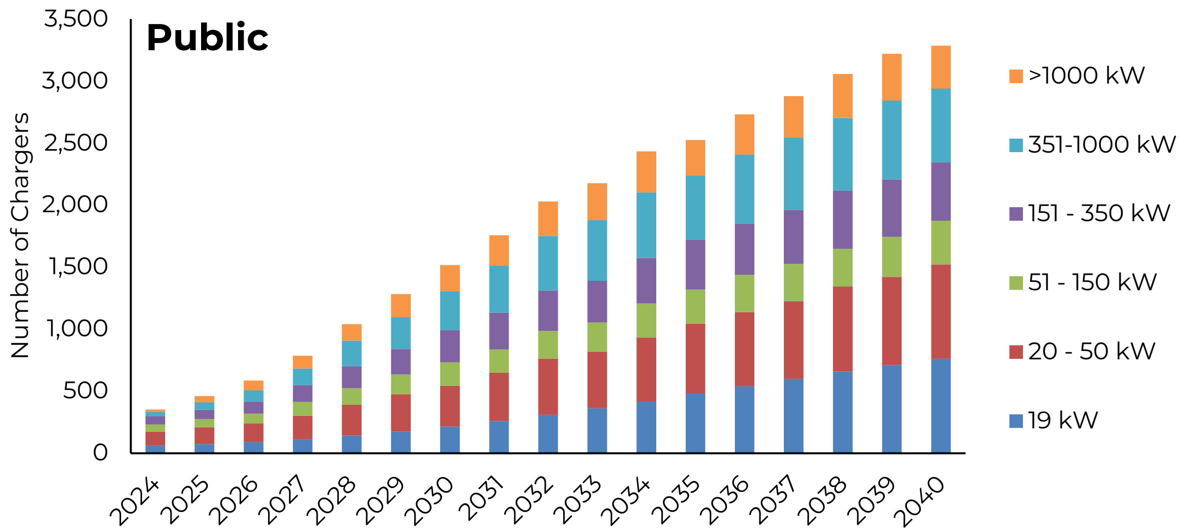
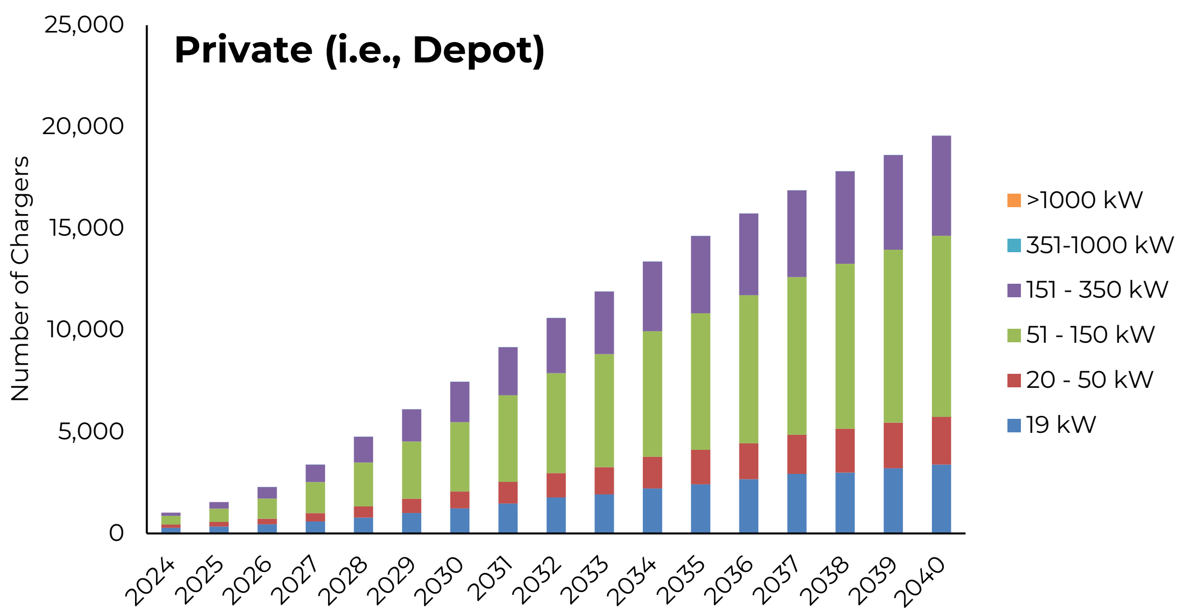


Figure 37. Number of Depot Charger Deployments in San Diego Region by Power Level for Class 2b – 8 Vehicles

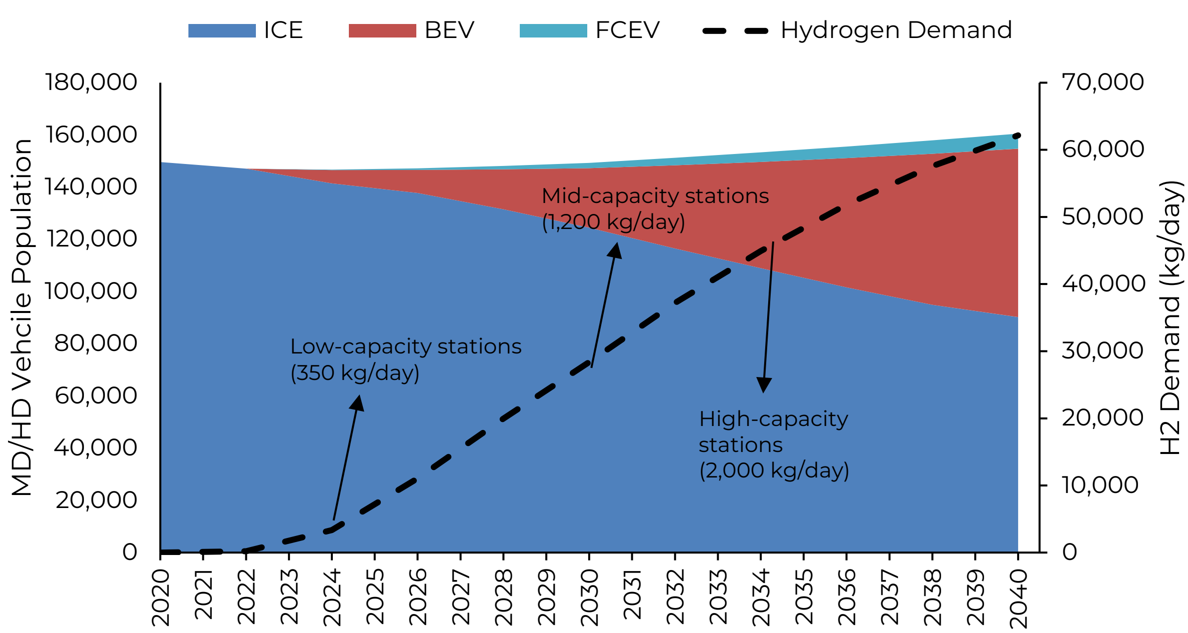


As illustrated in ***Figure 36***, the project team estimated that by 2040, the region will need a total of 3,200 public chargers with 350 of those being Megawatt chargers (i.e., > 1,000 kW), ~1,100 of those being high power DC fast chargers (150 kW – 1,000 kW), and the rest (~1,800) being a combination of Level 2 and < 150 kW DC fast chargers. This analysis showed that while there is a significant need for charging infrastructure in the region majority of those infrastructure are assumed to be private chargers deployed in truck and bus depots and only 14% of them being public charging infrastructure. As discussed earlier, while the number of public charging infrastructure is much less than the depot chargers, they are consisted of higher power chargers which can serve higher number of battery electric trucks per each charger.

Hydrogen Fueling Infrastructure

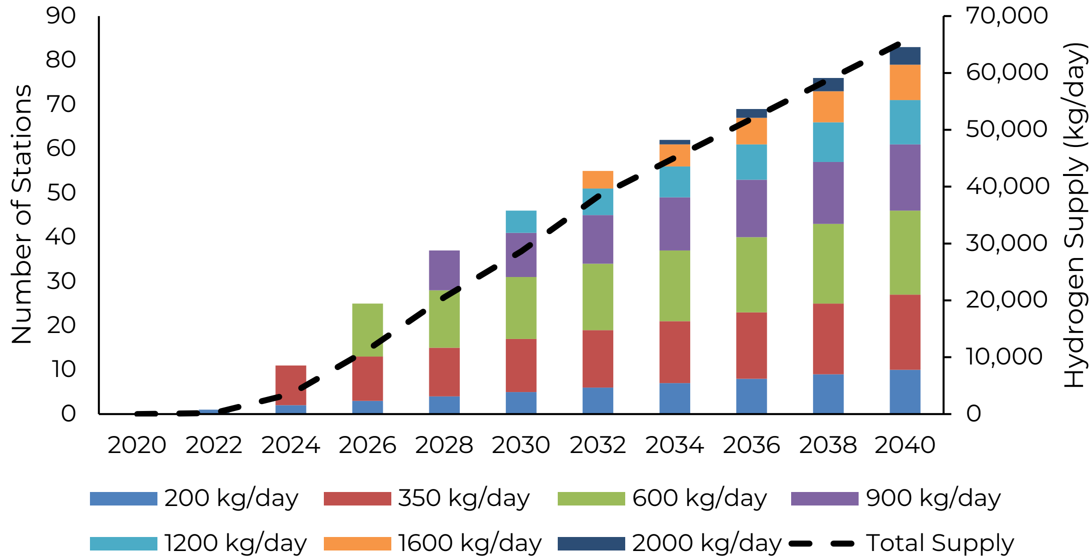
The regional FCEV modeling in this vehicle study identifies the likely number of FCEVs that will be deployed in the region. Using this fleet modeling, the project team estimated the amount of hydrogen fuel needed (in kilograms) for all FCEVs in the region between 2020 through 2040 under the ACF scenario. In ***Figure 38***, the distribution of the region's MD-HD vehicles by fuel type and the hydrogen fuel demand are shown together. Based on the hydrogen fuel demand estimated earlier, the project team determined a schedule for the number of hydrogen stations by capacity that needs to be deployed. The CARB Self-Sufficiency report guides the estimation, especially the approach taken for station growth over time. For this project, the project team assumed that average station capacity is low between 2020 through 2024, between 200 through 600 kg H2 per day. In later years, between 2026 and 2030, mid station capacities between 900 through 1200 kg H2 per day are available. Beginning in 2030, high station capacities between 1,600 through 2,000 kg H2 per day will be the primary stations built to meet the demand. Additionally, the project team assumed that the number of low-capacity stations grow at a two percent rate.

Figure 38. San Diego Region MD/HD Vehicles by Fuel Type and Hydrogen Fuel Demand



The results for the number of hydrogens fueling stations by station capacity between 2020 through 2040, as well as the total hydrogen supply by station capacity are shown in ***Figure 39***. Between 2022 through 2026, the majority of stations deployed to meet hydrogen fuel demand have capacities between 350 kg/day and 600 kg/day. By 2030, both low- and mid-capacity hydrogen stations are recommended for deployment, such that 46 hydrogen fueling stations provide 26,600 kilograms of hydrogen per day for FCEVs in the region. The highest capacity stations, 2,000 kg/day are recommended for deployment beginning in 2034. By 2040, a total of 83 hydrogen fueling stations provide 65,650 kilograms of hydrogen per day for FCEVs in the region.

Figure 39. Hydrogen Station Deployment Schedule by Capacity per day



Summary & Conclusion

This report evaluated the needs for zero emission medium and heavy-duty (MD-HD) vehicles and infrastructure in the San Diego region. The report began by discussing existing regulations that are designed to accelerate the adoption of such vehicles, including the ACT regulation and the proposed ACF regulation. In addition to these regulations, the report also highlighted key incentive programs in California and the region that promote the adoption of ZE MD-HD vehicles, such as the Hybrid and Zero-Emission Truck and Bus Voucher Project, the Carl Moyer Program, and the Clean Transportation program.

The report also covered the current and projected state of technology for ZE MD-HD vehicles, including battery electric and hydrogen fuel cell electric technology. It provided an overview of the existing ZE infrastructure technology and highlights recent developments in high power charging and hydrogen production and delivery. The report included estimates on the costs of charging and hydrogen fueling infrastructure, as well as a review of TCO analyses comparing ZE vehicles to their internal combustion engine counterparts. For example, CARB's ACF TCO analysis showed that in general BEVs achieved TCO cost savings through a combination of lower operational costs and revenue from LCFS credits. TCO cost competitiveness for FCEVs occurs later than BEVs, around 2030 – depending on the vehicle class. Additionally, because this analysis assumed all vehicles were financed, although upfront costs were higher compared to diesel vehicles, that operational savings would accrue before substantial cashflow would be required.

The report also presented a regional vehicle and infrastructure study, using CARB's EMFAC2021, LBNL's HEVI-LOAD, and NREL's EVI-PRO models to simulate the likely number of ZE MD-HD vehicles and infrastructure expected to be deployed in the region based on State regulations. The fleet modeling conducted as part of this assessment showed that by 2040, the region's total Class 2b through 8 vehicle population by fuel type is expected to be 40 percent BEV, 32 percent diesel, 23 percent gasoline, 5 percent FCEV, and less than 1 percent natural gas. The infrastructure evaluation looked at both charging and fueling infrastructure separately, following the battery and fuel cell electric vehicle population estimates derived from the fleet modeling. The results showed that by 2040, the region will need approximately

23,000 chargers, providing a maximum of 3,800 MW of power to the approximately 64,500 battery-electric MD-HD vehicles (Class 2b – 8) operating within the region. Additionally, the region will likely be served by 83 hydrogen fueling stations with a total daily hydrogen capacity of more than 65,000 kilograms per day to serve approximately 5,800 FCEVs.

Overall, this report provided a comprehensive overview of the regulatory, incentive, technological, and economic aspects of zero-emission medium and heavy-duty vehicles along with the needed charging and fueling infrastructure to power these vehicles. It highlighted the availability and projected development of battery electric and hydrogen FCEV, as well as the current state of charging and hydrogen fueling infrastructure.

APPENDIX A: COMMERCIALLY AVAILABLE ZE TRUCKS

Table 16. Commercially Available Battery-Electric MD/HD Vehicles According to CARB[55]

Vehicle Make and Model	Parent Company	Vehicle Weight Class	Body Type	In Production / Delivered to Customer	Accepting Orders[56]
Arrival Van	Arrival	Class 2b	Cargo Van	-	X
Canoo MPDV1	Canoo	Class 2b	Passenger Van	-	X
Tesla CyberTruck Single Motor RWD	Tesla	Class 2b	Pickup Truck	-	O
Brightdrop EV600	GM	Class 2b	Delivery Van	X	X
Rivian R1T	Rivian	Class 2b	Pickup Truck	X	X
Ford E-Transit	Ford	Class 2b	Cargo Van	X	X
Canoo Pickup Truck	Canoo	Class 2b - 3	Pickup Truck	-	X
Rivian Van	Rivian	Class 2b - 3	Passenger Van	X	X
GMC Hummer EV Pickup	GM	Class 2b - 3	Pickup Truck	X	X
GMC Hummer EV SUV	GM	Class 2b - 3	SUV	X	X
Lightning Electric Ford Transit LEV60/120	Lightning eMotors	Class 2b - 3	Transit Bus	X	X
Workhorse C650	Workhorse	Class 3	Cargo Van	-	X
EVT 2020 Urban Truck	EVTV	Class 3	Cab and Chassis	X	X
Lightning Electric Zero Emission Transit Cargo Van	Lightning eMotors	Class 3	Cargo Van	X	X
Lightning Electric Zero Emission Transit Passenger Van	Lightning eMotors	Class 3	Passenger Van	X	X
Workhorse C1000	Workhorse	Class 3	Step Van	X	X
Global M3 / M4 Street Sweeper (BEV & Hydrogen)	Global Environemental Products	Class 3 - 4	Street Sweeper	X	X
Lightning Electric Zero Emission E-450 Box Truck	Lightning eMotors	Class 4	Box Truck	X	X
GreenPower EV Star CC	GreenPower Motor	Class 4	Cab and Chassis	X	X
GreenPower EV Star Cargo Plus	GreenPower Motor	Class 4	Cab and Chassis	X	X
GreenPower EV Star Plus	GreenPower Motor	Class 4	Shuttle Bus	X	X
Optimal E1	Vicinity Motor Corp.	Class 4	Cab and Chassis	-	X
Phoenix Zeus 500 Trucks	Phoenix Motorcars	Class 4	Cab and Chassis	X	X
Lightning Electric Zero Emission E-450 Shuttle Bus	Lightning eMotors	Class 4	Shuttle Bus	X	X
Micro Bird D-Series Electric Shuttle Bus (on E450 Platform)	Blue Bird	Class 4	Shuttle Bus	X	X
Motiv on Ford E-450 Platform School Bus	Motiv Power Systems	Class 4	School Bus	X	X
Motiv on Ford E-450 Platform Shuttle Bus	Motiv Power Systems	Class 4	Shuttle Bus	X	X
Optimal S1LF	Vicinity Motor Corp.	Class 4	Shuttle Bus	-	X
Phoenix ZEUS 300 Passenger Shuttle	Phoenix Motorcars	Class 4	Shuttle Bus	X	X

[55] https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fww2.arb.ca.gov%2Fsites%2Fdefault%2Ffiles%2Fbarcu%2Fregact%2F2022%2Facf22%2Fappj.xlsm&wdOrigin=BROWSELINK
[56] "X" represent yes, and "O" represents vehicle in the pre-production demonstration stage.

Vehicle Make and Model	Parent Company	Vehicle Weight Class	Body Type	In Production / Delivered to Customer	Accepting Orders[56]
Phoenix ZEUS 400 Shuttle Bus	Phoenix Motorcars	Class 4	Shuttle Bus	X	X
Phoenix ZEUS 600 School Bus Type A	Phoenix Motorcars	Class 4	School Bus	X	X
EVT 2020 Logistics Van	EVTV	Class 4	Cargo Van	X	X
GreenPower EV Star Cargo	GreenPower Motor	Class 4	Cargo Van	X	X
Phoenix ZEUS 400 Transit Bus	Phoenix Motorcars	Class 4	Transit Bus	X	X
SEA 4500 EV (on GMC 4500 with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA 5500 EV (on GMC 5500 with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
Micro Bird G5 Electric (on E450 Platform)	Blue Bird	Class 4 - 5	School Bus	X	X
SEA F-450 EV (on FORD F-450 with SEA-DRIVE Power)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA F53 EV (on FORD F-53 with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA F-550 EV (on FORD F-550 with SEA-DRIVE Power)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA M4 EV (on HINO M4 with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA M5 EV (on HINO M5 with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA NPR EV (on ISUZU NPR with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
SEA NQR EV (on ISUZU NQR with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Cab and Chassis	X	X
Lightning Electric Zero Emission F-53/F-59 Van	Lightning eMotors	Class 4 - 5	Step Van	X	X
SEA F59 EV (on FORD F-59 with SEA-DRIVE Power System)	SEA Electric	Class 4 - 5	Step Van	X	X
SEA MT45 EV (on Freightliner MT45 with SEA-DRIVE Power)	SEA Electric	Class 4 - 5	Step Van	X	X
Lightning Electric Zero Emission F-550 Bus	Lightning eMotors	Class 5	Shuttle Bus	X	X
Freightliner MT50e	Daimler Trucks	Class 5	Step Van	X	X
GreenPower EV Star	GreenPower Motor	Class 5 - 6	Shuttle Bus	X	X
GreenPower EV Star ADA	GreenPower Motor	Class 5 - 6	Shuttle Bus	X	X
BYD 6F	BYD Motors	Class 6	Box Truck	X	X
BYD 6R	BYD Motors	Class 6	Refuse truck	X	X
BYD C6M 23 All-Battery Electric Coach Bus	BYD Motors	Class 6	Coach Bus	X	X
Kenworth K270E	PACCAR	Class 6	Cab and Chassis	X	X
Lightning Electric Isuzu FTR / Chevrolet 6500XD	Lightning eMotors	Class 6	Cab and Chassis	X	X
Lion A Mini School Bus	Lion	Class 6	School Bus	X	X
Lion 6	Lion	Class 6	Cab and Chassis	X	X
Motiv EPIC F-53	Motiv Power Systems	Class 6	Cab and Chassis	X	X
Motiv on F-53 Platform Hometown Trolley	Motiv Power Systems	Class 6	Trolley	X	X
ROUSH CleanTech Ford F-650 Battery Electric Vehicle	ROUSH CleanTech	Class 6	Cab and Chassis	-	X
XOS SV01	XOS Trucks	Class 6	Step Van	X	X
Lion C School Bus	Lion	Class 6 - 7	School Bus	X	X
Lion M Shuttle Bus	Lion	Class 6 - 7	Shuttle Bus	X	X
SEA 6500 EV (on GMC 6500 with SEA-DRIVE Power)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA F53 EV (on FORD F-53 with SEA-DRIVE Power System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA F59 EV (on FORD F-59 with SEA-DRIVE Power System)	SEA Electric	Class 6 - 7	Step Van	X	X
SEA F-650 EV (on FORD F-650 with SEA-DRIVE Power)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA F-750 EV (on FORD F-750 with SEA-DRIVE Power System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA FSR EV (on Isuzu FSR with SEA-Drive Power-System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA L6 EV (on HINO L6 with SEA-DRIVE Power System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X

Vehicle Make and Model	Parent Company	Vehicle Weight Class	Body Type	In Production / Delivered to Customer	Accepting Orders[56]
SEA L7 EV (on HINO L7 with SEA-DRIVE Power System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA MB65 EV (on Freightliner MB65 with SEA-Drive Power-System)	SEA Electric	Class 6 - 7	Transit Bus	X	X
SEA MT55 EV (on Freightliner MT55 with SEA-DRIVE Power)	SEA Electric	Class 6 - 7	Step Van	X	X
SEA NRR EV (on ISUZU NRR with SEA-DRIVE Power System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA S2 C EV (on Freightliner S2 C with SEA-Drive Power)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
SEA S2 EV (on Freightliner S2 with SEA-Drive Power-System)	SEA Electric	Class 6 - 7	Cab and Chassis	X	X
Blue Bird Vision Electric	Blue Bird	Class 7	School Bus	X	X
Freightliner eM2	Daimler Trucks	Class 7	Cab and Chassis	-	X
IC Bus Electric CE Series	Navistar	Class 7	School Bus	X	X
Kenworth K370E	PACCAR	Class 7	Cab and Chassis	X	
Lion D School Bus	Lion	Class 7	School Bus	X	X
Peterbilt 220 EV	PACCAR	Class 7	Cab and Chassis	X	X
Thomas Built eC2 Jouley School Bus	Daimler Trucks	Class 7	School Bus	X	X
Volvo VNR 4x2 Straight	Volvo	Class 7	Cab and Chassis	X	X
BYD C8M 35 All-Battery Electric Coach Bus	BYD Motors	Class 7 - 8	Coach Bus	X	X
BYD C8MS All-Battery Electric Double-Decker Coach Bus	BYD Motors	Class 7 - 8	Double Decker Bus	X	X
BYD C9M 40 All-Battery Electric Coach Bus	BYD Motors	Class 7 - 8	Coach Bus	X	X
BYD K7M 30 All-Battery Electric Transit Bus	BYD Motors	Class 7 - 8	Transit Bus	X	X
BYD K7M-ER 30 All-Battery Electric Transit Bus	BYD Motors	Class 7 - 8	Transit Bus	X	X
BYD K8M All-Battery Electric Transit Bus	BYD Motors	Class 7 - 8	Transit Bus	X	X
BYD K9M 40 All-Battery Electric Transit Bus	BYD Motors	Class 7 - 8	Transit Bus	X	X
BYD Type D School Bus	BYD Motors	Class 7 - 8	School Bus	X	X
CCW ZEPS Bus Conversion	Complete Coach Works	Class 7 - 8	Coach Bus	X	X
ARBOC Equess Charge	NFI Group	Class 8	Transit Bus	-	X
Blue Bird All-American RE Electric	Blue Bird	Class 8	School Bus	X	X
BYD 8R	BYD Motors	Class 8	Refuse truck	X	X
BYD 8TT	BYD Motors	Class 8	Tractor Truck	X	X
BYD 8Y	BYD Motors	Class 8	Terminal Tractor	X	X
BYD C10M 45 All-Battery Electric Coach Bus	BYD Motors	Class 8	Coach Bus	X	X
BYD C10MS 45 All-Battery Electric Double-Decker Coach Bus	BYD Motors	Class 8	Double Decker Bus	X	X
BYD K11M 60 Articulated All-Battery Electric Transit Bus	BYD Motors	Class 8	Transit Bus	X	X
BYD K9MD	BYD Motors	Class 8	Transit Bus	X	X
Collins Bus Magellan	REV-Collins Bus	Class 8	Coach Bus	X	X
Proterra ZX5 35 ft	Proterra	Class 8	Transit Bus	X	X
Proterra ZX5 40 ft	Proterra	Class 8	Transit Bus	X	X
ElDorado National AXESS Battery Electric Transit Bus	REV-ENC	Class 8	Transit bus	-	X
Freightliner eCascadia	Daimler Trucks	Class 8	Tractor Truck	X	X
GILLIG 29;35;40 Low Floor Battery Electric Bus	GILLIG	Class 8	Transit Bus	X	X
GreenPower BEAST	GreenPower Motor	Class 8	School Bus	X	X
GreenPower EV250	GreenPower Motor	Class 8	Transit Bus	X	X
GreenPower EV350	GreenPower Motor	Class 8	Transit Bus	X	X

Vehicle Make and Model	Parent Company	Vehicle Weight Class	Body Type	In Production / Delivered to Customer	Accepting Orders[56]
GreenPower EV550	GreenPower Motor	Class 8	Transit Bus	**X**	**X**
GreenPower SYNAPSE Shuttle Bus	GreenPower Motor	Class 8	Shuttle Bus	**X**	**X**
GreenPower SYNAPSE 72 School Bus	GreenPower Motor	Class 8	School Bus	**X**	**X**
Hyundai Xcient Tractor	Hyundai	Class 8	Tractor Truck	**-**	**O**
Hyundai Xcient Straight Truck	Hyundai	Class 8	Cab and Chassis	**-**	**O**
Kalmar Ottawa T2E Terminal Tractor	Kalmar	Class 8	Terminal Tractor	**X**	**X**
Kenworth T680 FCEV	PACCAR	Class 8	Tractor Truck	**-**	**O**
Kenworth T680E	PACCAR	Class 8	Tractor Truck	**X**	**X**
Lightning Electric City Transit Bus Repower	Lightning eMotors	Class 8	Transit Bus	**X**	**X**
Lion 8-Refuse Truck	Lion	Class 8	Refuse Truck	**X**	**X**
Lion 8-Straight Truck	Lion	Class 8	Cab and Chassis	**X**	**X**
Lion 8-Tractor	Lion	Class 8	Tractor Truck	**X**	**X**
Lonestar SV S12/T12	Lonestar SV	Class 8	Terminal Tractor	**X**	**X**
Lonestar SV S22/T22	Lonestar SV	Class 8	Terminal Tractor	**X**	**X**
Mack LR Electric	Volvo	Class 8	Tractor Truck	**X**	**X**
MCI D45 CRT LE CHARGE	NFI Group	Class 8	Coach Bus	**X**	**X**
MCI J4500 CHARGE	NFI Group	Class 8	Coach Bus	**X**	**X**
New Flyer XCELSIOR CHARGE H2 40	NFI Group	Class 8	Transit Bus	**X**	**X**
New Flyer XCELSIOR CHARGE H2 60	NFI Group	Class 8	Transit Bus	**X**	**X**
New Flyer XCELSIOR CHARGE NG 35	NFI Group	Class 8	Transit Bus	**X**	**X**
New Flyer XCELSIOR CHARGE NG 40	NFI Group	Class 8	Transit Bus	**X**	**X**
New Flyer XCELSIOR CHARGE NG 60	NFI Group	Class 8	Transit Bus	**X**	**X**
Nikola TRE BEV	Nikola Motors	Class 8	Tractor Truck	**X**	**X**
Nova Bus LFSe	Volvo-Nova Bus	Class 8	Transit Bus	**X**	**X**
Nova Bus LFSe Plus	Volvo-Nova Bus	Class 8	Transit Bus	**-**	**X**
OrangeEV T-Series	OrangeEV	Class 8	Terminal Tractor	**X**	**X**
Peterbilt 520 EV	PACCAR	Class 8	Refuse Truck	**X**	**X**
Peterbilt 579 EV	PACCAR	Class 8	Tractor Truck	**X**	**X**
Proterra ZX5 35 ft	Proterra	Class 8	Transit Bus	**X**	**X**
Proterra ZX5 40 ft	Proterra	Class 8	Transit Bus	**X**	**X**
SEA Cascadia EV (on Freightliner Cascadia with SEA-DRIVE Power System)	SEA Electric	Class 8	Tractor Truck	**X**	**X**
SEA Econic EV (on Freightliner Econic with SEA-Drive Power-)	SEA Electric	Class 8	Cab and Chassis	**X**	**X**
SEA M2 106 EV (on Freightliner M2 106 with SEA-DRIVE Power)	SEA Electric	Class 8	Cab and Chassis	**X**	**X**
Tesla Semi	Tesla	Class 8	Tractor Truck	**-**	**O**
Van Hool CX45E	Van Hool NV / ABC Companies	Class 8	Coach Bus	**X**	**X**
Volvo VNR 4x2 Tractor	Volvo	Class 8	Tractor Truck	**X**	**X**
Volvo VNR 6x2 Tractor	Volvo	Class 8	Tractor Truck	**X**	**X**
XOS Et-One	XOS Trucks	Class 8	Tractor Truck	**-**	**X**

APPENDIX B: EMFAC VEHICLE CATEGORY AND VEHICLE ALIGNMENT

Table 17. CARB Percent Population Estimates of ACF Fleets by Vehicle Category

Vehicle Category	Public	Drayage	High Priority Fleet	Unregulated
All Other Buses	31%	0%	37%	32%
LHD1	6%	0%	5%	89%
LHD2	8%	0%	8%	84%
Motor Coach	0%	0%	43%	57%
OBUS	17%	0%	16%	67%
T6 CAIRP Class 4	0%	0%	32%	68%
T6 CAIRP Class 5	0%	0%	49%	51%
T6 CAIRP Class 6	0%	0%	42%	58%
T6 CAIRP Class 7	0%	0%	85%	15%
T6 Instate Delivery Class 4	0%	0%	38%	62%
T6 Instate Delivery Class 5	0%	0%	45%	55%
T6 Instate Delivery Class 6	0%	0%	49%	51%
T6 Instate Delivery Class 7	0%	0%	65%	35%
T6 Instate Other Class 4	0%	0%	21%	79%
T6 Instate Other Class 5	0%	0%	38%	62%
T6 Instate Other Class 6	0%	0%	40%	60%
T6 Instate Other Class 7	0%	0%	51%	49%
T6 Instate Tractor Class 6	0%	0%	31%	69%
T6 Instate Tractor Class 7	0%	0%	66%	34%
T6 OOS Class 4	0%	0%	84%	16%
T6 OOS Class 5	0%	0%	84%	16%
T6 OOS Class 6	0%	0%	84%	16%
T6 OOS Class 7	0%	0%	84%	16%
T6 Public Class 4	100%	0%	0%	0%
T6 Public Class 5	100%	0%	0%	0%
T6 Public Class 6	100%	0%	0%	0%
T6 Public Class 7	100%	0%	0%	0%
T6 Utility Class 5	0%	0%	100%	0%
T6 Utility Class 6	0%	0%	100%	0%
T6 Utility Class 7	0%	0%	100%	0%
T6TS	0%	0%	50%	50%
T7 CAIRP Class 8	0%	0%	43%	57%
T7 NNOOS Class 8	0%	0%	87%	13%
T7 NOOS Class 8	0%	0%	66%	34%
T7 Other Port Class 8	0%	100%	0%	0%
T7 POAK Class 8	0%	100%	0%	0%
T7 POLA Class 8	0%	100%	0%	0%
T7 Public Class 8	100%	0%	0%	0%
T7 Single Concrete/Transit Mix Class 8	0%	0%	91%	9%
PTO	0%	0%	91%	9%
T7 Single Dump Class 8	0%	0%	29%	71%
T7 Single Other Class 8	0%	0%	53%	47%
T7 SWCV Class 8	30%	0%	57%	13%
T7 Tractor Class 8	0%	12%	49%	39%
T7 Utility Class 8	0%	0%	100%	0%
T7 Yard Tractors	0%	0%	71%	29%
SBUS	0%	0%	0%	100%
UBUS	0%	0%	0%	100%
MH	0%	0%	0%	100%
T7IS	0%	0%	36%	64%

Table 18. ICF's Assumptions for BEV and FCEV Percent Population Allocations for ACF Scenario

Vehicle Category	Battery % 2024-2026	Hydrogen % 2024-2026	Battery % 2027+	Hydrogen % 2027+
All Other Buses	100%	0%	90%	10%
LDA	100%	0%	100%	0%
LDT1	100%	0%	100%	0%
LDT2	100%	0%	100%	0%
LHD1	100%	0%	100%	0%
LHD2	100%	0%	100%	0%
MCY	100%	0%	100%	0%
MDV	100%	0%	100%	0%
MH	100%	0%	100%	0%
Motor Coach	100%	0%	90%	10%
OBUS	100%	0%	90%	10%
PTO	100%	0%	100%	0%
SBUS	100%	0%	90%	10%
T6 CAIRP Class 4	50%	50%	50%	50%
T6 CAIRP Class 5	50%	50%	50%	50%
T6 CAIRP Class 6	50%	50%	50%	50%
T6 CAIRP Class 7	50%	50%	50%	50%
T6 Instate Delivery Class 4	100%	0%	90%	10%
T6 Instate Delivery Class 5	100%	0%	90%	10%
T6 Instate Delivery Class 6	100%	0%	90%	10%
T6 Instate Delivery Class 7	100%	0%	90%	10%
T6 Instate Other Class 4	100%	0%	90%	10%
T6 Instate Other Class 5	100%	0%	90%	10%
T6 Instate Other Class 6	100%	0%	90%	10%
T6 Instate Other Class 7	100%	0%	90%	10%
T6 Instate Tractor Class 6	90%	10%	75%	25%
T6 Instate Tractor Class 7	90%	10%	75%	25%
T6 OOS Class 4	50%	50%	50%	50%
T6 OOS Class 5	50%	50%	50%	50%
T6 OOS Class 6	50%	50%	50%	50%
T6 OOS Class 7	50%	50%	50%	50%
T6 Public Class 4	100%	0%	90%	10%
T6 Public Class 5	100%	0%	90%	10%
T6 Public Class 6	100%	0%	90%	10%
T6 Public Class 7	100%	0%	90%	10%
T6 Utility Class 5	100%	0%	90%	10%
T6 Utility Class 6	100%	0%	90%	10%
T6 Utility Class 7	100%	0%	90%	10%
T6TS	100%	0%	90%	10%
T7 CAIRP Class 8	50%	50%	50%	50%
T7 NNOOS Class 8	50%	50%	50%	50%
T7 NOOS Class 8	50%	50%	50%	50%
T7 POAK Class 8	90%	10%	75%	25%
T7 POLA Class 8	90%	10%	75%	25%
T7 Other Port Class 8	90%	10%	75%	25%
T7 Public Class 8	100%	0%	90%	10%
T7 Single Concrete Class 8	100%	0%	90%	10%
T7 Single Dump Class 8	100%	0%	90%	10%
T7 Single Other Class 8	100%	0%	90%	10%
T7 SWCV Class 8	100%	0%	90%	10%
T7 Tractor Class 8	90%	10%	75%	25%
T7 Utility Class 8	100%	0%	90%	10%
T7IS	100%	0%	90%	10%
UBUS	100%	0%	90%	10%