University of California, Irvine

A Replicable Infrastructure Blueprint for Zero-Emission Medium- and Heavy-Duty Vehicles in the South Coast Air Basin

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ABSTRACT

This report presents a replicable Zero-Emission Infrastructure Blueprint for medium-and heavy-duty electric charging and hydrogen fueling in the South Coast Air Basin. The goal of the Blueprint is to outline a replicable framework for the build-out of a cost-effective, reliable, and resilient charging and fueling network with consideration to disadvantaged communities. To achieve the goal, the Blueprint includes:

- Regional station network deployment scale and timeline to meet state's goals.
- Spatially resolved deployment of heavy-duty ZEV charging and hydrogen fueling in SoCAB between 2020 and 2050.
- Local fleet infrastructure requirements and timelines for infrastructure planning, construction, and operation.
- Workforce requirements and opportunities.
- Benefits to and impacts on disadvantaged communities.

Keywords: Blueprint; medium-and heavy-duty vehicles; charging and fueling infrastructure; air quality; disadvantaged communities

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EXECUTIVE SUMMARY

The South Coast Air Basin (SoCAB), a region encompassing Orange County, and portions of Los Angeles, San Bernardino, and Riverside Counties, historically has been impacted by degraded air quality. The degradation of air quality within SoCAB stems from a combination of a high concentration of economic activity, such as goods movements to and from the San Pedro Bay Ports, and geographic and meteorological conditions that build and concentrate air pollutants within the region. A major strategy to address climate and air quality is the adoption of zero-emission vehicle (ZEV) technologies.

The transition to ZEVs requires an overhaul of the transportation sector not only in terms of vehicle deployment but also fueling infrastructure. The adoption process is challenged by the lack of guidance associated with the rollout of charging and hydrogen refueling infrastructure. Currently, the approach for infrastructure planning involves building charging and hydrogen stations on a fleet-specific basis. Yet, this method can be difficult for fleets to navigate, especially without established models for successful infrastructure implementation in medium- and heavy-duty (MD/HD) use cases. Transitioning to zero-emission vehicles, whether battery electric or fuel cell electric, incurs significant costs and necessitates coordinated planning with lengthy lead times for vehicle procurement and infrastructure setup. Fleets need assurance that their plans will minimize risks and adequately meet their operational requirements in the long run.

The Zero-Emission Infrastructure Blueprint for regional charging and hydrogen station networks is designed to facilitate the planning of ZEV infrastructure deployment within the SoCAB region, with particular focus on drayage, long haul, and transit applications. The report provides technology comparisons, maps, timelines, and job-training considerations, and incorporates input from community and industry stakeholders. The Blueprint is also designed to serve as a replicable template for fleets, targeting specific challenges within the transit, drayage, and long haul sectors.

Current and projected demand for each vocation is quantified and feasible ZEV adoption pathways are established based on existing State goals and vehicle constraints. Vehicle travel demand is projected to grow between now and 2045 with higher demand resulting in greater greenhouse gas and criteria pollutant emissions without the transition to ZEVs. Adopting ZEVs with target adoption percentages between 75-100% by 2045 results in significant reduction in greenhouse gas (GHG) and criteria air pollutant (CAP) emissions reduction and assists in achieving the State’s goal of 85% reduction in net GHG emissions compared to 1990 levels by 2045 as established in AB 1279.

Widespread ZEV adoption necessitates a large charging and hydrogen fueling network. The number and placement of stations is dependent on several factors including whether stations are fleet-based or public, station capacity, charging or fueling rate, utilization, and MD/HD travel patterns. Transit infrastructure will predominantly rely on fleet-based charging and hydrogen fueling at depots. Drayage and long haul trucks are likely to rely on public hydrogen infrastructure and a combination of depot and public charging infrastructure. Public stations can provide additional back-up to fleets who rely primarily on depot infrastructure. Coordinated planning can optimize sizing and placement of stations within a region.

The Blueprint proposes a methodology for optimizing the placement of public hydrogen stations applying a location-allocation algorithm utilizing spatial travel demand data, candidate station sites based on existing truck stops, and station and vehicle parameters. By applying this algorithm, station placement is optimized to maximize demand coverage. To meet projected drayage and long haul truck hydrogen demand, it was estimated that at least 5 stations are needed in 2025, 42 in 2035, and 127 in 2045. Additional stations could provide improved network resiliency in the case of a station outage. While the data utilized in this analysis are specific to California, the framework can be applied to other regions using similar data.

ACRONYMS

AB	Assembly Bill
AC	Alternating Current
ACF	Advanced Clean Fleets
ACT	Advanced Clean Trucks
ATEP	Advanced Technology and Education Park
ATL	Advanced Transportation and Logistics
BenMAP	Environmental Benefits Mapping and Analysis Program
BEV	Battery Electric Vehicle
Caltrans	California Department of Transportation
CAAP	Clean Air Action Plan
CAAQS	California Ambient Air Quality Standards
CAP	Criteria Air Pollutant
CARB	California Air Resources Board
CEC	California Energy Commission
CHSS	Compressed Hydrogen Storage System
CMAQ	Community Multiscale Air Quality
CPUC	California Public Utilities Commission
DAC	Disadvantaged Communities
DCFC	Direct Current Fast Charging
DER	Distributed Energy Resource
EMFAC	EMission FACtor
EnergIIZE	Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles
EO	Executive Order
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
EVSE	Electric Vehicle Supply Equipment
FAF5	Freight Analysis Framework 5
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gases
HDV	Heavy-Duty Vehicle
H_2	Hydrogen
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
ICT	Innovative Clean Transit
ISO	International Organization for Standardization
kW	Kilowatt
LDV	Light-Duty Vehicle
MCS	Megawatt Charging System
MD/HD	Medium-Duty and Heavy-Duty
MW	Megawatt
NAAQS	National Ambient Air Quality Standards

NOx	Nitrogen oxides
PM	Particulate Matter
SAE	Society of Automotive Engineers
SB	Senate Bill
SCAQMD	South Coast Air Quality Management District
SOC	State of Charge
SoCAB	South Coast Air Basin
STEP	Sustainable Transportation Equity Project
STREET	Spatially & Temporally Resolved Energy & Environment Tool
TOU	Time-of-Use
U.S. EPA	United States Environmental Protection Agency
VMT	Vehicle Miles Traveled
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2L	Vehicle-to-Load
ZANZEFF	Zero and Near Zero-Emission Freight Facilities
ZEB	Zero-Emission Bus
ZEV	Zero-Emission Vehicle

1 Blueprint Scope

1.1 Introduction

The South Coast Air Basin (SoCAB) encompasses Orange County, and portions of Los Angeles, San Bernardino, and Riverside Counties (see Figure 1). Historically, this air basin has been impacted by degraded air quality from a combination of a high concentration of economic activity, such as goods movements to and from the Los Angeles and San Pedro ports, and geographic and meteorological conditions that build and concentrate air pollutants within the region.

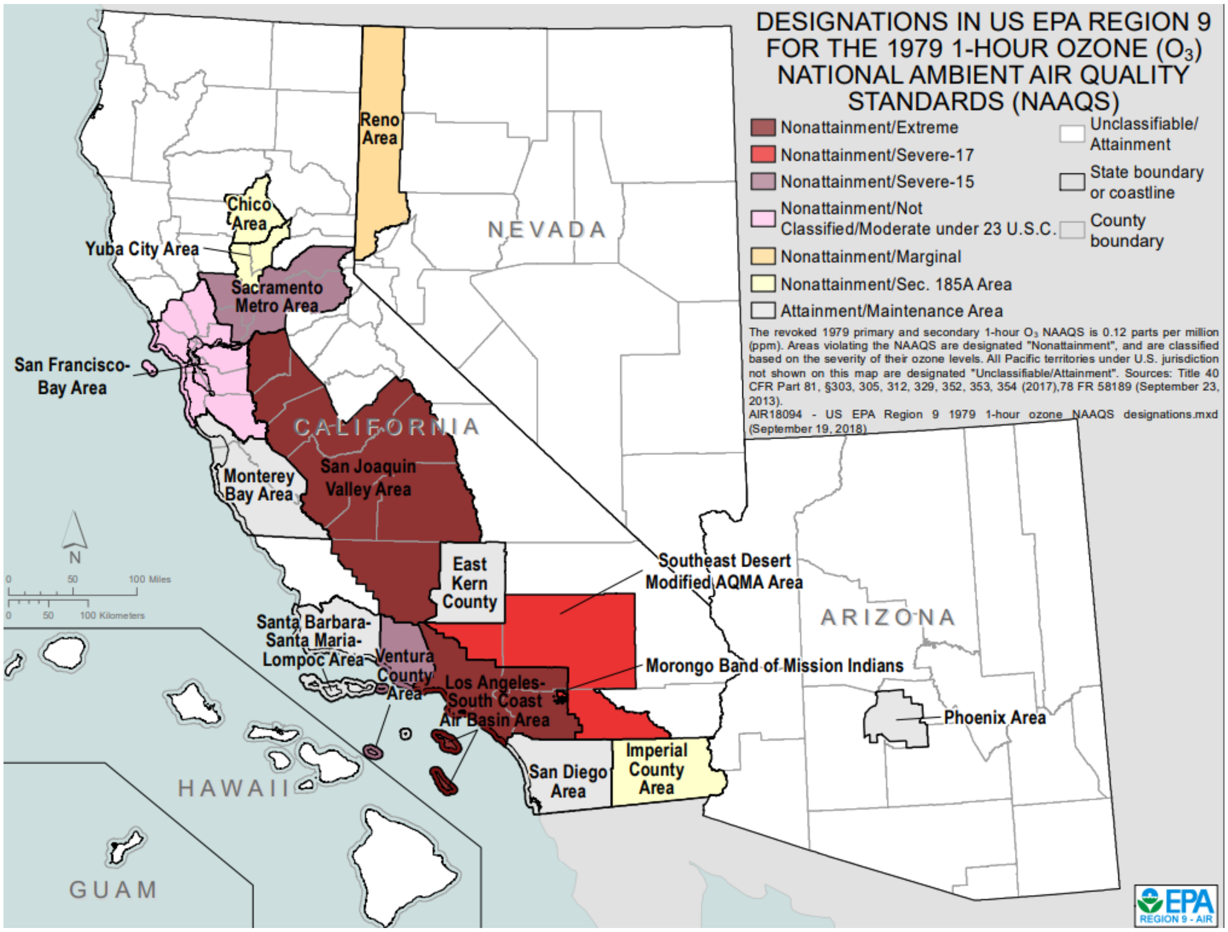
Figure 1. South Coast Air Basin

The SoCAB region is in nonattainment for several National Ambient Air Quality Standards (NAAQS) and California Ambient Air Quality Standards (CAAQS). Table 1 presents an overview of the relevant standards. Current non-attainment designations include 1-hour Ozone (see Figure 2, Extreme), 8-hour Ozone (Extreme), PM_{10} (CAAQS only), $PM_{2.5}$ (Serious), and lead (Partial) [1].

Table 1. National and California Ambient Air Quality Standards for Ozone and PM

Pollutant	Averaging Time	California Standard	U.S. Standard (primary)
Ozone (O_3)	1 hour	90 ppb	(none)
	8 hour	70 ppb	(Same as CA)
Particulate Matter ($PM_{2.5}$)	24 hour	(none)	35 µg/m³
	Annual average	12 µg/m³	12 µg/m³
PM_{10}	24 hour	50 µg/m³	150 µg/m³

Figure 2. Ozone Non-attainment Areas within California



Reproduced from U.S. EPA https://www3.epa.gov/region9/air/maps/pdfs/r9-1hr-o3-naaqs-desigs-air18094.pdf

The adoption of medium and heavy-duty zero-emission vehicles (MD/HD ZEVs) is a major strategy to reduce transportation criteria air pollutants (CAPs) as well as greenhouse gas emissions (GHG). Currently, the pace of adoption is challenged by the lack of guidance and public-private sector coordination on the rollout of charging and hydrogen refueling infrastructure. Presently, charging and hydrogen stations are being built on a fleet-by-fleet basis. In the absence of an overall guide for fleet and public MD/HD ZEV stations, it will be challenging for stakeholders to navigate the processes of planning, construction, and operation of stations. Investing in ZEVs, whether battery electric or fuel cell electric, is a considerable cost and requires coordinated planning with long lead times for both the procurement of vehicles and setting up the necessary charging and/or refueling infrastructure. MD/HD operators, to transition to MD/HD ZEVs, need to be confident that electric charging and hydrogen fueling infrastructure is evolving based on a MD/HD ZEV infrastructure Blueprint that minimizes risk and meets operational needs.

1.1.1 Environmental Policy Targets

Several policies at the federal, state, and local levels target criteria air pollutant emissions, greenhouse gas emissions, ZEV and infrastructure deployments, and equity relevant to the development of a SoCAB MD/HD ZEV infrastructure Blueprint. At the federal level, President Biden’s Executive Order (E.O.) 14057 directs the United States to reduce its scope 1 and 2 greenhouse gas emissions by 65% below 2008 levels by 2030 and achieve a 100% ZEV acquisitions by 2035, with the ultimate goal of a net-zero emissions economy by 2050 [2]. Under E.O. 14008, the President established the Justice40 Initiative, which directs federal agencies to ensure that at least 40% of benefits achieved through the climate and clean energy investments be realized within disadvantaged communities [3].

At the state level, California is committed to combatting climate change and in doing so, also addressing inequity related to its current energy system [4]. To that end, several emissions reduction goals have been adopted. For example, Senate Bill (SB) 32, Assembly Bill (AB) 1279, and several Executive Orders (S-3-05 and N-79-20), have set the following GHG emissions reduction targets:

- Reduce GHG emissions to 40 percent below 1990 levels by 2030 (SB 32),
- Achieve net zero GHG emissions by 2045 (AB 1279, 2022), and
- Reduce GHG emission to 80 percent below 1990 levels by 2050.

As directed by E.O. N-79-20 and established by the Advanced Clean Trucks (ACT) Regulation and the Advanced Clean Fleets (ACF) regulation, California has also set future ZEV requirements:

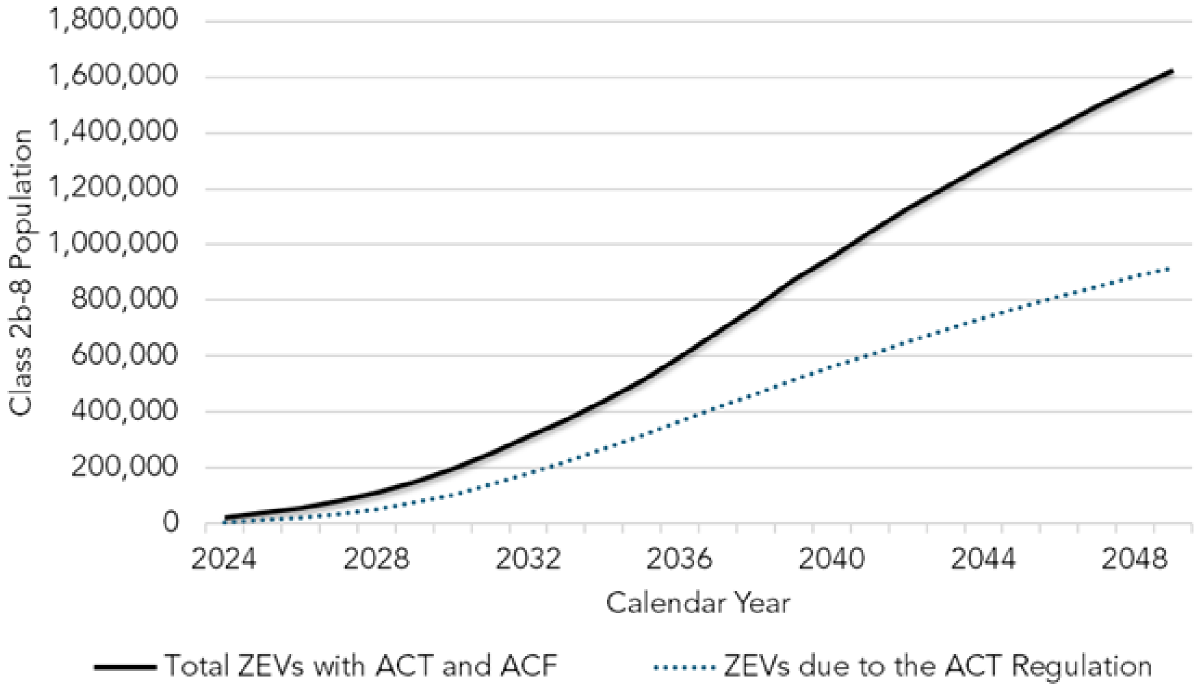
- All new passenger vehicle sales by 2035,
- All drayage trucks by 2035,
- All other MD/HD vehicles by 2045, where feasible and
- All off-road vehicles and equipment by 2035, where feasible.

Within the South Coast Air Basin (SoCAB) region, the South Coast Air Quality Management District (SCAQMD) has a number of initiatives to improve regional air quality. For example, the South Coast AQMD Clean Port Initiative outlines steps that the SCAQMD in partnership with other agencies can take to reduce local port pollution, including emissions associated with drayage trucks. Additionally, the two ports in SoCAB—the Port of Los Angeles and the Port of Long Beach—have agreed to the San Pedro Clean Air Action Plan which targets NOx and PM emissions reductions and sets the goal of 100% zero-emission operations by 2035 [5].

1.1.2 Zero-Emission Vehicle Adoption Projections

Figure 3 presents projected MD/HD ZEVs in California under the two truck-centric regulations. CARB anticipates a significant increase in the adoption of ZEVs under the added mandates under the Clean Fleets Regulation compared to the ACT regulation by itself. This increase is necessary to meet the State's GHG emissions reduction targets by 2045.

Figure 3. Projected Medium- and Heavy-Duty Zero-Emission Vehicles under California Regulations



Reproduced from CARB https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary

The 2022 Scoping Plan published by CARB has also projected MD/HD ZEV adoption out to the year 2045 in line with State GHG emissions reduction targets [6]. The 2022 Scoping Plan developed statewide ZEV adoption pathways for general vehicle categories (light-duty, medium-duty, heavy-duty, and buses). The vehicle pathways are presented in Appendix A, Figures A-1, A-2, and A-3. These pathways have the MD/HD sector transitioning to approximately 75% ZEV by 2045 [7]. This percentage is based on reasonable ZEV adoption feasibility given the established transition timeline as well as technology operational constraints.

For this analysis, region-specific ZEV projections are calculated with input from State modeling, announced local ZEV commitments, and other previous analyses. Modeling assumptions for each scenario explored are stated in Chapter 4.

1.2 Project Goals

The goals of this project, "A Replicable Zero-Emission Blueprint for Medium-and Heavy-Duty Fleets in the South Coast Air Basin," are to (1) develop a replicable Blueprint for medium- and heavy-duty charging and hydrogen infrastructure within the South Coast Air Basin with a focus on transit, drayage, and long haul trucking, (2) consider stakeholder input, and (3) ensure that the Blueprint is available to the public, and to industry and community stakeholders. To achieve the goals of the project, ten objectives were met:

1. Develop a replicable Blueprint for the SoCAB region based on compiled data, technology assessment, stakeholder input, and workforce opportunities.
2. Make the Blueprint available to the public.
3. Define technoeconomic and environmental breadth of the Blueprint based on existing policies and plans.
4. Define technical, economic, and environmental metrics of the proposed MD/HD ZEV infrastructure deployment.
5. Assess charging/fueling station requirements, including overall process, critical steps, and timelines of implementing individual stations within a network.
6. Analyze future region-specific charging/refueling demands focusing on transit, drayage, and long haul requirements within the SoCAB region.
7. Assess regional infrastructure network optimization with consideration of vocation-specific needs and impacts on disadvantaged communities.
8. Attract and engage industry stakeholders.
9. Attract and engage community stakeholders.
10. Develop, with Saddleback College, a curriculum extension to their automotive education program that focuses on the evolution of light-duty and MD/HD ZEV.

1.3 Background

1.3.1 Previous and Existing Efforts

While over 1,000 MD/HD-BEVs and 115 MD/HD-FCEVs have been deployed in the SCAQMD (as of mid-2023) through one of California's ZEV funding programs,[1] most of the available zero-emission infrastructure for electric charging and hydrogen fueling deployed is designed to serve light-duty vehicle demand. Statewide, over 60 hydrogen refueling stations and over 9,000 DC fast chargers are deployed [8]. The ability of MD/HD vehicles to use light-duty-based infrastructure is limited, given (1) a higher fuel demand and longer fueling time that could frustrate a nascent LDV FCEV market, (2) a different fueling/charging protocol [9], [10], and/or (3) difficulty in navigating the station due to station design (location, spacing).

A limited number of MD/HD-ZEV hydrogen and charging stations are located within the region to serve transit, drayage, and delivery applications (see Figure 4). So far, these stations have been designed mainly to meet specific fleet needs. Example stations include: The Port of Long Beach hydrogen refueling station dispensing hydrogen sourced exclusively from biogas using tri-generation to produce hydrogen fuel (along with electricity and heat) to support the use of FCEV Class 8 drayage trucks [11], the WattEV charging depot at the Port of Long Beach [12], two hydrogen fueling stations along drayage routes servicing drayage trucks from the Port of Los Angeles [13], a HD charging depot in El Monte [14], and a depot-based hydrogen refueling station at the Orange County Transit Authority (OCTA) [15].

Figure 4. Current and Proposed Hydrogen Stations within the SoCAB Region

Source: CEC

Several transit agencies with the SoCAB region have already begun to transition to zero-emission buses (ZEB), including OCTA, LA Metro, and Foothill Transit (see Table 2), in line with requirements outlined in the Innovative Clean Transit (ICT) regulation implemented by CARB [16].

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[1] California's funding programs include, but may not be limited to: CAP, CMIS, Prop 1B, Rural School Bus Pilot Project, Sacramento Regional ZE School Bus Deployment Project, VW Settlement https://californiahvip.org/industryinitiatives/#infrastructure

Table 2. Zero-Emission Bus Transition Status of Major Transit Agencies within the SoCAB Region

Transit Agency	Transition Status	Total Fleet Size	Current BEV Fleet	Current FCEV Fleet
Antelope Valley Transit Authority	100% fixed-route ZEB	At least 65	All BEB	0
City of LA DOT	100% by 2028	503	29, 30 more planned	0
Culver CityBus	100% by 2028	54	4, 6 more ordered	0
Foothill Transit	100% by 2030	At least 350	33	20 planned
GTrans (Gardena MBL)	100% by 2035	At least 65	2	0
Glendale Beeline	100% by 2040	About 80	0	0
LA Metro	100% by 2030	About 2,300	At least 40	
Long Beach Transit	100% by 2030	About 250	10, 20 more planned	0
Montebello Bus	100% by 2040	66	0	0
Orange County TA	100% by 2040	508	10	10
Santa Clarita Transit	100% by 2040	56 local, 28 commuter, 1 trolley, 21 Dial-A-Ride, 8 ASI	0	0
Santa Monica Bus	100% by 2030	195	At least 18	0
Omnitrans	100% by 2040	269	4	0
Riverside TA	100% by 2040	334	0	0

Sources: https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans; https://www.avta.com/avta-passes-a-new-electric-milestone-seven-million-miles-of-zero-emission-bus-operations; https://ladot.lacity.org/dotnews/los-angeles-department-transportation-install-solar-and-storage-microgrid-and-ev-charging; https://ww2.arb.ca.gov/sites/default/files/2020-12/LADOT_ROP_Reso_ADA12172020.pdf; https://content.govdelivery.com/accounts/CACULVER/bulletins/2f358c3; https://ww2.arb.ca.gov/sites/default/files/2020-09/Foothill_ROP_Cover%20LetterADA09092020.pdf; https://luskin.ucla.edu/wp-content/uploads/2021/06/1GTransBusesRevised_RA.pdf; https://www.latimes.com/socal/glendale-news-press/news/story/2020-01-30/glendale-buys-new-buses-environmental-debate; https://ridelbt.com/pr-new-bebs/

CARB hosts the existing ZEB rollout plans on its ICT website [16]. The listed agencies with existing plans are planning to rely mostly on depot-based charging/fueling. The following analysis accounts for these stations.

1.3.2 Challenges and Data Gaps

The electric vehicle supply equipment (EVSE) market has grown significantly over the last 10 years with over 40 companies currently supplying EVSE. As technologies mature, best practices are being adopted, expediting deployments and improving performance. However, there remain several challenges and data gaps that cause customer uncertainty and slow adoption.

For example, COVID-19 and other global events impacted EVSE supply chains. Lead times on equipment remain prolonged and may impact expected timelines for electric vehicle charging station (EVCS) construction. Timing the purchase of MD/HD-ZEVs in coordination with the commissioning of new EVCS can be challenging, especially if funding programs set time restrictions for receiving vehicles or constructing infrastructure.

Another challenge being addressed is low EVSE reliability. Approximately 30% of charging sessions fail [17] for a number of reasons, including hardware and software malfunctions [18]. These include interoperability issues, challenges with payment systems, hardware failure, and communication failures (e.g., failed start-up sequence). The large number of product offerings has contributed to interoperability issues between EVSE and vehicles. MD/HD charging will require a greater level of reliability due to the MD/HD vehicle commercial purposes. Failed charging sessions can lead to reduced vehicle availability, increased operating costs, and lower consumer confidence in the technology.

High capital costs also remain a challenge. Transitioning to MD/HD ZEVs is a major undertaking. There are significant long-term implications when deciding the charging infrastructure specifications, including site location(s), technologies and charging rates, and utility transformer upgrade needs. A higher charging rate can mean faster charging times and greater operational flexibility; however, it also means higher upfront costs as well as potentially higher demand charges[2] from the electric utility. A fleet should consider several factors in selecting the proper charger type(s), including vehicle operations, energy demand, electricity costs, EVSE costs, and space available for EVSE [19], [20].

Similar to BEV charging, emergency response teams have limited experience with hydrogen refueling stations. As the number and capacity of hydrogen stations increase,

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[2] Demand charges are monthly utility fees set by the peak electricity demand

it is important that safety guidelines (e.g., NFPA 2) are more broadly understood. Local and regional variability in station permitting, hydrogen understanding, and emergency response training lead to longer commissioning times and a slower growth of MD/HD-FCEV deployment. Lead times can also affect project costs and overall feasibility. While several state initiatives on the EVSE-side have endeavored to streamline permitting (e.g., through AB 1236), there has been less progress on streamlining hydrogen refueling station permitting.

Faster refueling is limited by current dispenser equipment and the existing standards. The current protocols are designed for LDVs. Applying these same protocols to MD/HD applications is not optimal and results in slow fill times and difficulty achieving 100% SOC. This difficulty stems from SAE J2601's overly conservative approach. The HDV-specific high flow protocol is still in development and any delay in its release may hinder efforts to accelerate MD/HD-FCEV deployment in the next few years.

Lastly, current procedures for commissioning hydrogen refueling stations are designed for light-duty vehicle stations. It is probable that new procedures and devices are needed to accommodate differences in fueling protocols, station equipment, and vehicle design. There are several concurrent efforts developing devices, test methods, and validation procedures. It is anticipated that these procedures will be standardized within new ISO and SAE standards once documents for high flow protocols (ISO 19885-3, SAE J2601-5) are finalized. Again, the timing of the release of these procedures can affect MD/HD FCEV deployment.

2 Establishing a Baseline and Projecting Future Medium- and Heavy-Duty Activity

2.1 Baseline Regional Emissions and Medium- and Heavy-Duty Vehicle Activities

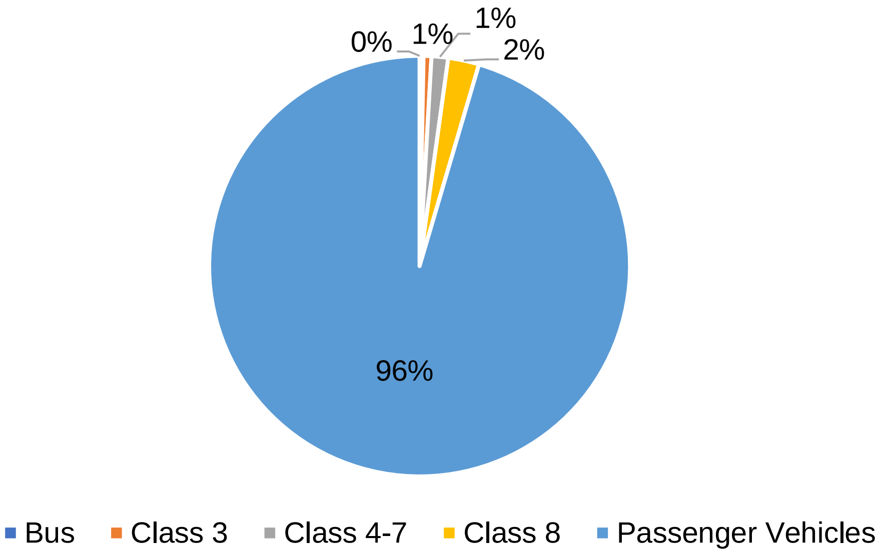
Regional vehicle travel can be categorized by vehicle class based on gross vehicle weight (see Table 3). This analysis focuses on MD/HD vehicles and in particular transit buses, drayage trucks (Class 8), and long haul trucks (Class 8). Figure 5 presents the breakdown of vehicle miles traveled (VMT) within the SoCAB region for the year 2022. Passenger vehicles (light-duty vehicles, medium-duty cars and trucks, and motorcycles) represent 96% of the on-road VMT in the region. MD/HD vehicles represent the remaining 4%. MD/HD vehicles contribute a disproportionate amount of GHG emissions compared to their VMT share, because they have lower fuel efficiencies compared to the lighter passenger vehicles. As Figure 6 shows, passenger vehicles represent 83% of regional on-road transportation emissions, with the remaining 17% from MD/HD vehicles.

Table 3. Vehicle Classifications

Gross Vehicle Weight Rating (lbs.)	**Vehicle Classifications**			
	Class	**California ARB (EMFAC 2021)** [21]		**U.S. FHWA** [22]
0-6,000	1	Light-Duty Cars and Trucks (LDA, LDT1, LDT2)		Light Truck
6,001 – 8,500	2A	Medium-Duty Cars And Trucks (MDV)		
8,501-10,000	2B	Light-Heavy Duty Trucks (LHD1)	Buses (SBUS, Motor Coach, UBUS, OBUS, All Other Buses)	Light/Medium Duty Truck
10,001 – 14,000	3	Light-Heavy Duty Trucks (LHD2)		Medium Duty Truck
14,001 – 16,000	4	(T6 Class 4) Public, Instate Delivery, Instate Other, CAIRP, OOS		
16,001 – 19,500	5	(T6 Class 5) Public, Instate Delivery, Instate Other, CAIRP, OOS		
19,501 – 26,000	6	(T6 Class 6) Public, Instate Delivery, Instate Other, CAIRP, OOS		
26,001 – 33,000	7	(T6 Class 7) Public, Instate Delivery, Instate Other, CAIRP, OOS		Heavy Duty Truck
33,001 – 60,000	8A	(T7 Class 8) Public, CAIRP, Utility, NNOOS, NOOS, POAK, POLA, Other Port, Single Concrete/Transit Mix Truck, Single Dump, Single Other, Tractor, SWCV, T7IS, PTO		
>60,000	8B			

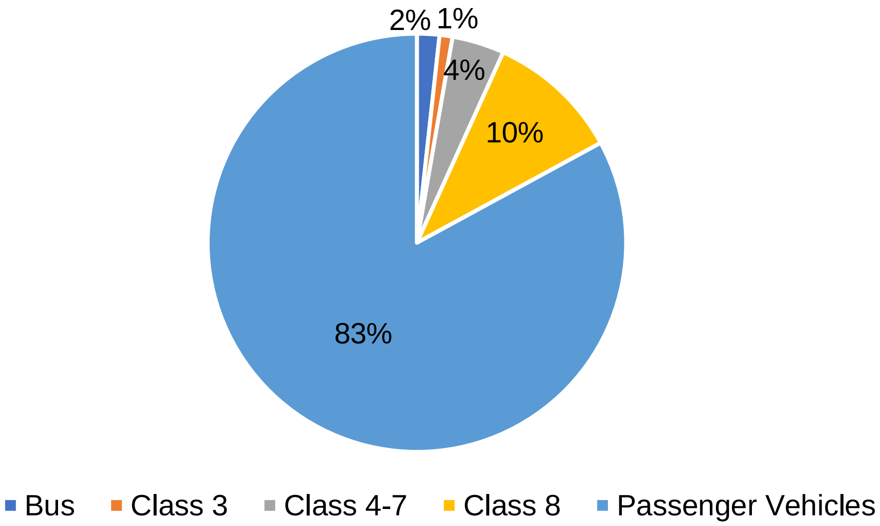
Data from EMFAC2021

Figure 5. Regional Vehicle Miles Traveled by Vehicle Class for Year 2022



Data from CARB EMFAC tool

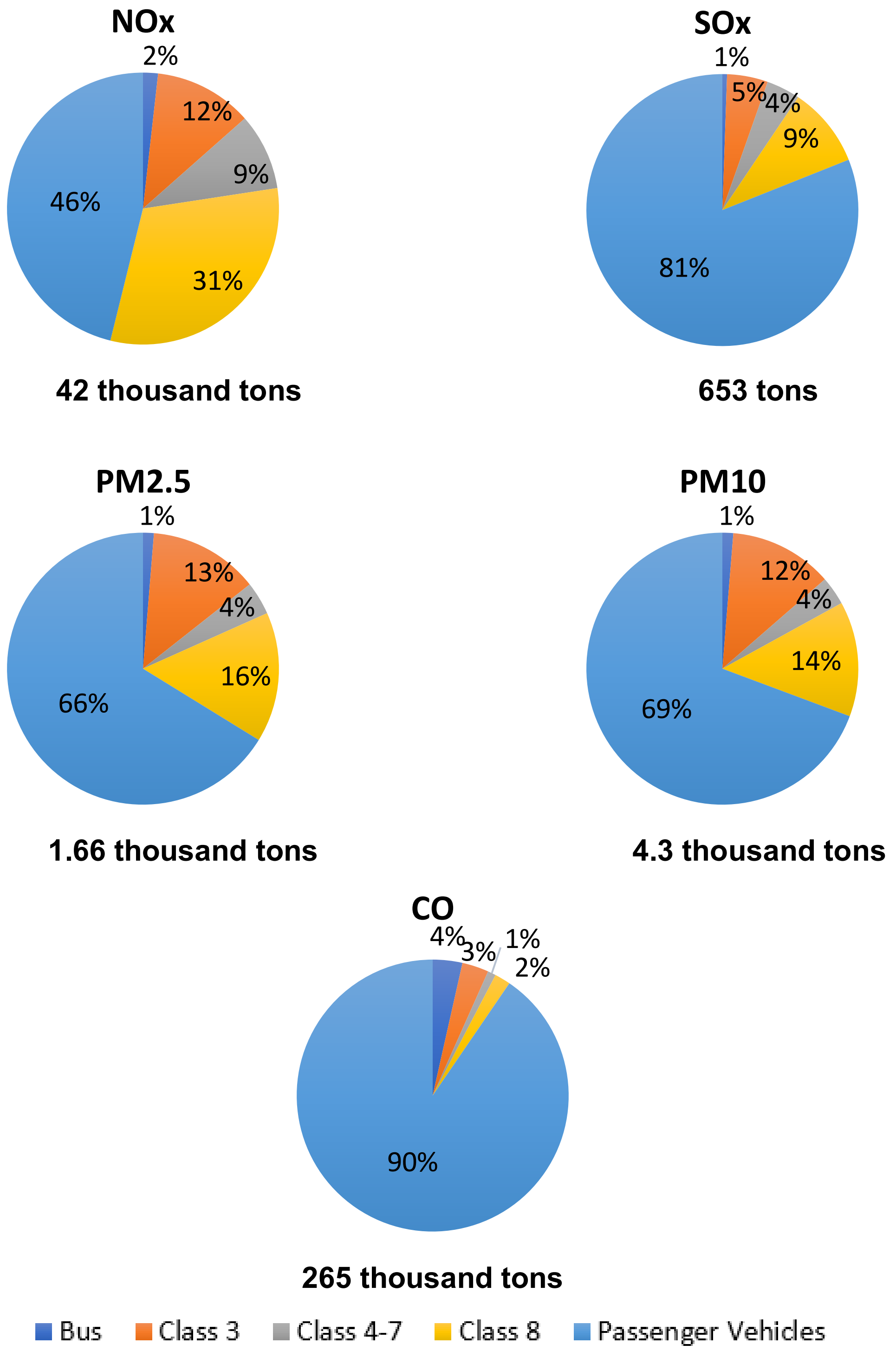
Figure 6. SoCAB Transportation GHG Emissions for Year 2022



Data from CARB EMFAC tool

MD/HD vehicle classes contribute disproportionally to CAP emissions as well (see Figure 7). CAP emissions are generally emitted from the vehicle tailpipe, but PM2.5 and PM10 are also emitted from brake and tire wear. Heavy-heavy duty vehicles contribute a significant portion of NOx emissions, greater in proportion to their VMT within the region. In addition, buses make up less than one percent of vehicle miles traveled, but still contribute significantly to GHG emissions and criteria pollutant emissions. They also operate within urban environments, exposing sensitive communities to pollutants.

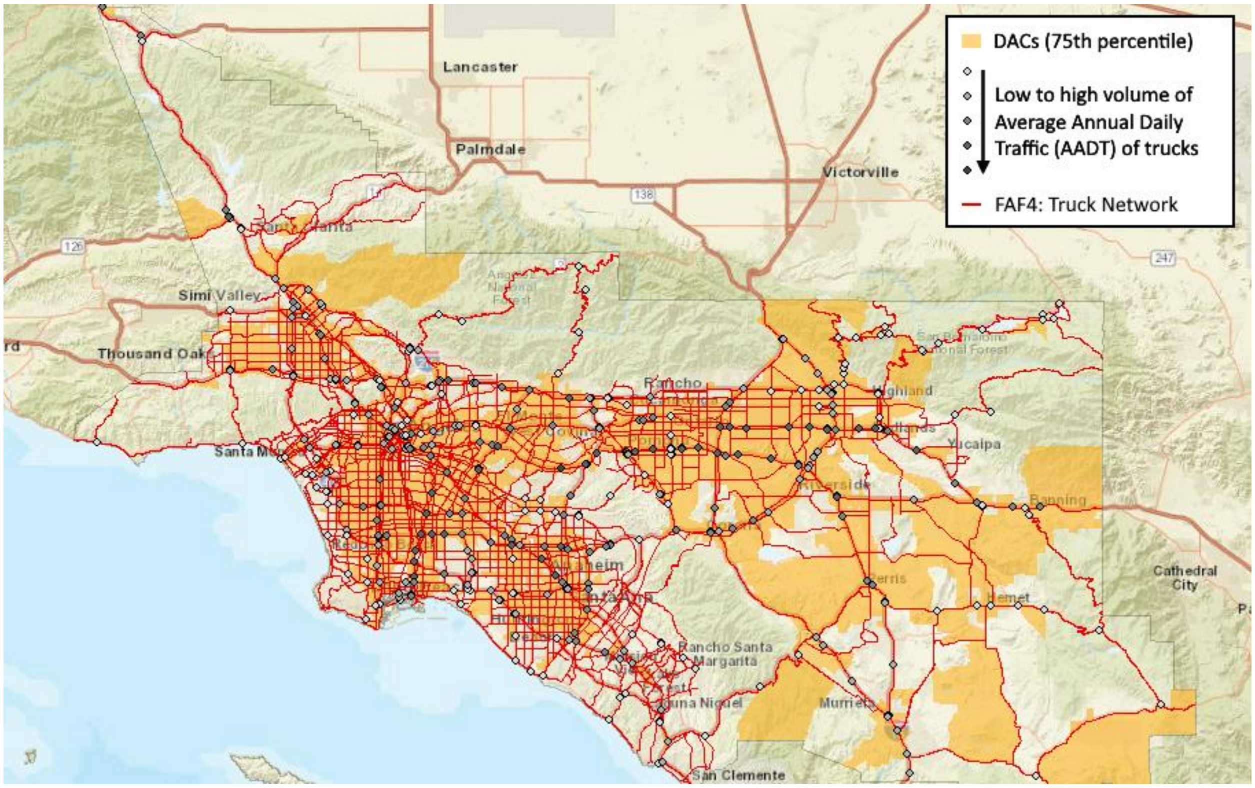
Figure 7. 2022 SoCAB Transportation Criteria Pollutant Emissions



Data from CARB EMFAC tool

The spatial travel patterns of trucks are presented in Figure 8. This map uses truck traffic flow data from the California Department of Transportation (Caltrans) and overlays the spatial distribution of disadvantaged communities (DACs) that score at or above the 75th percentile under the scoring method established under SB 535. Several high volume traffic areas fall within DACs, including around the Los Angeles and San Pedro Ports and along the following freeways: I-5, I-710, I-110, I-91, I-60, I-210, and I-10. Much of this traffic is associated with goods movement to and from the ports as well as from distribution centers to local, regional, and interregional endpoints.

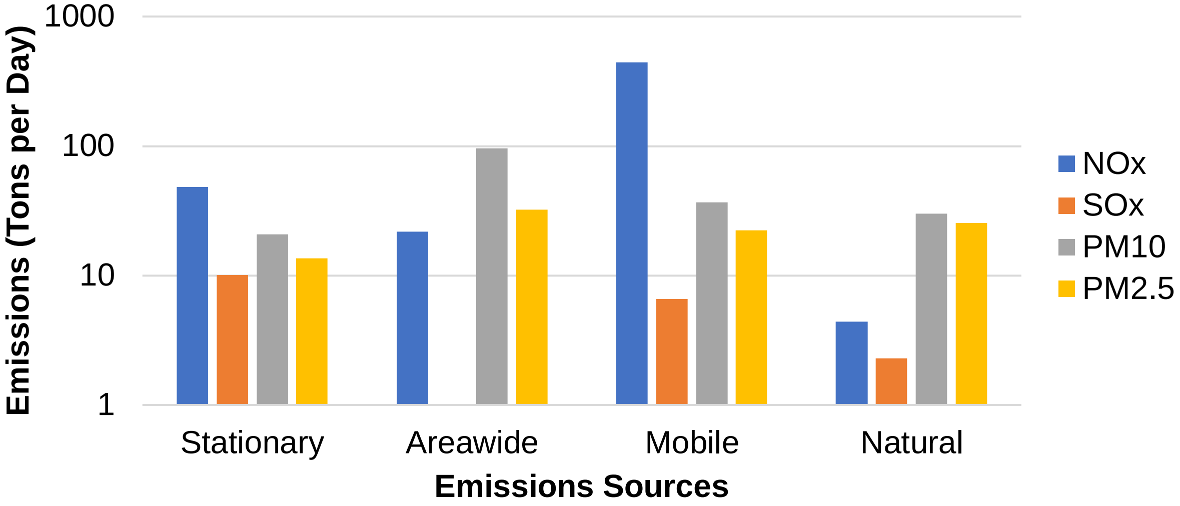
Figure 8. Regional Truck Traffic and Disadvantaged Communities



Basemap from arcGIS. *Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community* Data Sources: CalEnviroScreen 4.0; Caltrans AADT Data; Bureau of Transportation Statistics FAF4 Truck Network

It is important to note that vehicles are not the only sources of CAP emissions. Other key pollutant sources include stationary, areawide, and natural sources (see Figure 9). The air quality analysis in Section 4.5 assumes that other CAP emission sources remain constant, so that the impact of changing MD/HD vehicle emissions on air quality and health impacts can be isolated and quantified.

Figure 9. SoCAB Regional Criteria Pollutant Emissions for Year 2012



Data from California Air Resources Board

2.2 Projecting Future Medium- and Heavy-Duty Vehicle Travel Demand

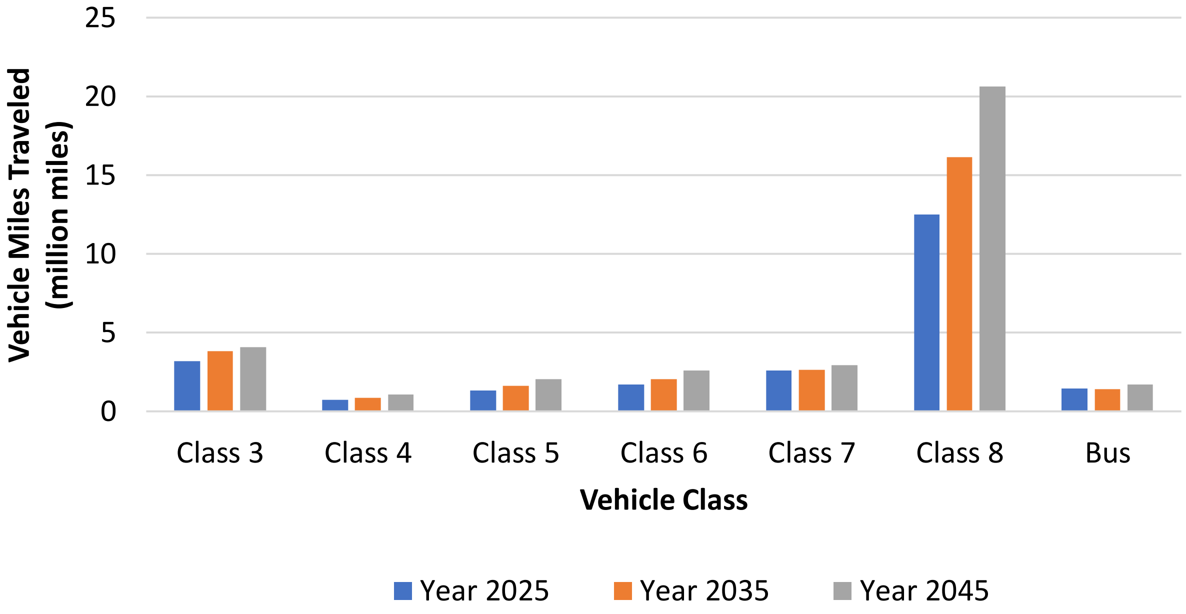
ZEV demand and associated emissions reductions are calculated using three approaches: (1) a top-down approach using statewide adoption projections from previous studies to extrapolate regional ZEV adoption across all on-road vehicles and calculate the associated emissions reductions, (2) vocation-specific modeling focused on two of the MD/HD target vocations—drayage and long haul, and (3) publicly available data on transit ZEB rollout.

2.2.1 Regional Medium- and Heavy-Duty Vehicle Miles Projections

Future MD/HD VMT growth is dependent on economic and planning decisions, however, VMT is anticipated to increase across all vehicle classes between now and the year 2045. This analysis utilizes the VMT projection assumptions in the California Air Resources Board (CARB) EMFAC tool [21]. These VMT projections combined with fuel efficiency and emissions factor assumptions can be utilized to determine the net emission of GHG and criteria air pollutant emissions under different ZEV deployment scenarios.

Figure 10 presents the projected VMT for MD/HD vehicle classes for the years 2025, 2035, and 2045. Class 8 trucks see the largest increase in VMT, up nearly 30% in 2035 compared to current demand. Bus categories, of which transit is a sub-category, see relatively consistent demand out to 2035, but increase by about 20% between 2035 and 2045.

Figure 10. Daily Vehicle Miles Traveled by Vehicle Class for Years 2025, 2035, and 2045



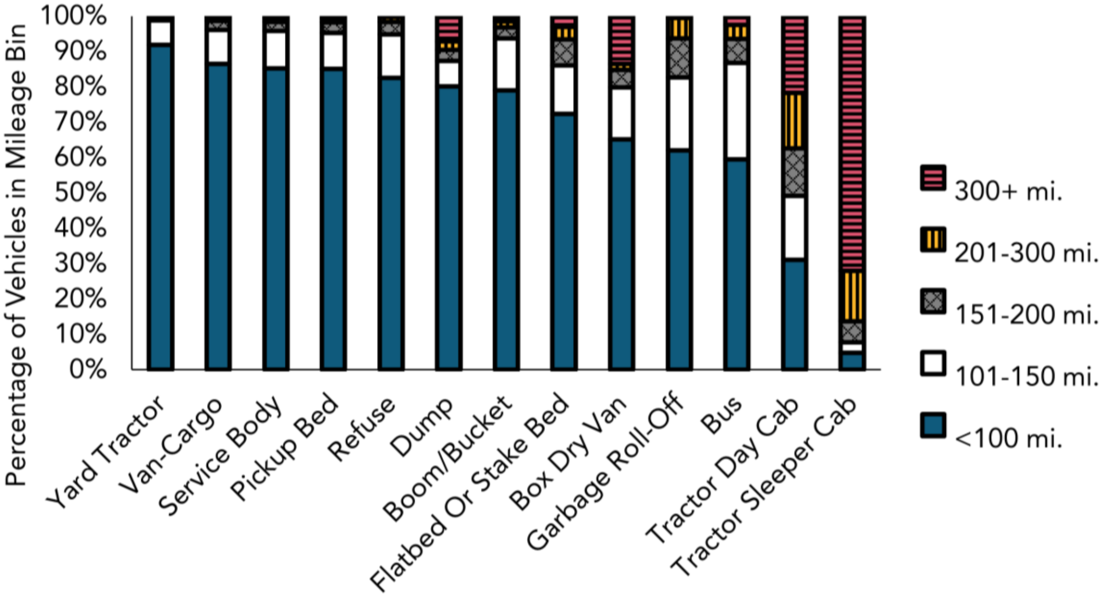
Data from CARB EMFAC tool

The 2022 Scoping Plan does not have vocation-specific projections for transit, drayage, or long haul and therefore, additional scenarios were developed for this analysis as presented in the following section. The selected scenarios are generally more aggressive in adopting ZEVs than the 2022 Scoping Plan.

2.2.2 Long Haul, Drayage, and Transit Miles Projections

For the vocation-specific scenarios, three vocations were investigated: drayage, long haul, and transit. The adoption of BEVs versus FCEVs for drayage and long haul trucks is informed by the Transportation Rollout Affecting Cost and Emissions (TRACE) model, and for transit is informed by publicly available data on individual transit agencies' ZEB rollout plans [23]. The split between BEVs and FCEVs takes into consideration the varying daily VMT for different vehicle types. The distribution of daily miles traveled for sample vehicle types is illustrated in **Figure *11***, from [24]. Transit buses most align with the "bus" category, drayage trucks align with "tractor day cab," and long haul trucks, "Tractor Sleeper Cab." Daily VMT will directly affect charging/fueling times, which are covered in more detail in Section 2.4.1 and Section 2.4.2.

Figure 11. Large Entity Reporting Average Daily Miles Traveled by Vehicle Type



Credit: CARB

This analysis also utilizes future growth in vehicle populations and VMT from EMFAC. For this analysis, the EMFAC vehicle categories as grouped in Table 4 are used. Drayage and long haul trucks make up a combined 82% of total HDV VMT in California. The largest portion is out-of-state long haul (51%), including those vehicles registered out of state as well as those registered to operate internationally.

Table 4. Target Vehicle Categories mapped to EMFAC

Vehicle Category for Study	EMFAC Classification(s)	Percent of 2022 HDV or Bus Population	Percent of 2022 HDV or Bus VMT
Instate Long Haul	T7 Class 8 Tractor	24%	16%
Out-of-State Long Haul	T7 Class 8 CAIRP, T7 Class 8 NNOOS, T7 NOOS Class 8	25%	51%
Drayage	T7 Class 8 POLA, T7 Class 8 POAK *	14%	15%
Transit Buses	UBUS	25%	49% (bus)

**For the year 2019 in EMFAC2021, there is one POAK drayage truck that operates within the SoCAB region. According to the model, no 'Other Port' trucks operate within SoCAB for the timespan examined.*

EMFAC projects all target vocations will experience increases in population and VMT out to the year 2045, see Figure 12 and Figure 13, respectively. The drayage truck population is anticipated to increase by 26% between 2022 and 2045, transit is anticipated to increase by 47%, in-state long haul by 139%, and out-of-state long haul by 83%. Note, long haul truck growth is steady between 2022 and 2045, but drayage truck and transit growth are less consistent, with most drayage growth happening before 2025 and transit growth more concentrated between 2035 and 2045. These trends will impact when and how many ZEV stations will need to be deployed to meet vocational ZEV demand.

Figure 12. Projected SoCAB Population of Target Categories, Years 2019 – 2045

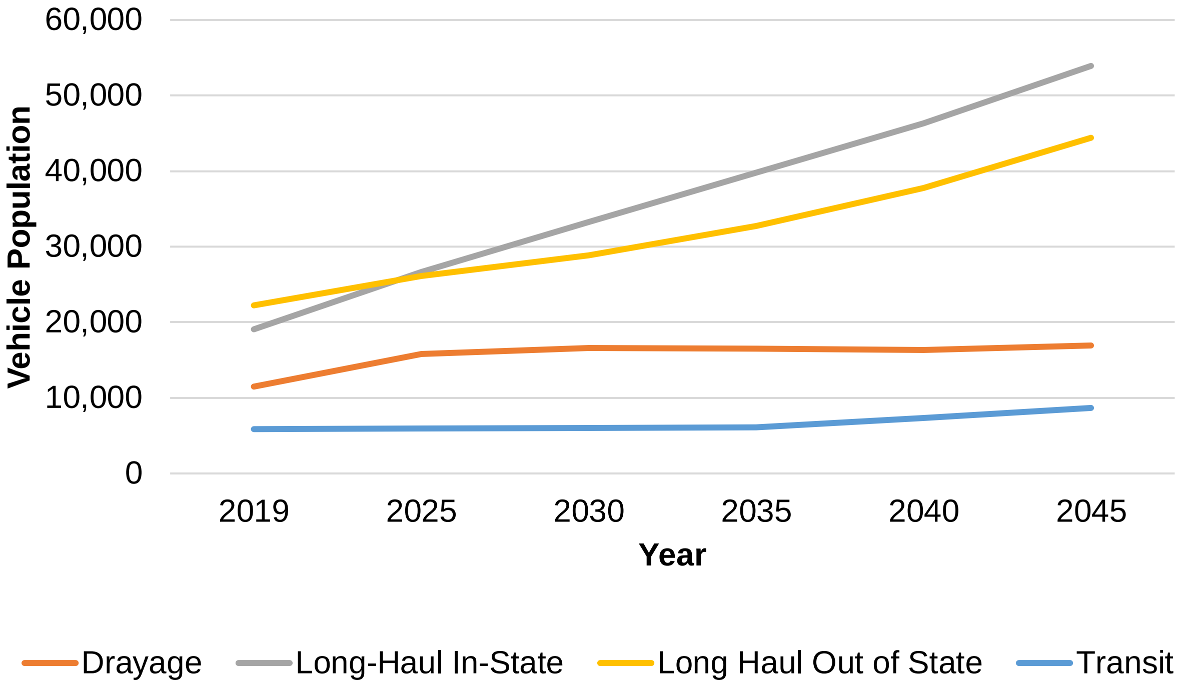
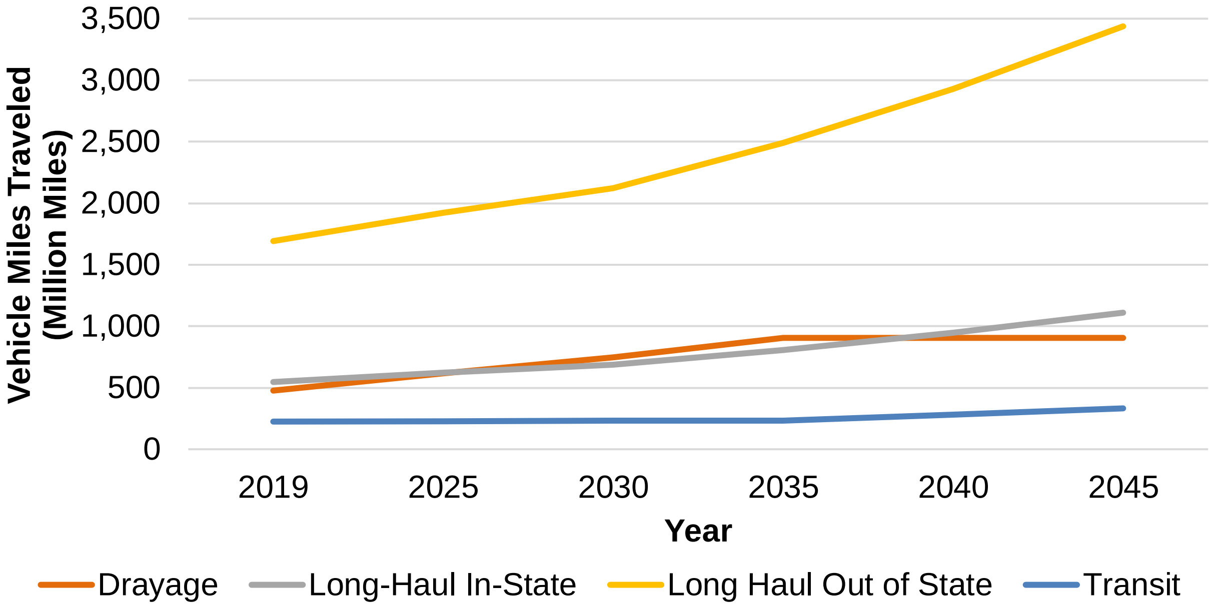


Figure 13. Projected Annual SoCAB Vehicle Miles Traveled of Target Categories, Years 2019-2045



Tackling out-of-state vehicle emissions is critical in reducing overall HDV emissions due to their disproportionate contribution. However, it is unclear to what degree ZEV mandates will apply to out-of-state trucks. Imposing zero-emission mandates on out-of-state trucks will require new enforcement measures. The state can expand the scope of existing programs or establish new programs to implement these new measures. Existing programs include the heavy-duty vehicle inspection program and periodic smoke inspection program [25]. The ZEV scenarios explored in this Blueprint examine the impact that out-of-state ZEV adoption will have on overall GHG and CAP emissions reductions achieved in future years.

Vehicle fuel efficiency is dependent on vehicle weight and drive cycle. Fuel efficiency is critical in determining the electricity and hydrogen consumption of ZEVs. As ZEV technologies mature, their fuel efficiency is anticipated to increase. This analysis uses the ZEV fuel efficiency assumptions in Table 5, from Brown et al. (2021) [26]. This analysis applies the EMFAC emissions factors to estimate the change in GHG and CAP emissions under different ZEV adoption scenarios.

Table 5. Fuel Efficiency Projections

Fuel Type	Vehicle Category	Fuel Efficiency (mi/GGE)		
		2025	2035	2045
BEV	Transit	15.7	16.9	18.2
	Drayage	20.0	21.7	23.4
	Long Haul	16.3	17.2	18.1
FCEV	Transit	10.8	11.7	12.5
	Drayage	8.8	9.9	10.8
	Long Haul	8.8	9.9	10.8

Data Source: Brown et al. 2021 [26]

2.3 Zero-Emission Options for Medium- and Heavy-Duty Vehicles

The two electric vehicle options available today to meet zero-emission mandates are battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV). Both electric vehicle types use an all-electric powertrain. A BEV uses energy stored chemically in its battery to produce electricity and power the vehicle, whereas hydrogen is used as the energy source in an FCEV. Hydrogen is split electrochemically by the on-board fuel cell to produce electricity and power the vehicle. Table 6 presents a selection of ZEVs currently eligible through the HVIP program.

OEMs have announced several BEV and FCEV models for MD/HD vehicle applications. BEV options range from Class 2b to Class 8 trucks and buses, whereas FCEV options are all class 8 trucks and buses. The FCEV options have ranges up to twice those of the BEV options. HVIP has approved over 150 ZEVs to be eligible for its incentive program. Of those, 143 are BEVs and seven are FCEVs. Not all ZEVs are eligible for the program. This list is expected to grow as the California ZEV sales mandates start and demand grows.

Table 6. Example Available Medium- and Heavy-Duty Zero-Emission Vehicles

Make	Model	Class(es)	Type	Range (mi)
Blue Bird	All American Battery Electric Bus	Class 6, 7, 8	BEV	120 mi
BYD Motors	6F Plus Battery Electric Truck	Class 6	BEV	180 mi
BYD Motors	K8M Battery Electric Bus	Class 8	BEV	170 mi
General Motors	BrightDrop ZEVO 600 Battery Electric Vehicle	Class 2b-3	BEV	250 mi
Ford	T350 Van 2WD Battery Electric Vehicle	Class 2b	BEV	230 mi
Freightliner	eCascadia Battery Electric Truck	Class 8	BEV	155, 220, or 230 mi
Hyundai	XCIENT Fuel Cell Electric Truck	Class 8	FCEV	450 mi
Hyzon Motors	FCEV8-200 Fuel Cell Electric Vehicle	Class 8	FCEV	350 mi
New Flyer	Xcelsior CHARGE FC 40’ Fuel cell-electric bus	Class 8	FCEV	370 mi
Nikola	TRE FCEV Fuel Cell Electric Truck	Class 8	FCEV	500 mi

Data from HVIP website: https://californiahvip.org/vehicles/ [27]

2.4 Infrastructure Options for Medium- and Heavy-Duty Zero-Emission Vehicles

ZEVs require access to either charging or hydrogen refueling stations, depending on the vehicle type. Fueling frequency and scale can vary by vehicle class and application. When deciding which technology to deploy, fleets will need to consider vehicle travel patterns, including travel distances, dwell times, and dwell locations. Travel patterns can vary between fleets and vehicle types (see Figure 11).

2.4.1 Charging Infrastructure

2.4.1.1 Charging Infrastructure Technologies

Table 7 provides an overview of the charger types available in the U.S, both AC and DC options. In general, AC "level 2" chargers provide charging rates up to 19.2 kW, although the newer standard J3068 provides higher charging rates. The most common charging rate configurations include 19.2 kW, 30 kW, 150 kW, and 180 kW, with 450 kW being the highest rated power offered. The higher charging rates are achieved by stacking power modules (30-50 kW per module).

Table 7. Charging Standards Applicable to Medium- and Heavy-Duty Vehicle Deployment in California

	Current Standards					**In Development**	
Connector	**SAE J1772**	**CCS1**	**SAE J3105**[3]	**SAE J3068**	**SAE J2954-2**[4]	**NACS (Tesla Proprietary)**	**SAE J3271 (MCS)**
Current Type	AC[5]	AC/DC[6]	DC	AC	Inductive	AC/DC	DC
Power (kW)	AC: Up to 19.2 DC: Lvl 1- 80 Lvl 2 – 400	Up to 350, Planned 450	Level 1: 350 kW Level 2: 1.2 MW	Up to 133-166	20, 50, 75, 150, 250, 500	AC: up to 19.2 DC: 250, 350 Planned	Up to 4.5 MW
Voltage (V)	120/240 1ɸ, 208 3ɸ	920, Planned 1000	Up to 1000	480/600	N/A	AC: 240 DC: 1000	1,500
Current (A)	80	380 (Rated 500)	Up to 1200	160 3ɸ (Rated 300)	N/A	AC: 80A DC: 250, 350 Planned	3,000

Level 2 AC charging may be suitable for a limited number of medium-duty vehicle applications that have low daily miles (less than 200 miles) and dwell for a long time (>8 hours) between shifts. However, most MD/HD BEVs will require DC fast charging. There are two prominent DCFC technologies in the U.S.: CCS1 and Tesla's proprietary charger. Tesla has initiated standardizing its charger under SAE International, with the new label "North American Charging Standard" (NACS). SAE is developing a megawatt

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[3] Recommended Practice

[4] Technical Specification

[5] DC power transfer mode only implemented in Europe at Tesla Supercharger stations.

[6] CCS1 ports accept Type 1 AC chargers, respectively.

charging system (MCS) standard that should be available within the next few years. Proprietary charging systems delivering up to MW charging rates are also being developed in parallel with potentially shorter times to market.

BEV charging rate varies as the battery state-of-charge (SOC) increases. Figure 14 presents a generalized curve of charging power as a function of battery SOC. In general, at low SOC, the charger will supply power near the rated power of the charger. As the battery approaches the 40-60% SOC, the charger will begin to step down the power. At about 80% SOC, power supplied will begin to drop significantly until 100% SOC is achieved. Exact SOC levels when each stage occurs can vary as well as the percentage of rated power at each stage. Fleets may select to operate their vehicles between 0-80% battery SOC in order to minimize charging times.

Figure 14. Battery Charging Curve as a Function of Battery State of Charge

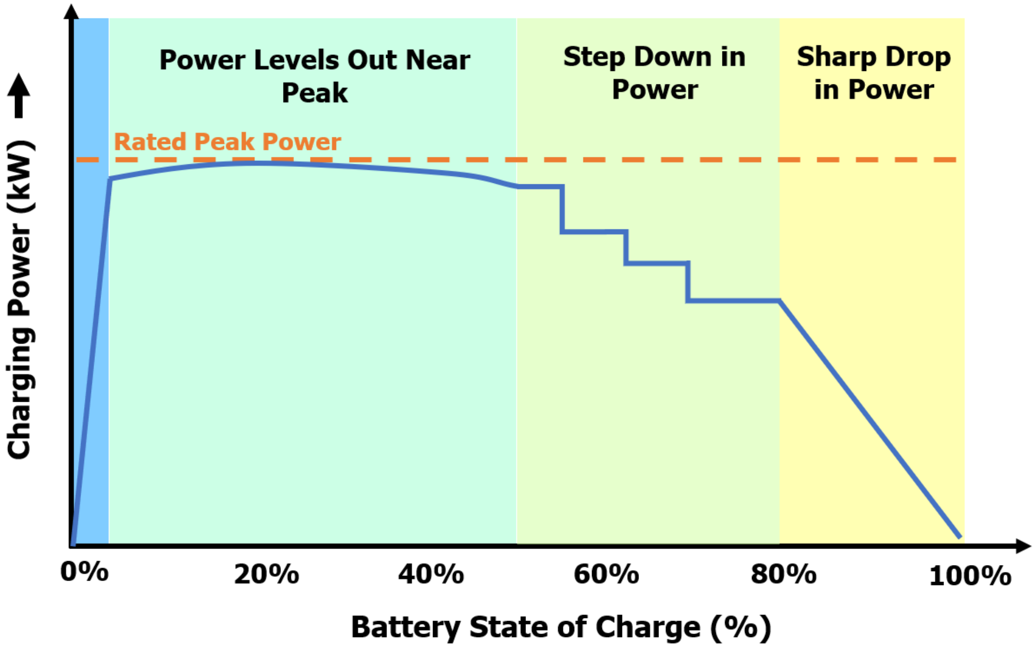


Figure 15 and Figure 16 present sample daily charging times assuming different daily VMT ranges for a 150 kW and 1 MW charger, respectively. Average fuel efficiency of 2 kWh/mi. Average charging power is 90% of rated power capacity. The VMT bins mirror those used in **Figure *11***. For fleets that average over 300 miles, 150 kW chargers may be insufficient for daily charging. Increasing the charging rate to 1 MW greatly reduces the daily amount of charging time needed from hours to minutes, see Figure 16.

Figure 15. Estimated Daily Charging Times for 150 kW Rated Power

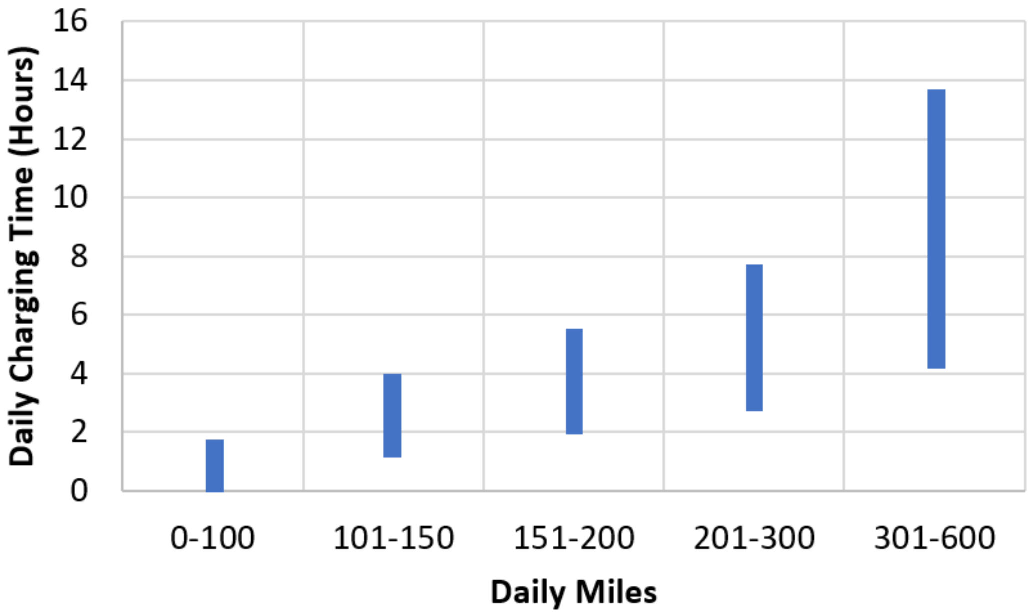
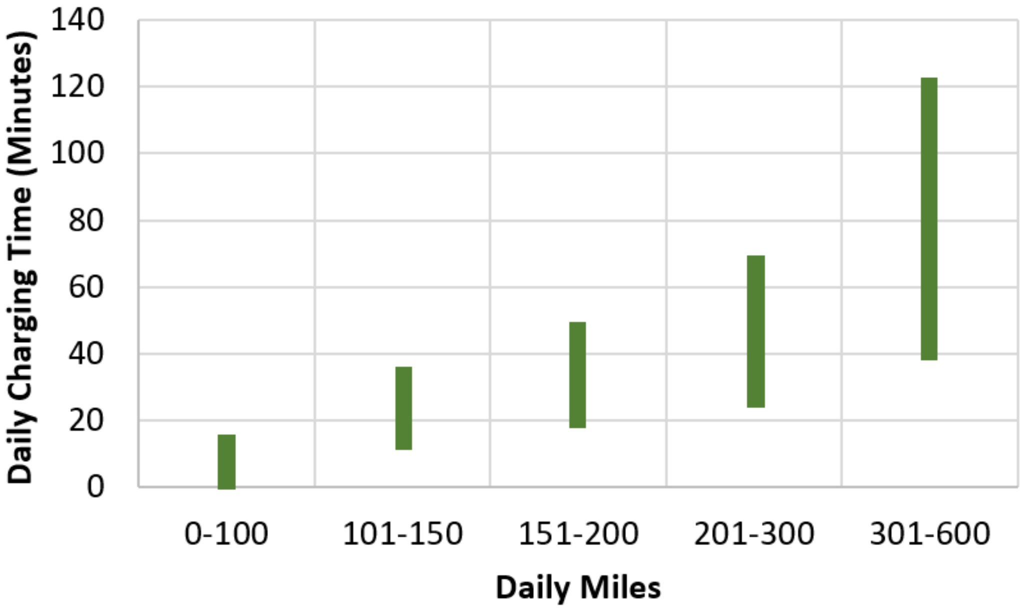


Figure 16. Estimated Daily Charging Times for 1 MW Rated Power

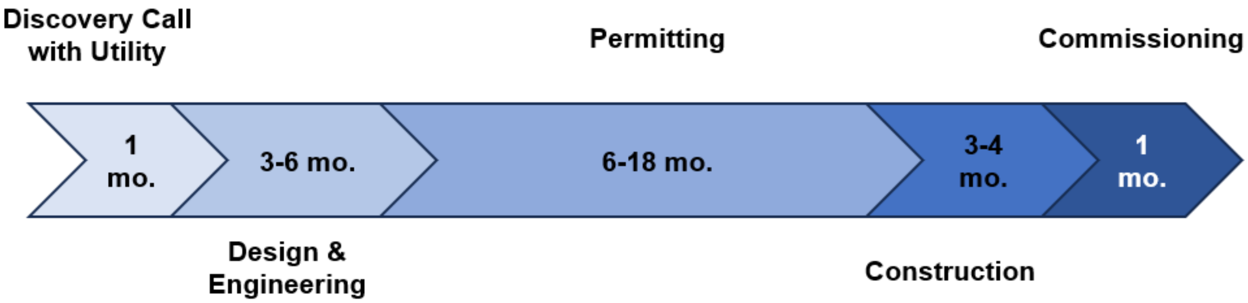


2.4.1.2 Charging Station Deployment Overview

The general steps to commissioning an electric vehicle charging station (EVCS) are: (1) planning (including design review and engineering), (2) permit approval (including local and regional permits as well as any utility required steps), (3) construction, and (4) commissioning. The permitting stage may be integrated into the planning stage. Utilities may request that companies signal their interest in building an EVCS as early in the process as possible so that the utility can determine whether there is adequate local electric grid infrastructure to supply electricity to a charging station.

An average timeline for the deployment of an EVCS is in Figure 17. Times are estimated based on data from San Diego Gas and Electric (SDGE) as well as CALSTART's INSITE tool [28], [29]. The INSITE tool estimates that the total process can take between 3.5 to 29 months [29]. A large challenge in estimating time to completion is the uncertainty in design and construction timelines, as well as the variability in permitting procedures across different regions. A small project may have a shorter completion time for each stage, and any stage can be significantly longer if the project is large, complex, and/or requires additional utility upgrades. If the desired site does not have sufficient capacity to support the peak power of the planned EVCS, a transformer upgrade on the utility side of the meter will be needed. In addition, laying cable may require trenching, which adds time and cost to the design and construction phases.

Figure 17. Average Timeline for Battery Electric Vehicle Charging Station Deployment



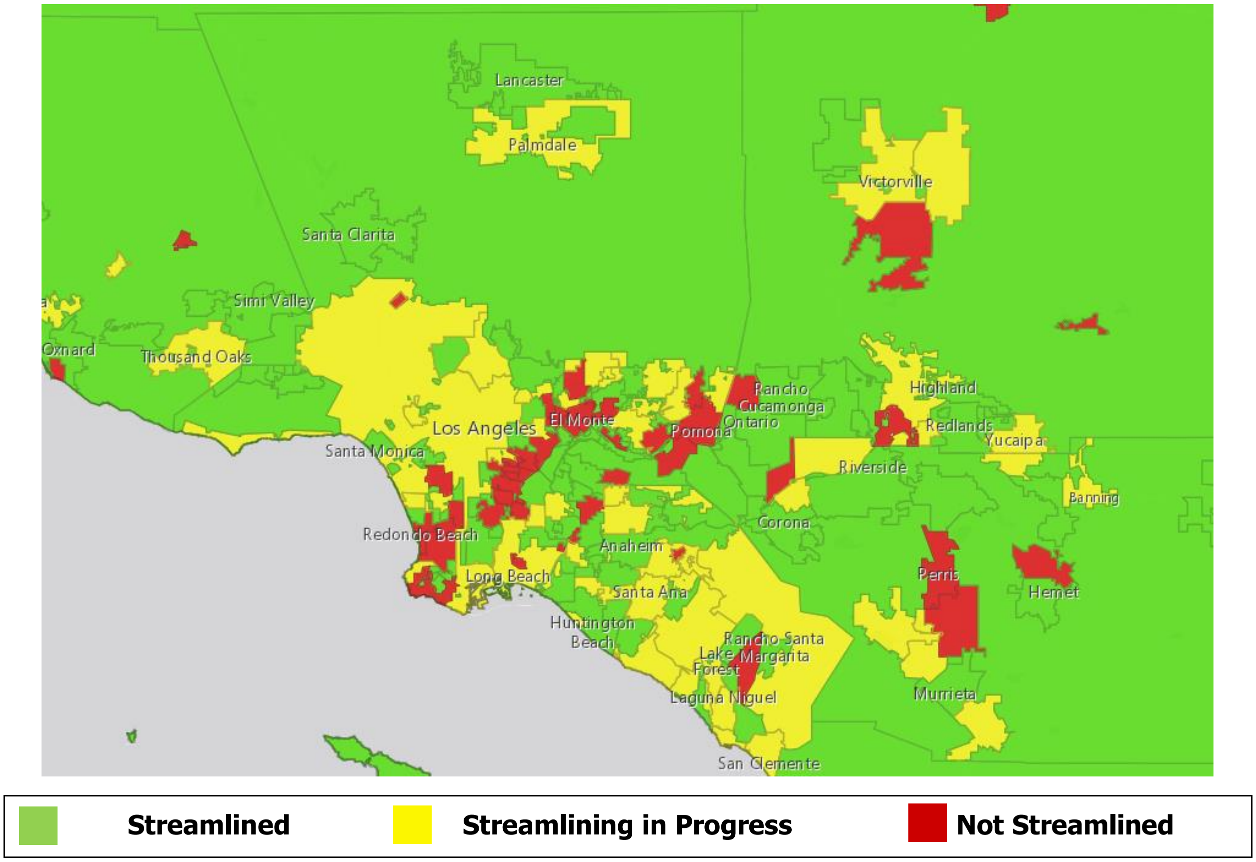
Source: CEC

Permit Streamlining

The state has passed legislation to help streamline permitting. AB 1236 requires city and county general plan for electric vehicle charging station (EVCS) deployment, including an application process to acquire a permit [30]. Standards are required as defined in Article 625 of the National Electrical Code. AB 970 further clarified this process for all cities [31]. California's Governor's Office of Business and Economic Development has released an "EV Charging Station (EVCS) Permit Streamlining Map" that scores cities and counties on their EVCS permitting process and how streamlined it is [32]. Figure 18 presents that scoring results for the SoCAB region.

The streamlining score is based on seven criteria: (1) there is an EVCS-specific ordinance to streamline permitting, (2) a permitting checklist is publicly available, (3) approval is based on a non-discretionary permit (i.e., approval is based solely on compliance with requirements), (4) project review scope is based on health and safety only,(5) electronic signatures are allowed, (6) project does not require approval by an association , and (7) one correction letter can be provided in the case of application errors [32].

Figure 18. CA Electric Vehicle Charging Station Permit Streamlining Map



Source: https://business.ca.gov/industries/zero-emission-vehicles/plug-in-readiness/

Codes and Standards Compliance

In the SoCAB region, EVCS must comply with federal and state codes and regulations, as well as local ordinances. Codes and regulations primarily stipulate requirements with public health and safety in mind. Requirements can span equipment specifications (e.g., technologies, performance metrics, cable sizing), system design (e.g., ventilation), and site spacing. Fleets seeking funding to build a hydrogen refueling station may also be required to develop a hydrogen safety plan. General codes and standards are listed in Table 8.

EVCS must comply with the National Electric Code (NFPA 70) and other national codes that stipulate required safety standards and technical specifications (e.g., cable sizing, ventilation, spacing). In addition, California has its own codes that apply to EVCS installations, including Title 4, Division 9, Article 1 and Title 24 (multiple parts), which both incorporate national codes (e.g., NIST HB 44 and NFPA 70, respectively) with amendments and additional, California-specific requirements [20]. The U.S. and California also have accessibility requirements that need to be met.

Table 8. General Codes and Standards Required for Battery Electric Vehicle Charging Stations

Code or Standard	**Description**
NFPA 70	National Electric Code
CCR, Title 4	Tolerances and Specifications for Commercial Weighing and Measuring Devices
Title 24, Part 2	California Building Code
Title 24, Part 3	California Electrical Code
Title 24, Part 6	California Energy Code
Title 24, Part 9	California Fire Code
Title 24, Part 11	EV Capable Infrastructure
California Public Utilities Code (PUC) section 740.20	Regulation of Public Utilities, Rates, EVSE

Furthermore, California agencies set codes relevant to the scope of their jurisdiction. For example, the California Department of Food and Agriculture, Division of Measurement and Standards oversees accurate accounting of electricity dispensed by EVSE. The California Public Utilities Code section 740.20 stipulates requirements for installation of EVSE and associated infrastructure, including that at least one electrician on-site has completed the Electric Vehicle Infrastructure Training Program certification [33]. Lastly local jurisdictions may have additional ordinances that need to be followed before a station can be commissioned.

Codes for EVSE and EVCS are continuing to evolve, with changes to HB 44 regarding EVSE testing tolerances for electricity delivered already scheduled [34]. With the introduction of megawatt charging systems, it is anticipated that these new systems will need to adhere to existing codes and additional tests may be required. For that reason, MCS standardization efforts already are incorporating testing data and test procedures.

EVCS that receive public funding are also required to follow requirements set by the funding program(s). For example, the federal government, California agencies, regional agencies, and utilities commonly offer incentives or rebates. Relevant current infrastructure funding programs include the National Electric Vehicle Infrastructure (NEVI) formula program, Energy Infrastructure Incentives for Zero- Emission Commercial Vehicles (EnergIIZE Commercial Vehicles), and Volkswagen Diesel Emissions Environmental Mitigation Trust [35]–[37]. In general, programs will list required codes, standards, and other specifications as a condition of eligibility. To assist potential applicants, funding programs may provide a list of eligible or approved vendors.

All equipment installed needs to be certified compliant with required codes and standards. Of particular focus are verification of equipment performance and safety. The main testing standards for EVSE are listed in Table 9.

Table 9. Equipment Testing Standards

Code or Standard	Scope
UL 1741	Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
UL 2231-1, -2	Standard for Safety Personnel Protection Systems for Electric Vehicle Supply Circuits
UL 2251	Standard Testing for Charging Inlets and Plugs
UL 2594	Standard for Electric Vehicle Supply Equipment
UL 9741	Bidirectional EV Charging System Equipment

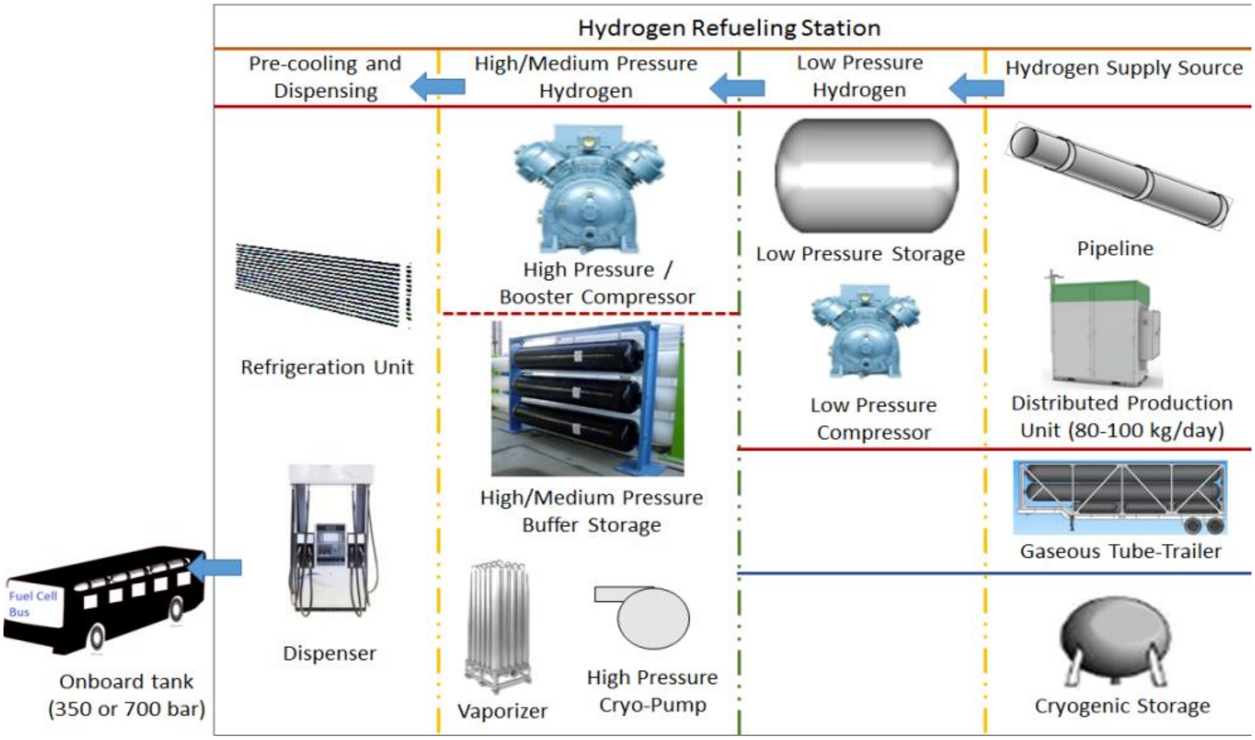
There are several testing programs administered at the national and state level that provide testing and certification. Most relevant to this study are the Occupational Safety & Health Administration (OSHA)'s Nationally Recognized Testing Laboratory (NRTL) program, which certifies product compliance with OSHA safety standards [38]; the National Conference on Weights and Measures' National Type Evaluation Program (NTEP), which certifies weighing devices [39]; and the California Type Evaluation Program (CTEP), which participates in the larger NTEP program and certifies weighing and measuring devices corresponding to California laws [40]. For relevant products, companies are required to complete the certification process(es) before making the products commercially available. There are also additional, optional certification programs, such as Energy Star [41].

2.4.2 Hydrogen Refueling

2.4.2.1 Hydrogen Infrastructure Technologies

In the U.S., gaseous hydrogen is delivered at two pressures: 350 bar and 700 bar. An overview of common station configurations is presented in Figure 19. In general, for the same tank size, 700 bar will provide twice as much hydrogen as the 350 bar. Transit agencies that have already adopted fuel cell buses are generally using the 350 bar fueling, as it is cheaper and the lower state-of-charge (SOC) compared to the 700 bar is sufficient for their operational needs. Class 8 truck stations are expected to prioritize 700 bar fueling.

Figure 19. Overview of Heavy-Duty Hydrogen Refueling Station Configurations

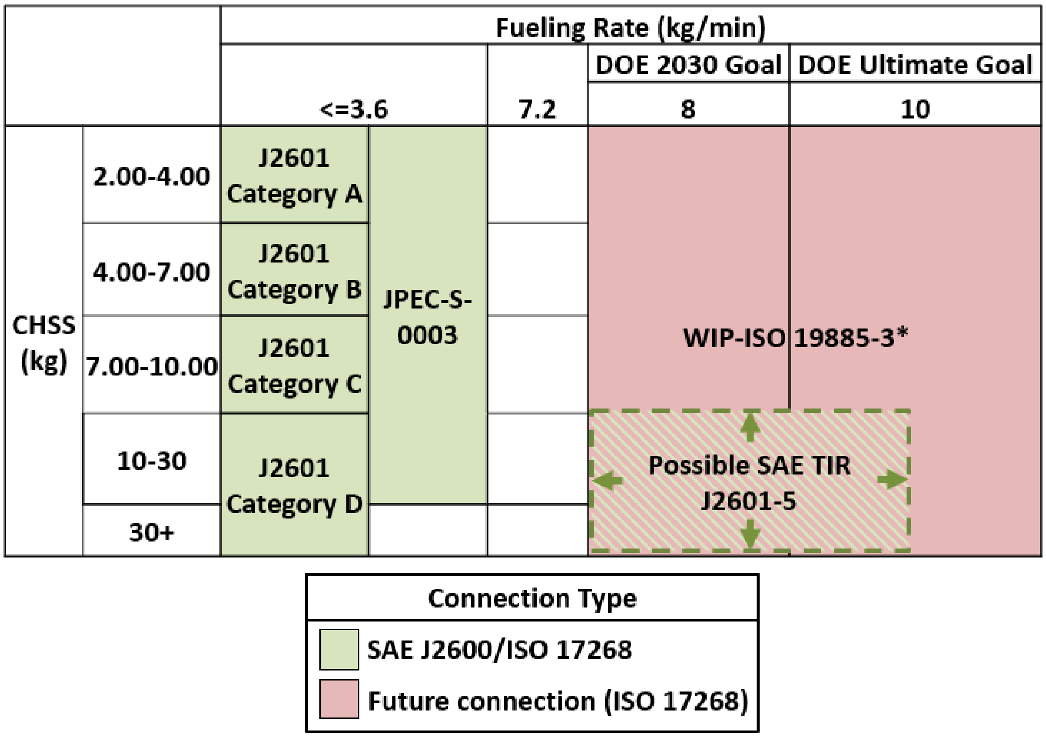


Reproduced from Argonne National Laboratory. website: https://hdsam.es.anl.gov/index.php?content=hdrsam

Fueling methods are dictated by hydrogen fueling standards, primarily J2601, as well as custom fueling protocols extrapolated from guidance documents, such as J2601-2 (see Figure 20). The goal of hydrogen fueling protocols is to achieve a fast fill with a high end SOC within safety limits. In general, fueling rate is dependent on several factors including the rated pressure and size of the on-board hydrogen storage tank, hydrogen delivery temperature, ambient temperature, current tank pressure, and whether there is communication between the vehicle and dispenser.

There are several heavy-duty specific fueling protocols in development that are being standardized within SAE (J2601-5) and ISO (ISO 19885-3). The target fueling rate of these new standards is almost three times greater than the existing 700 bar fueling protocol. It is expected that recently funded heavy-duty hydrogen refueling stations will utilize these developments to provide faster refueling for the next generation of MD/HD FCEVs.

Figure 20. Fueling Rates of Current and Proposed 700 bar Hydrogen Fueling Protocols



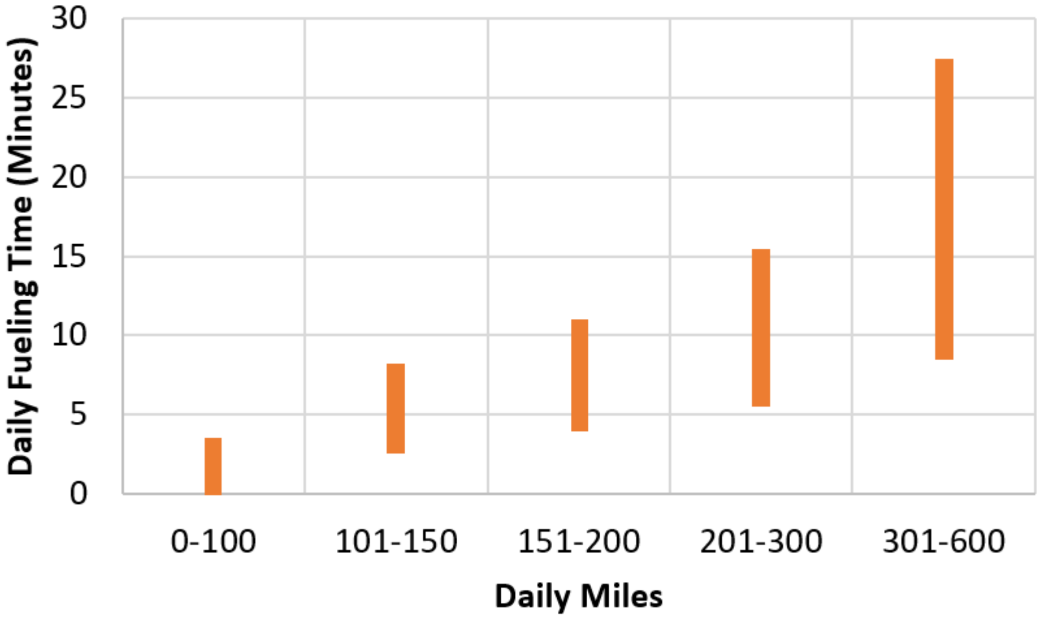
		Fueling Rate (kg/min)				
					DOE 2030 Goal	DOE Ultimate Goal
		<=3.6		7.2	8	10
CHSS (kg)	2.00-4.00	J2601 Category A	JPEC-S-0003		WIP-ISO 19885-3*	
	4.00-7.00	J2601 Category B				
	7.00-10.00	J2601 Category C				
	10-30	J2601 Category D			Possible SAE TIR J2601-5	
	30+					

Connection Type
🟩 SAE J2600/ISO 17268
🟥 Future connection (ISO 17268)

Credit: UCI APEP

*CHSS: Compressed Hydrogen Storage System

Figure 21. Estimated Daily Hydrogen Fueling Based on Current Average Fast Fueling Rates



Assumptions: Average fuel efficiency of 10.8 mi/kg H_2. Average fueling rate of 3.1 kg/min is based on reported Transit station performance.[7]

Permitting Overview

Hydrogen refueling stations have the same general stages as EVCS: (1) planning (including design review and engineering), (2) permitting (including local and regional permits as well as any utility required steps), (3) construction, and (4) commissioning (see Figure 22). Again, permitting can be integrated into the planning stage. The permits required for a hydrogen refueling station are listed in Table 10. Permitting spans building and electrical requirements, fire safety, and environmental impacts (water and air). The permit streamlining initiative by AB 1236 did not apply to hydrogen refueling stations.

The final commissioning stage consists of multiple steps to verify station compliance with all legal requirements. Verification is conducted by the California Air Resources Board as well as automakers. In general, testing may require multiple rounds to address identified issues. The general commissioning process for stations is outlined in

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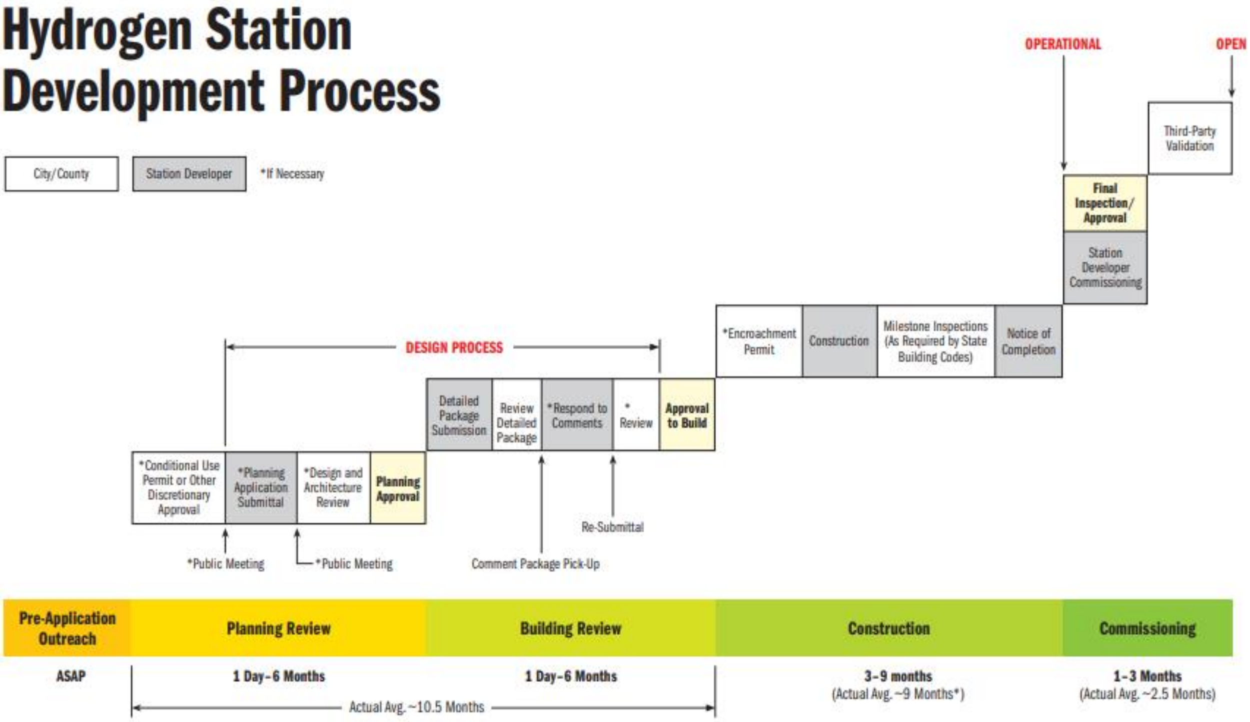
[7] https://cte.tv/game-changers-in-hydrogen-fueling/

Figure 23. In the future, it is possible that new testing methods will be applied to HDV stations in line with new high flow fueling equipment and protocols.

Figure 22. Overview of Hydrogen Refueling Station Development Process



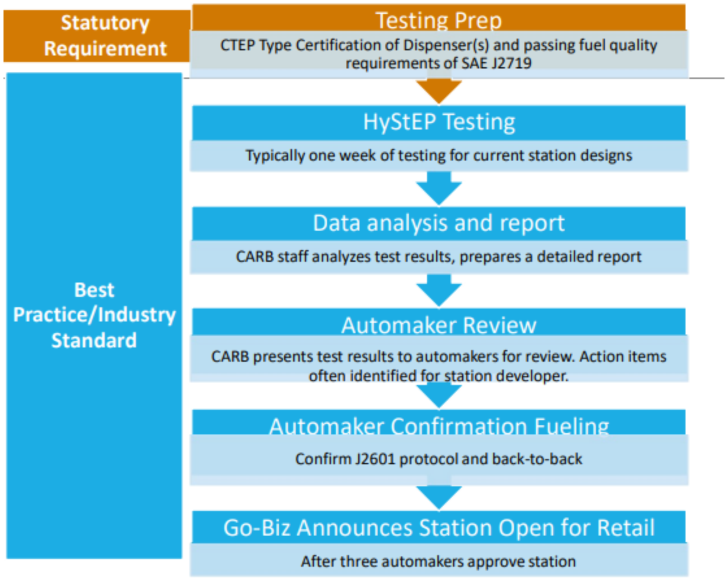
Source: https://static.business.ca.gov/wp-content/uploads/2019/12/GO-Biz_Hydrogen-Station-Permitting-Guidebook_Sept-2020.pdf

Table 10. Permit Requirements for Hydrogen Refueling Stations in SoCAB Region

Permit	Agency	Permit/Permit Scope
Construction	Building Department	Permit to Construct General/Address safety construction issues
Drainage	Engineering Department	Permit to Construct Drainage/Modification to sewer drainage
Site grading	Engineering Department	Permit to Construct Grading/Modification to site elevation
Electrical	Building/Electrical Department	Electrical Permit/Modification to electrical service
Demolition	Building Department	Construction permit/Demolish structures required for dispenser construction
Air emission impacts	South Coast Air Quality Management District	Air Quality permit or no impact declaration
Fire safety	Fire Department Plans Review Office	Fire safety permit/general fire code compliance
Water Quality	Water Quality Management Agency	Liquid discharges to the environment

Source: National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy13osti/56223.pdf

Figure 23. Steps for Station Commissioning



Source: California Air Resources Board, Assessment of a Hydrogen Station Verification Requirement for Public Hydrogen Stations (2018) https://ww2.arb.ca.gov/sites/default/files/2020-05/carb_presentation_0_ac.pdf

To expedite the certification process, the Department of Energy commissioned the development of a Hydrogen Station Equipment Performance (HyStEP) device that can be used at a hydrogen refueling station to validate that the hydrogen dispensers operate within the tolerance limits defined within the relevant codes and standards [42]. HyStEP was designed for and is currently being used at light-duty hydrogen refueling stations. New methods for testing HDV high flow fueling protocols are under development. CARB, in consultation with the CEC and NREL, is preparing a request for proposal (RFP) to design, engineer, build, test, and validate the next generation of the device, HyStEP 2.0, which will have a larger tank capacity with the ability to test MD/HD hydrogen refueling stations.

The timeline for station development is dependent on the station location, size, and type. The average time from planning to commissioning completion is currently one year. The estimated timeline range for hydrogen refueling stations is listed in Table 11 for different station hydrogen delivery assumptions. The timeline can vary depending on the proposed location of the station, with permitting taking longer in places that do not have previous experience with hydrogen.

Table 11. Estimated Timeline for Hydrogen Refueling Station Commissioning

Station Type	Estimated Timeline
Gaseous or Liquid Delivery	9.5 – 22 months
On-site Electrolysis	3.5 – 11 months
On-site Steam Methane Reformation	7 – 13 months

Source: INSITE Tool, https://insitetool.org/design_hydrogen

Codes and Standards Compliance

Several federal and state codes and regulations, as well as local ordinances are used in concert to define specific requirements of a given hydrogen refueling station, see Table 12. The key focus is on public health and safety. Safety codes and standards include general building considerations, electrical systems, energy systems, fire safety, hazardous materials, and accurate accounting of hydrogen dispensed. All equipment and stations require testing and certification. Testing can include interoperability testing across multiple and comparable standards. Proof of compliance generally occurs right after construction during the station commissioning stage [43].

A key safety standard referenced is NFPA 2, which defines primary safeguards needed across the hydrogen supply chain, spanning storage and handling, generation, delivery, use [44]. NFPA 2 covers gaseous and liquid hydrogen systems, describing safety considerations when planning the design of a station (e.g., ventilation, spacing) to address health and safety risks of hydrogen. Compliance with NFPA 2 is required for all hydrogen refueling stations within California [43].

Additional standards and codes required that address safety include OSHA's Reg. 29 CFR 1910 Subpart H (1910.103), which covers safety requirements during hydrogen delivery, storage, and use with a focus on worker safety [45]; California's Health and Safety Code Section 25510(a), which covers hazardous materials release ; and CCR Title 24. NFPA safety documents that are relevant to FCEVs but are outside the scope of the current project are NFPA 70, which describes electrical safety requirements for the powertrain and NFPA 55, which provides safety requirements for handling, storage, and use of hydrogen.

Table 12. Codes and Standards for Hydrogen Refueling Station Testing and Certification

Code or Standard	Scope
NFPA 2	Hydrogen Technologies Code
NFPA 55	Compressed Gases and Cryogenic Fluids Code
NFPA 70	National Electrical Code
California Health and Safety Code Section 25510(a)	Hazardous Materials Release Response Plans and Inventory: Business and Area Plans
California Code of Regulations (CCR) Title 4, Division 9, Chapter 1	Tolerances and Specifications for Commercial Weighing and Measuring Devices
CSA/ANSI HGV 4.3	Test Methods for Hydrogen Fueling
CSA/ANSI HGV 4.9	Hydrogen Fueling Stations
CGA G-5.3	Commodity Specification for Hydrogen
ISO/IEC 18000-3	Conformance tests for Air interface communications
ISO/IEC 18046	Test methods for RFID tag performance
NIST Handbook 44	Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices
NIST Handbook 130	Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality
OSHA’s Reg. 29 CFR 1910 Subpart H (1910.103)	Worker safety requirements for hydrogen supply chain
California Code of Regulations (CCR), Title 4, Division 9	Weights And Measures Field Reference Manual
CCR, Title 24, Part 2	California Building Code
CCR, Title 24, Part 3	California Electrical Code
CCR, Title 24, Part 6	California Energy Code
CCR, Title 24, Part 9	California Fire Code
UL 2075	Standard for Safety Gas and Vapor Detectors and Sensors

Other standards include CSA/ANSI HGV 4.9, which provides an overarching specification that encompasses requirements for the design, construction, operation, and maintenance of hydrogen refueling stations (gaseous) [46]. Elements of a station that require testing include hydrogen fuel quality, communications, fault detection, and fueling accuracy. CGA G-5.3 serves as a specification for hydrogen quality verification at a hydrogen refueling station [47]. Hydrogen fuel quality requirements, as defined in SAE J2719, include the minimum molar hydrogen content required (≥ 99.97%), as well as the maximum concentrations of contaminants of concern [48]. ANSI/CSA HGV 4.3 defines testing for evaluating hydrogen fueling dispenser compliance against J2601 (fueling) and J2799 (communications) [49]. CCR Title 4, Division 9, Chapter 1 includes national definitions (NIST Handbook 44), exceptions, and additional technical requirements and measuring devices [50].

In addition to codes, standards, and regulations, there are government-developed tools available to support the safe and secure deployment of hydrogen as a transportation fuel. Some examples include H2Tools, a suite of tools to promote hydrogen best practices [51], HyRAM, a toolkit for quantitative risk assessment and consequence analysis for hydrogen infrastructure [52], and H2FillS, a simulation tool for modeling hydrogen flow behavior during refueling to support safety and compliance with codes and standards [53].

2.5 Distributed Energy Resources and Microgrids to Support Station Resiliency

The increased frequency of extreme weather events under climate change has resulted in the reduced reliability of the electric grid. This has led to the increased deployment of distributed energy resources (DER) and microgrids. Common DERs deployed within microgrids included solar PV, wind turbines, battery energy storage systems, fuel cells, and thermal systems. DER can provide back-up power, increasing the reliability and resiliency of charging and hydrogen refueling stations, while providing additional benefits such as cost reduction and increased renewable utilization.

2.5.1.1 Microgrids

A microgrid, a local network of loads and DER that can operate independently from the larger electric grid, can increase local electric reliability and resiliency. Figure 24 provides an overview of an example microgrid. "Islanding" the microgrid—i.e., disconnecting it from the electric grid—means that the local network can maintain operations during an electric grid outage. Microgrids also have the potential to provide support to the wider community during an emergency by exporting power. Microgrid benefits include:

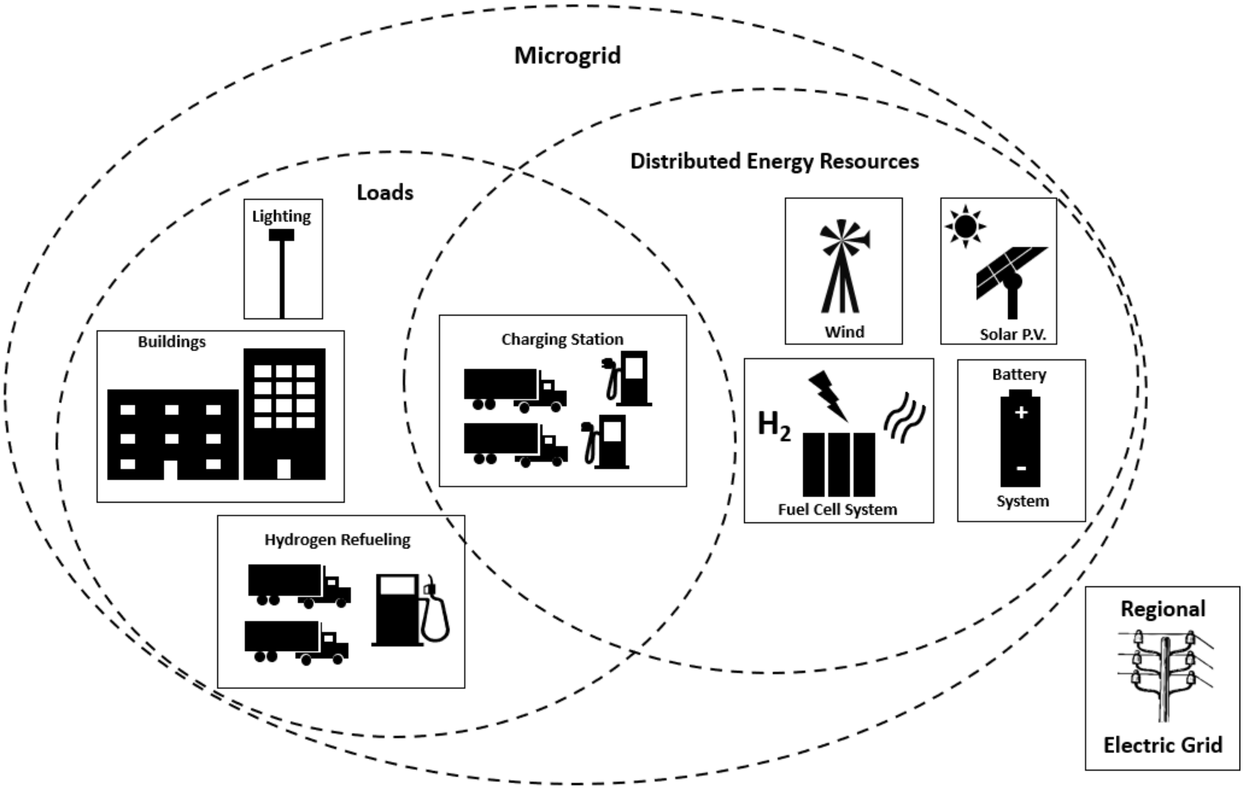
- Localized control of load and generation,
- Critical load support during emergencies,

- Reduced electric utility costs (e.g., demand charges),
- Increased renewable utilization,
- Improved system efficiency, and
- Increased revenue through grid services.

Developing and implementing a microgrid in coordination with electric vehicle supply equipment and/or hydrogen fueling deployment can establish the ability to sustain operational continuity in the face of unplanned outages and other emergency conditions. Charging stations that have bi-directional charging enabled, also can allow vehicles to discharge back to the microgrid or regional grid, serving as a DER. In addition to protecting operations during an outage, microgrid controls during grid-connected operations can help integrate renewable generation, improve DER efficiency, and minimize generation costs.

DER selection and sizing will depend on a site's energy management goals, including the classification of critical loads during an emergency, the duration of outage support, and the emissions associated with DER operation. In designing the microgrid, it is also important to balance load support versus cost as well as the footprint of the microgrid equipment.

Figure 24. Example Microgrid with Zero-Emission Fueling Stations



Source: UCI APEP

The fleet mix of ZEVs affects the design of the microgrid and resiliency planning. For example, chargers constitute a large load that will require significant DER capacities to support. AC level 2 chargers draw up to 19.2 kW and DC fast charging can require up to 350 kW per charger. In comparison, a 700-bar fill has a peak demand of 30-35 kW, and a 350-bar fill has a peak demand of around 12 kW [54]. Adopting a combination of BEVs and FCEVs can reduce reliance on the electric grid and DER support. Additionally, lowering the allowable charging rate or limiting the number of chargers online during an outage can reduce the burden on the microgrid, but it may affect operational capabilities during islanding.

2.5.1.2 Charging Management Strategies and Back-Up Options

Many BEV models have software to enable managed charging strategies. In general, these strategies are deployed to reduce operating costs and/or better manage fleet logistics. These strategies include:

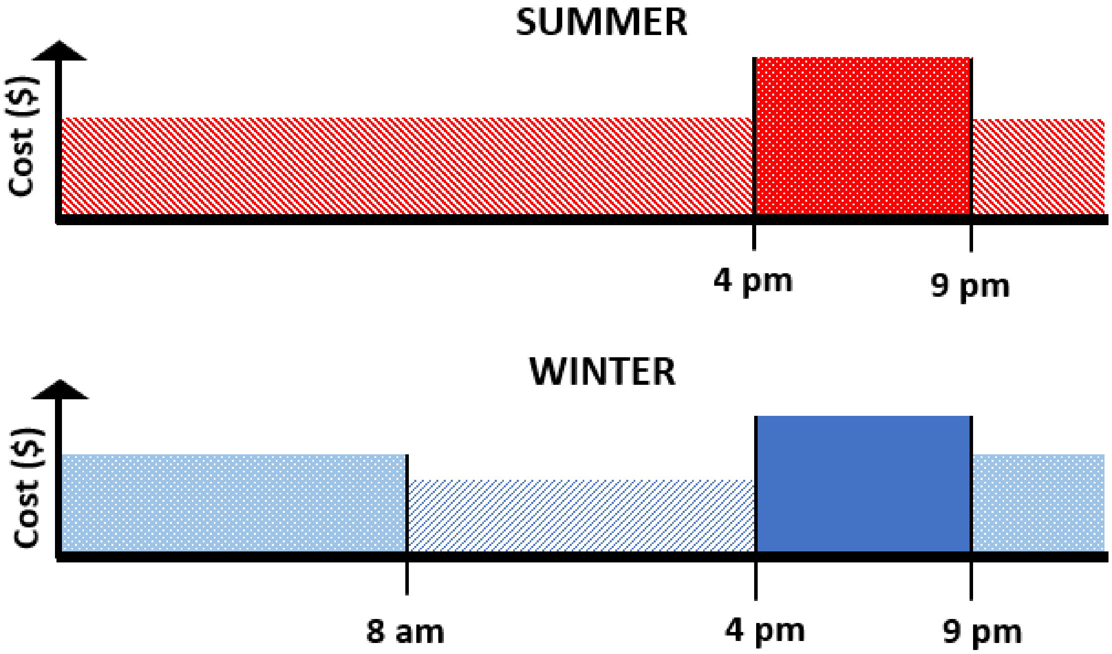
- **Delayed/scheduled charging:** Vehicle can be plugged-in at the end of shift but will wait to charge until the set start time. The start time can be based on time-of-use (TOU) rates or other operational objectives.

- **TOU-based charging:** Charging is timed to minimize cost. This strategy assumes that the electricity cost is based on a utility TOU rate, see Figure 25 for an example. Similar to scheduled charging, the TOU-based charging can delay charging until the cost to charge decreases to a set point. It also can stop charging if the charging cost increases. Operators may be able to set a minimum vehicle SOC that must be achieved by a scheduled time.

- **Smart charging:** Charging is started and stopped based on more complex communication signals. These signals can be from the electric utility or based on fleet management objectives such as minimizing demand charges, prioritizing which vehicles are charged first, and/or allocating charging power across multiple plugged-in vehicles.

In general, managed charging results in slower charging due to start/stop signals during the charging session. However, the added time to charge may be outweighed by electricity cost savings. It is important for a fleet to understand their operational constraints when using ZEVs as well as any utility rate structures that can affect charging costs.

Figure 25. Example EV Time-of-Use Rate



Data from Southern California Edison

Credit: UCI APEP

MD/HD ZEVs have significant on-board energy storage capacity. For BEVs, this energy is stored in the battery and for FCEVs, energy is stored as hydrogen. Bi-directional power transfer has been demonstrated for both BEVs and FCEVs [55], [56]. There are limited vehicle models with this capability, including select light-duty vehicles and school buses. It is anticipated that this capability will expand in future vehicle models. Bi-directional power transfer can be categorized as follows:

Vehicle-to-Load (V2L): Devices can be connected to the vehicle, using a USB, NEMA, or similar plug. Output power can be accessed using available, dedicated ports within the vehicle or using an adapter at the external vehicle charging port. Discharging is controlled by the vehicle. Maximum power output per port is limited to "level 1" charging rates (up to 1.44-1.7 kW). Multiple appliances can be charged simultaneously, limited by the rated power of the ports and the inrush current of the appliances.

Vehicle-to-Building (V2B): Vehicle discharges to supply power to a building. Power transfer is controlled through the electric vehicle supply equipment (versus the vehicle). V2B can provide different services, including increased renewable utilization, peak shaving, cost reduction, and back-up support during an outage [57]. Vehicles can be dispatched to charge when the building PV is producing excess electricity and discharge when PV is unavailable, increasing local utilization of renewable electricity and avoid use of non-renewable grid resources. Peak shaving refers to reducing peak electricity demand of the building, which can reduce utility costs (e.g., through lower demand charges and electricity consumption) and increase the lifetime of the local distribution network. Cost reduction is also possible by taking advantage of time-of-use electricity pricing—the vehicle can charge during low cost times and discharge during peak pricing. Lastly, a vehicle or set of vehicles can be islanded with a building to form a "nanogrid" during an outage. In this case, it is important to identify critical loads that will be supported during the outage.

Vehicle-to-Grid (V2G): Vehicle discharges in response to grid dynamics to provide grid services. Potential grid services include frequency regulation (up/down), peak shaving, spinning reserves, and congestion mitigation [58], [59]. V2G can provide a revenue source for vehicle owners and improve the performance of the electric grid as well as increase renewable integration. V2G requires an agreement with the local utility in order to provide power back to the grid.

There have been several on-going activities related to advancing bi-directional charging in electric vehicles. The California Public Utilities Commission (CPUC) In addition, the CPUC has approved the PEV Submetering Protocol and Electric Vehicle Supply Equipment Communication Protocols under Rulemaking 18-12-006 [60]. Under the Rulemaking, it requires all chargers to ISO 15118 ready, a key communication standard that can enable bi-directional charging.

2.5.1.3 Other Resiliency Considerations

Station resiliency can refer to an individual station's ability to recover from an outage, but it can also refer to the resiliency of the station network to continue to support the MD/HD ZEV fueling demand in the case that one or more stations are offline. Network resiliency is directly related to the placement and scale of excess fueling capacity available at any given time to support MD/HD ZEV fueling. In practice, this could include public stations that are placed along major truck corridors or high-density depot locations that can provide power or hydrogen to vehicles if a fleet's station goes down. Alternatively, it can include extra capacity (additional chargers or hydrogen stored) at a station in the case that a neighboring station goes offline.

3 Station Count and Siting Methodology

This analysis focuses on two station types: fleet-based (private) stations and public stations. More specifically, it is assumed that BEVs charge at fleet facilities (depot-based), fuel cell electric buses fuel at fleet facilities, and fuel cell electric trucks (drayage, long haul) fuel at public stations along routes. It is possible that while BEVs primarily rely on fleet-based charging, they may take advantage of public charging stations. Locating such public stations can follow the same methodology presented here for hydrogen fueling. For this analysis, co-locating en route public charging and hydrogen fueling is explored such that public stations can serve as a back-up network to fleet-based charging.

For the depot-based charging and fueling of transit buses, reported current and planned locations are mapped. For drayage and long haul BEVs, the number and capacity of battery electric EVCS and hydrogen refueling stations within the SoCAB region for the target vocations will be spanned based on a range of possible configurations.

For charging, two scenarios will be investigated: that chargers are deployed at a 1:1 ratio (one charger per one vehicle) and that they are deployed at a 1:2 ratio (one charger per two vehicles). Charger power ratings are anticipated to be 150-350 kW per charger. The ratio of chargers to vehicles has been examined in previous research, with results showing somewhere between 1:1 and 1:2 charger to vehicle ratios [26], [61]. For hydrogen refueling stations, station capacities between 4,000 and 10,000 kg hydrogen will be explored. There will also be a sensitivity conducted on daily utilization of the stations, i.e., the percentage of capacity that is dispensed in a given day. A station that has a 100% daily utilization rate implies that the station has to be resupplied with hydrogen daily and may have a poor user experience due to the risk of running out of fuel as well as lines to refuel. Lower station utilization may provide a more reliable, user-friendly experience to users.

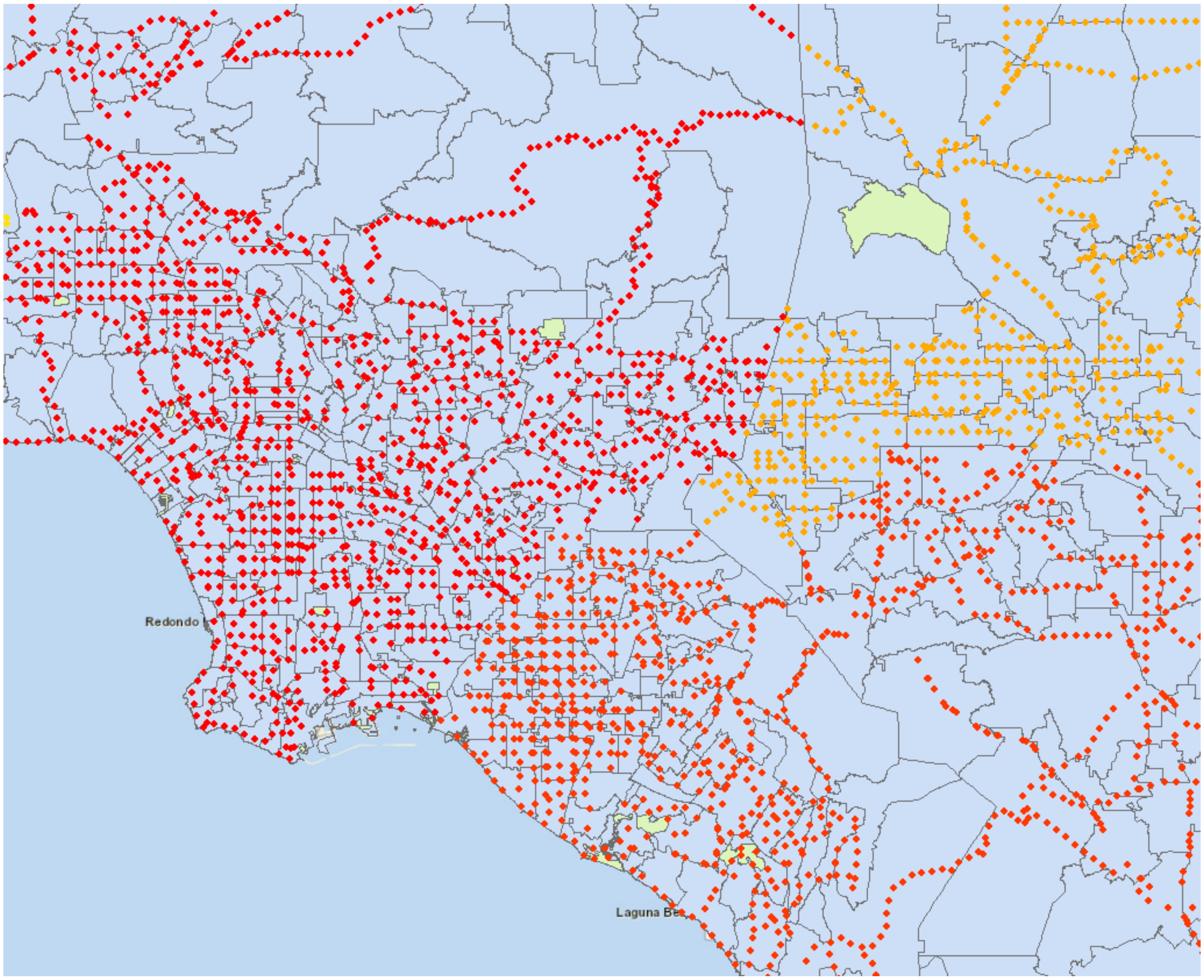
3.1 Driving Network and Demand Allocation

Candidate public MD/HD hydrogen station locations need to meet two key requirements. Firstly, the station location must be accessible by MD/HD vehicles. In California, not all roads are accessible by large vehicles. If the site has no truck accessible routes to it or any viable connection to highways, then it will not function as a refueling station for MD/HDVs. Second, the station must be in a location that is currently zoned for commercial applications.

The drayage and long haul analyses utilize the Freight Analysis Framework 5 (FAF5), which was produced through a partnership between the Bureau of Transportation Statistics and the Federal Highway Administration. Utilizing the FAF5 network of roadways establishes routes, travel distances, travel times, and station accessibility. The distance trucks are willing to travel to refuel can affect where refueling demand occurs across the region. For this analysis, a demand radius of 50 miles is used. For the full Blueprint, a sensitivity analysis of demand radius will be conducted.

To develop a spatial fuel demand weighting, county vehicle miles travelled from EMFAC are mapped to the FAF5 network. The resulting map is presented in Figure 26, and a zoom out of the state is shown in Figure 27.

Figure 26. Distribution of Vehicle Miles Traveled on FAF5 Network in SoCAB



Candidate hydrogen refueling stations are assumed to be existing diesel truck stops, see Figure 28. These locations are primarily located off highways, conveniently located along truck routes, and have good overall coverage of the MD/HD travel network. Furthermore, as ZEVs start to replace diesel trucks, it may be optimal to replace or augment existing stations. Siting ZEV stations on greenfield sites is a topic for future work.

Figure 27. Vehicle Miles Traveled on FAF5 Network Weighting

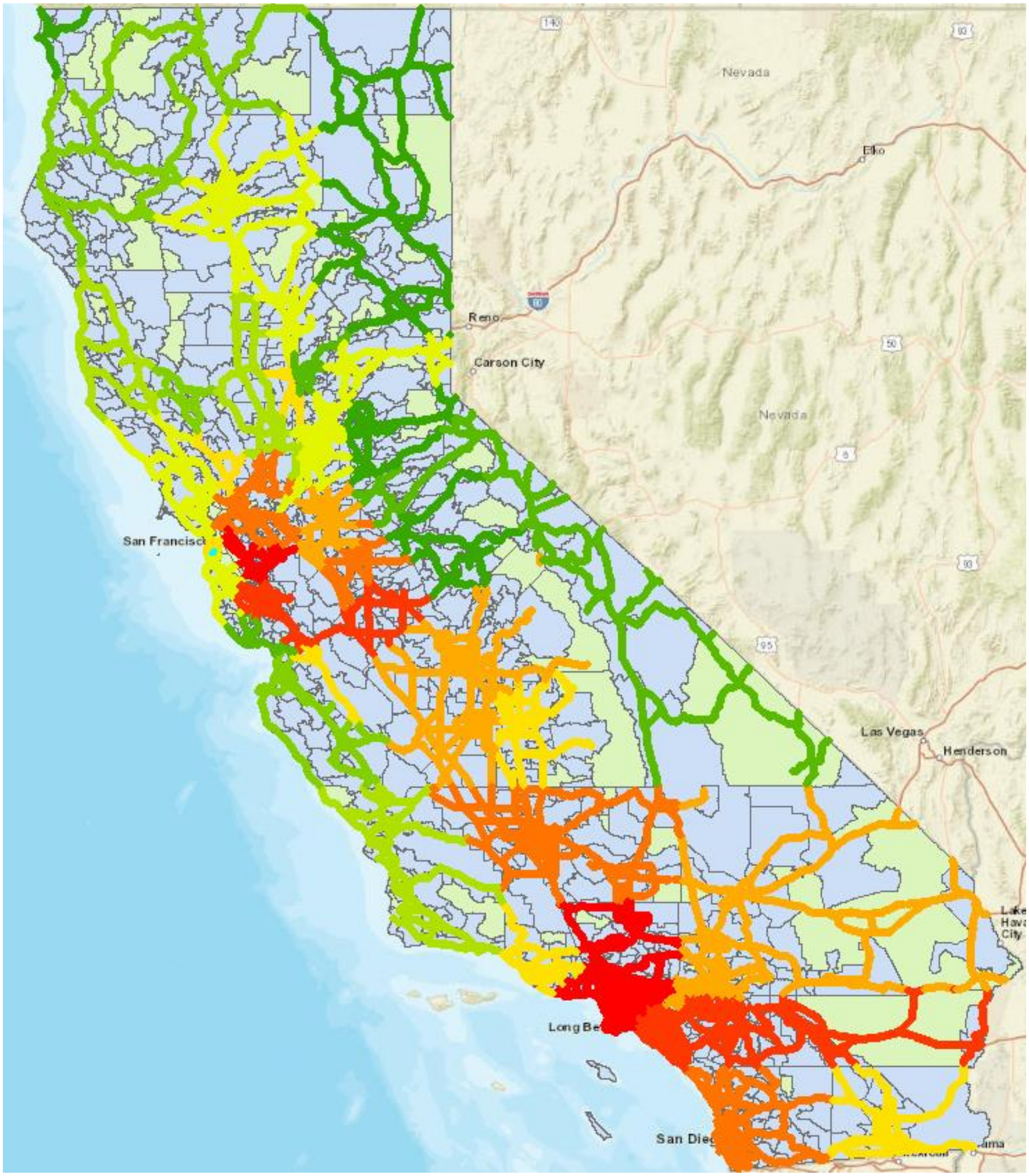
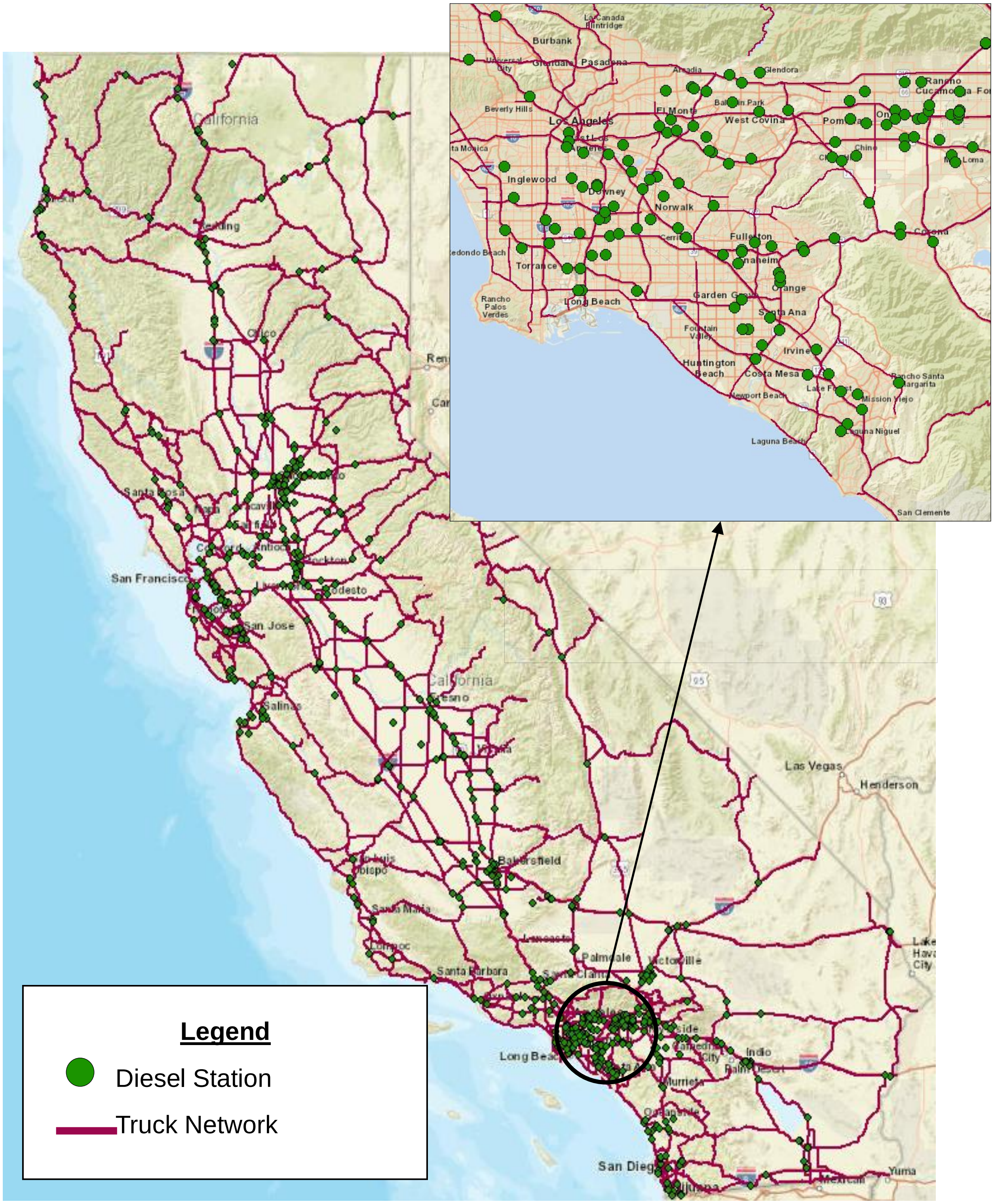


Figure 28. Public Station Candidate Sites



4 Infrastructure Rollout to Support Zero-Emission Vehicle Adoption

4.1 Deployment Scenarios Investigated

4.1.1 Reference Case

This analysis assumes the default vehicle demand projections in the EMFAC tool as the reference, "Business-as-Usual" case. Under this reference case, there is moderate adoption of ZEVs and as such, on-road GHG and most CAP emissions are projected to decrease. For drayage trucks, ZEV adoption in the reference case is less than 1% of the population for the year 2025, 7.3% for the year 2035, and 15% for the year 2045 (Figure 29). For in-state long haul trucks, ZEV adoption is less than 1% for 2025, 8.5% for 2035 and 15% for 2045 (Figure 30). For out-of-state long haul trucks, ZEV adoption is lower for each year, 0.5%, 7.4%, and 9.8% for each target year, respectively (Figure 31). For transit buses, the adoption rate is 7.5% for 2025, 5.8% for 2035, and 4.3% for 2045 (Figure 32).

Figure 29. Reference Case Projected Drayage Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

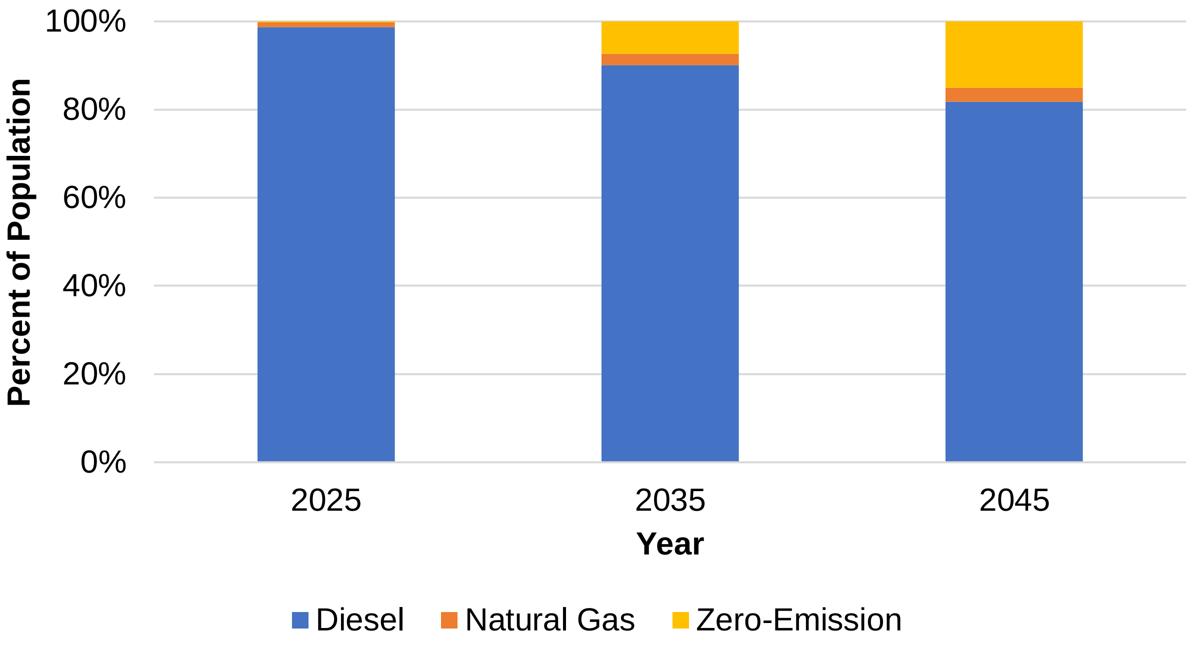


Figure 30. Reference Case Projected In-State Long Haul Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

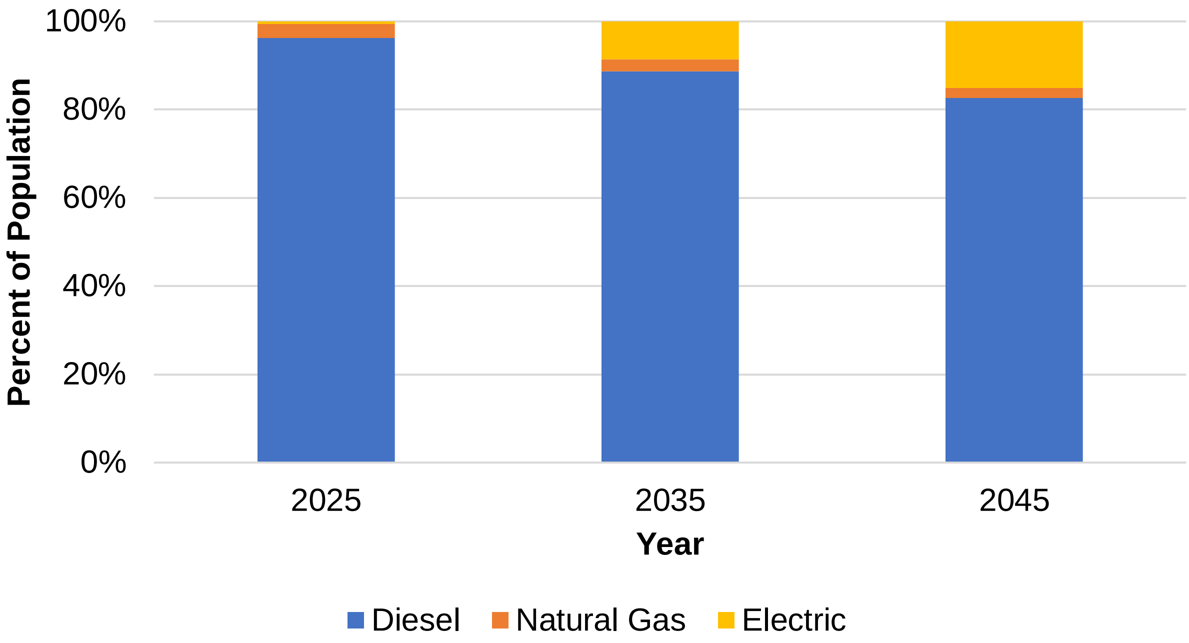


Figure 31. Reference Case Projected Out-of-State Long Haul Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

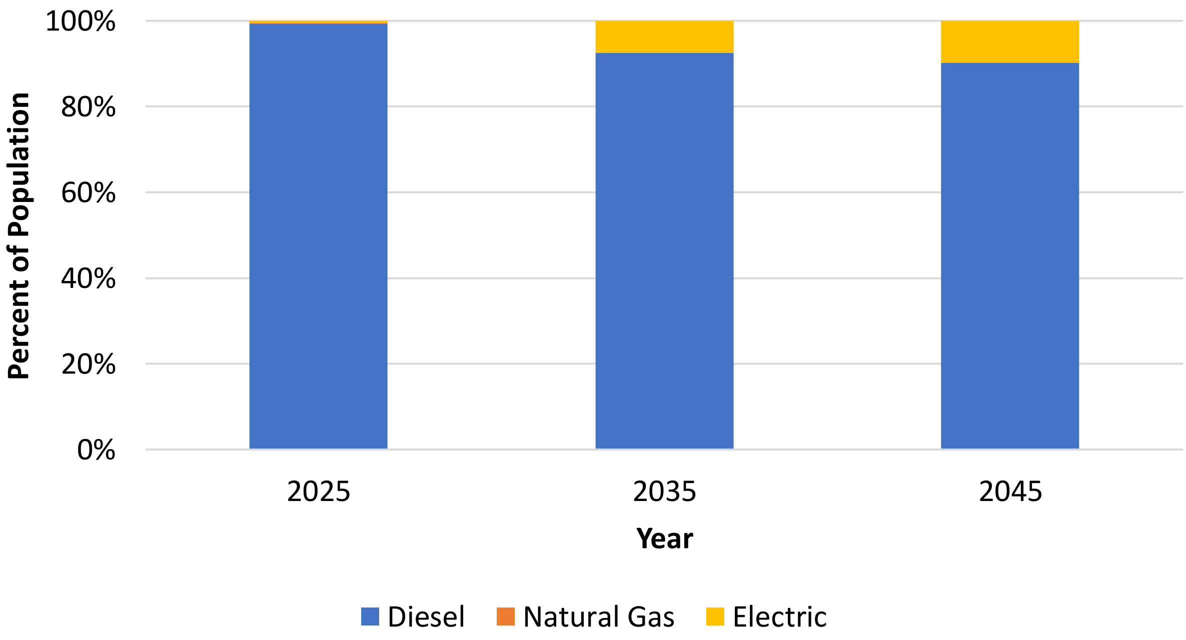
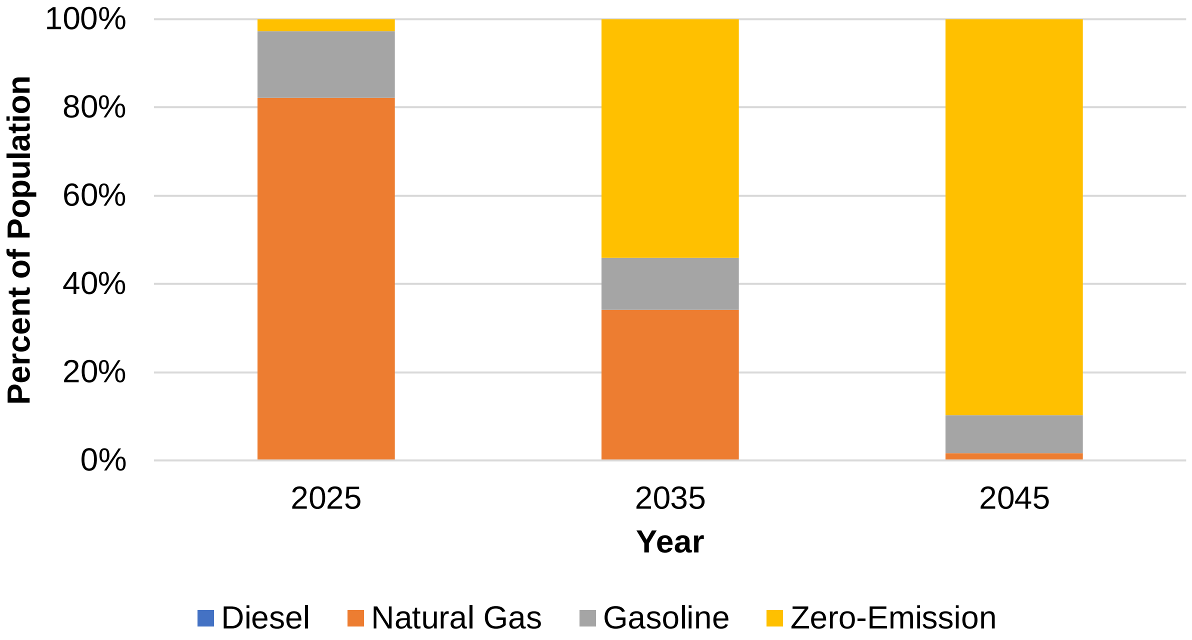


Figure 32. Reference Case Projected Transit Bus Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045



4.1.2 Zero-Emission Scenarios

4.1.2.1 Drayage

Two scenarios were modeled for expanded zero-emission drayage truck deployment. The "TRACE scenario" is the optimized rollout result from TRACE that meets state-level GHG emissions reductions and regional air quality goals [23]. The scenario projects about 18% of drayage trucks are zero-emission by 2025, about 82% will be zero-emission by 2035 and 98% by 2045 (Figure 33). TRACE further delineates the number of BEVs versus FCEVs across the years. The Clean Air Action Plan scenario ("CAAP scenario") assumes about 1.4% of drayage trucks are zero-emission by 2025, and all drayage trucks in SoCAB are zero-emission by 2035, in line with the San Pedro Bay Ports Clean Air Action Plan (Figure 34) [5]. The ratio of BEVs and FCEVs from TRACE are applied to the CAAP scenario as well.

Figure 33. TRACE Scenario Projected Drayage Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

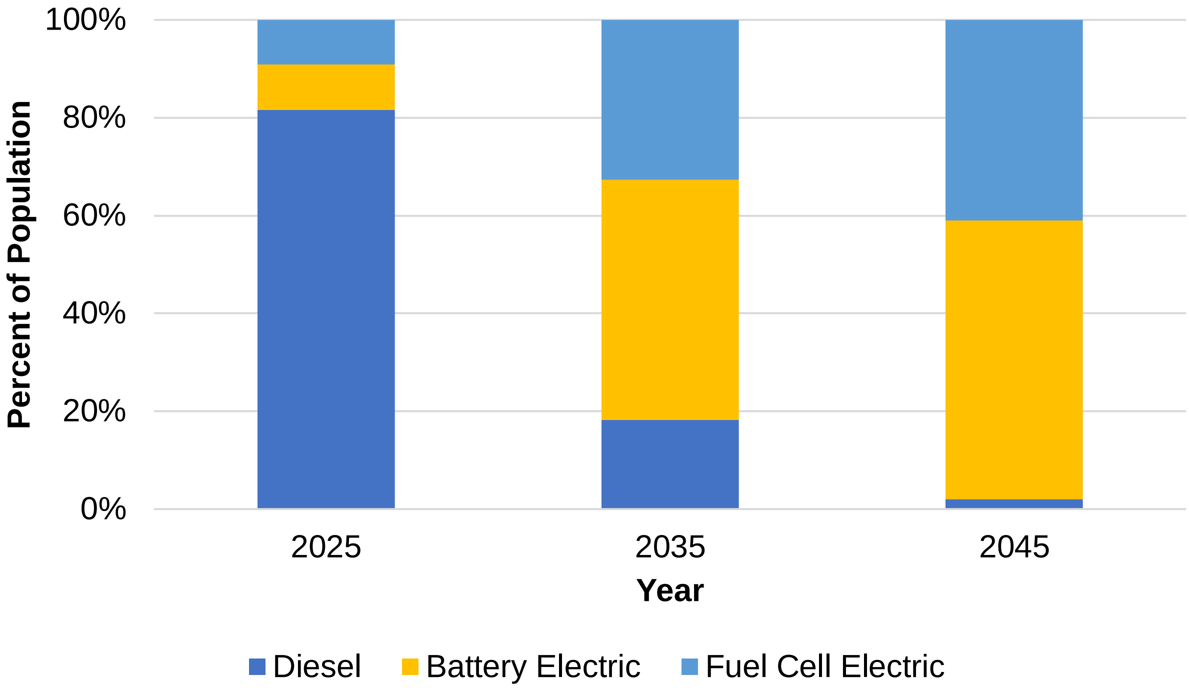
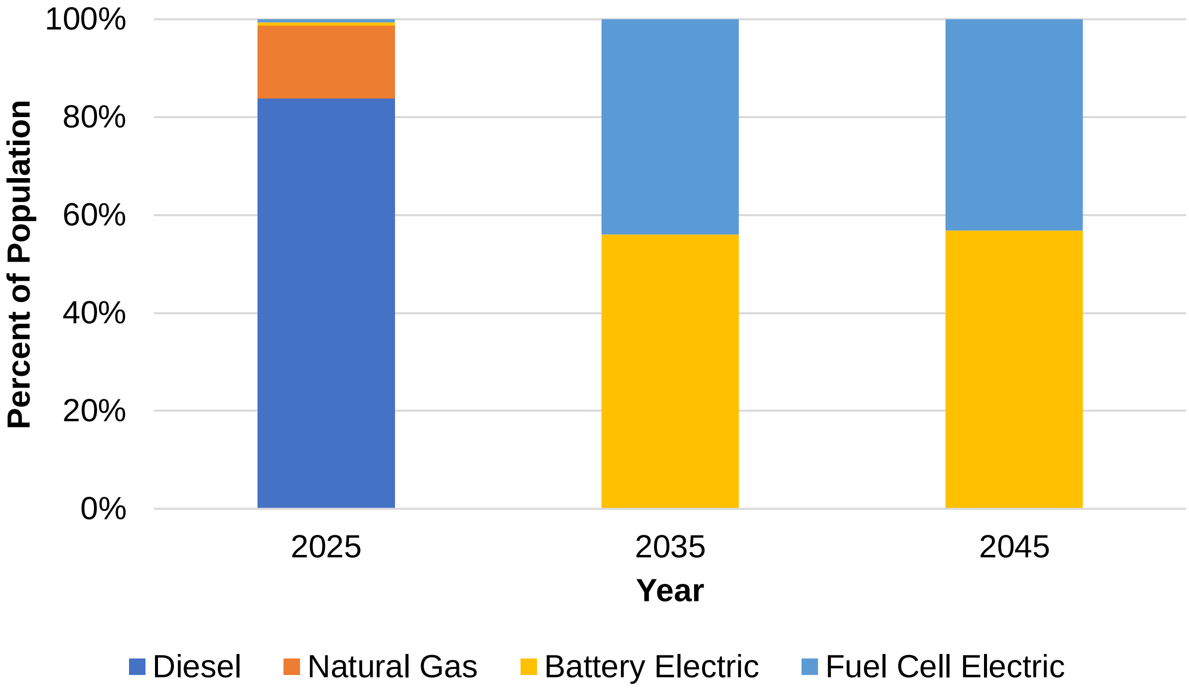


Figure 34. CAAP Scenario Projected Drayage Vehicle Distribution by Fuel Type for Years 2025, 2035, and 2045



4.1.2.2 Long Haul

Similar to drayage, long haul is modeled with two scenarios, Conservative and Optimistic. In-state long haul adoption in the "Conservative" scenario adopts the optimal deployment modeled in TRACE and out-of-state long haul following the reference case (Figure 35). The "Optimistic" scenario adopts in-state following TRACE adoption projections and out-of-state long haul trucks following estimated HD ZEV adoption in the 2022 Scoping Plan (Figure 36). In both figures, in-state and out-of-state vehicle populations are combined.

Figure 35. Conservative Scenario Projected Long Haul Vehicle Distribution by Fuel Type for Years 2025, 2035, and 2045

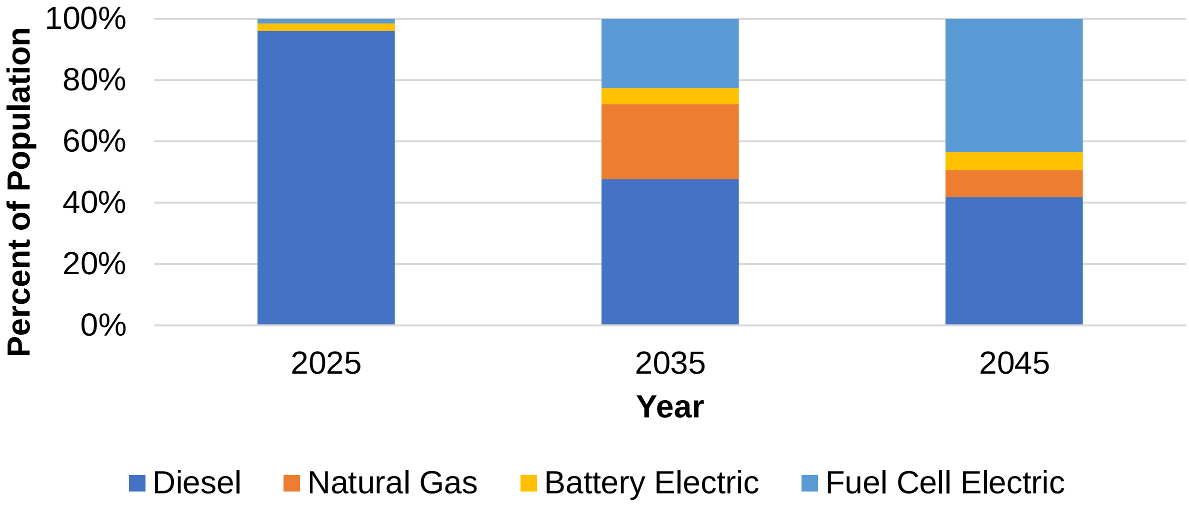
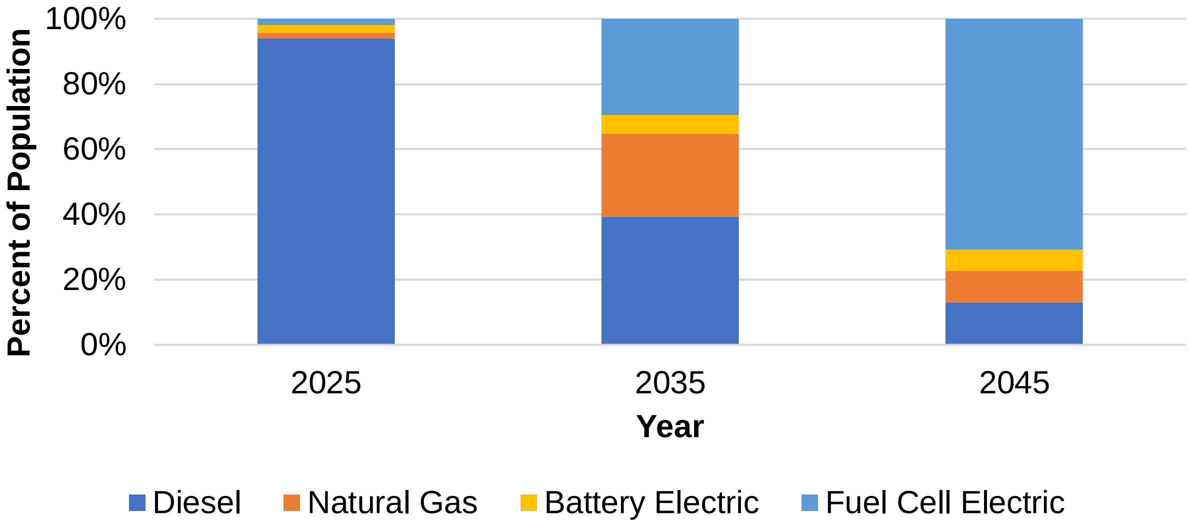


Figure 36. Optimistic Scenario Projected Long Haul Vehicle Distribution by Fuel Type for Years 2025, 2035, and 2045



4.1.2.3 Transit

While the 2022 Scoping Plan statewide estimates that 64% of buses will be zero-emission by 2035 in the SoCAB region, transit agencies have committed to transition to roughly 84% zero-emission by 2035 and 100% by 2045 (see Table B-1 in Appendix B to a full list of commitments). Almost all identified transit agencies have opted to build their own charging or hydrogen refueling stations at current or proposed transit depots. Burbank Bus has announced plans to coordinate its ZEB rollout in conjunction with Glendale to reduce the financial burden of building their zero-emission infrastructure [62].

For transit, two zero-emission bus adoption scenarios are modeled, ICT and 100% ZEB. The "ICT scenario" assumes adoption that meets the commitments made by Transit agencies in the SoCAB region (about 10% ZEB in 2025, 84% in 2035, and 100% by 2035) (see Figure 37). The "100% ZEB scenario" assumes that transit agencies have transitioned early, reaching 100% zero-emission options by the year 2035 (Figure 38).

Figure 37. ICT Scenario Projected Transit Bus Distribution by Fuel Type for Years 2025, 2035, and 2045

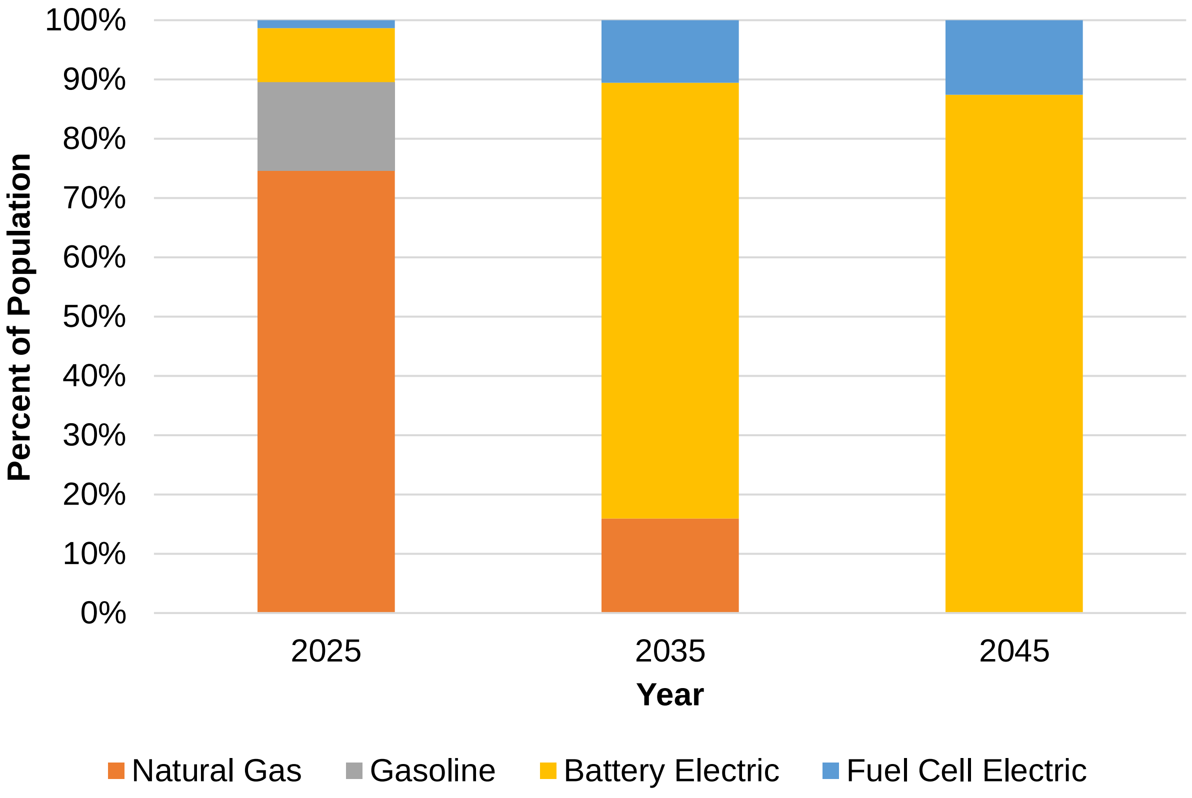
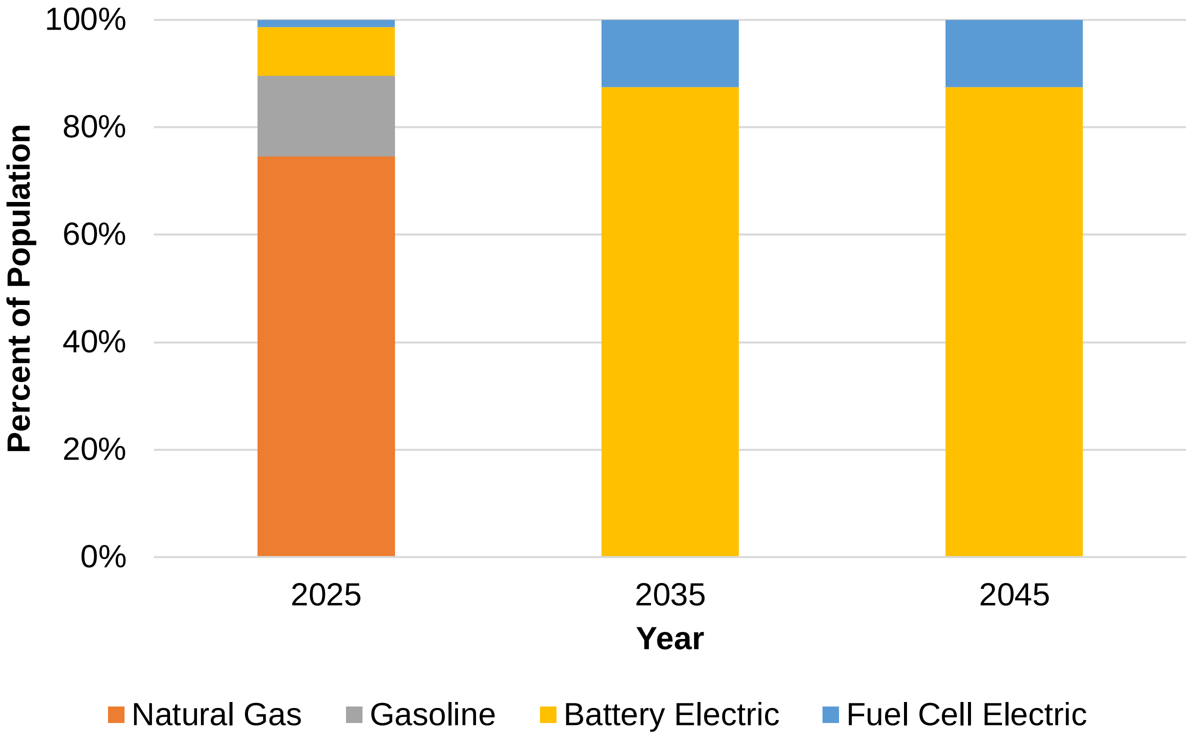


Figure 38. Accelerated ACT Scenario Projected Transit Bus Distribution by Fuel Type for Years 2025, 2035, and 2045



4.2 Scenario Results

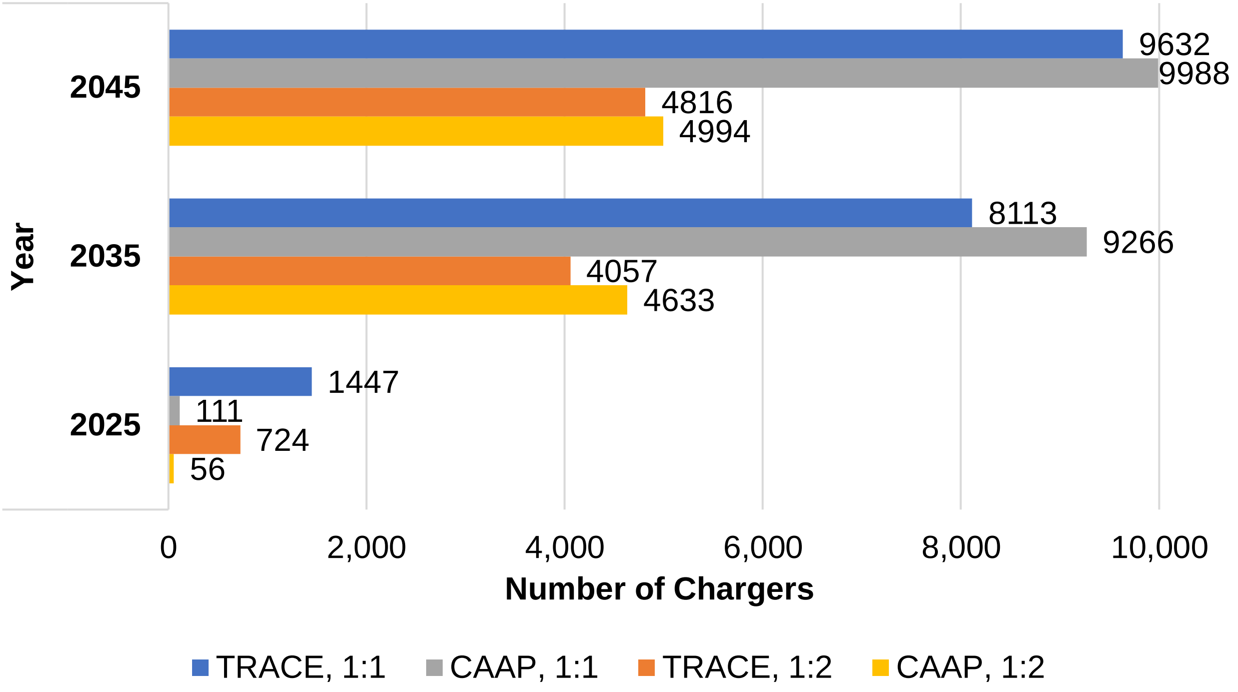
4.2.1 Station Counts

The number of charging and hydrogen refueling stations needed to support ZEV adoption between now and the year 2045 is dependent on the adoption rate of ZEVs, the ratio of BEVs to FCEVs, and assumptions in terms of fuel efficiency, VMT, and capacity of stations deployed. The following results explore the impact of varying ZEV adoption, vehicle-to-charger ratios as well as hydrogen station capacity and utilization on the total number of stations required.

4.2.1.1 Drayage

ZEV adoption is projected to increase under both the TRACE and CAAP scenarios compared to the reference cases, resulting in a significant increase in charging and hydrogen fueling infrastructure requirements to meet demand. The CAAP scenario, which assumes 100% zero-emission drayage trucks by 2035 has the highest charger demand, as expected. The assumed ratio of 1:1 vehicle to charger versus 1:2 has the greatest impact on total number of chargers needed for the scenarios investigated, see Figure 39. This ratio will also greatly affect the capital cost of deploying chargers for battery electric drayage trucks. Overall, transitioning to 100% drayage trucks by 2035 requires between 4.6 to 9.3 thousand chargers, depending on the ratio between vehicles and number of chargers. Due to the anticipated growth in drayage truck population between 2035 and 2045, an additional 350 to 700 chargers will need to be installed between 2035 and 2045 to continue to support 100% zero-emission drayage operations in SoCAB, assuming full transition in 2035. Under the TRACE scenario, a higher initial ZEV population in 2025 results in roughly twice as many chargers compared to the CAAP scenario in that year. However, slower adoption between 2025 and 2035 results in greater charger growth between 2035 and 2045, with an additional 800 to 1.5 thousand chargers needed by 2045.

Figure 39. Projected Number of Chargers for Drayage Trucks, Years 2025, 2035, and 2045



Total number of chargers needed is highly dependent on the ratio of BEVs to FCEVs assumed as well as the number of chargers per vehicle needed. Hydrogen refueling station counts are combined with long haul projections and are reported in the next section.

4.2.1.2 Long Haul

Figure 40 presents the number of chargers need to support battery electric long haul trucks under the conservative and optimistic scenarios. Despite long trucks making up a larger share of MD/HD vehicles compared to drayage, a smaller portion is anticipated to be battery electric due to longer average travel demands and higher payloads. Due to the longer travel times,

Figure 40. Projected Number of Chargers for Long Haul Trucks, Years 2025, 2035, and 2045

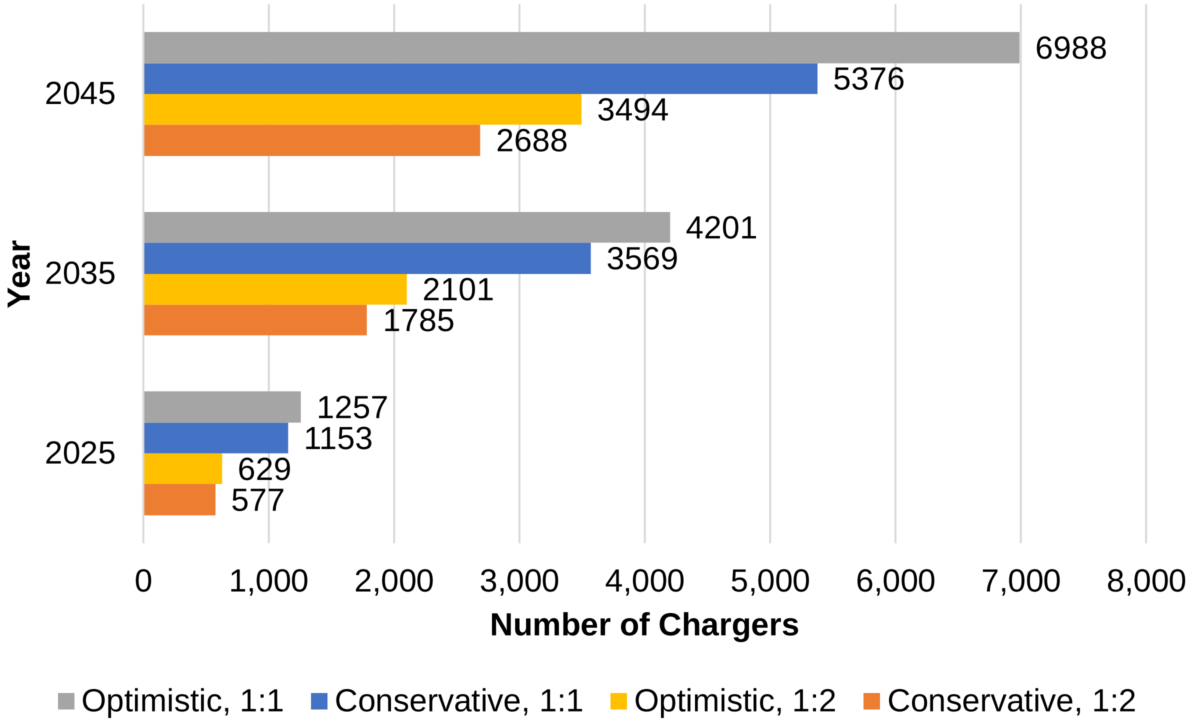
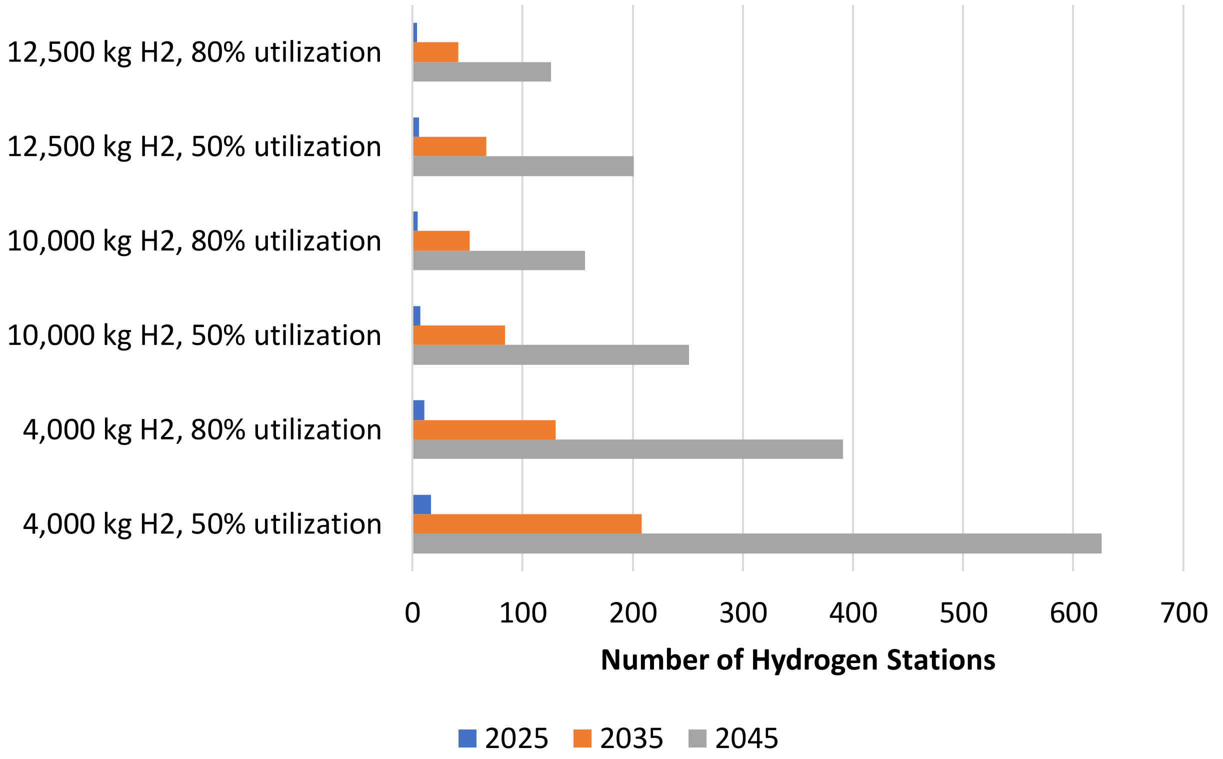


Figure 41 presents the projected number of hydrogen station needed to support drayage and long haul fueling demands for the years 2025, 2035, and 2045 with different station capacity and utilization assumptions. The range of station sizes explored is based on a combination of available data on future stations as well as the assumption that expanding hydrogen demand will result in larger stations, as has been seen in the LDV sector. Spanning station capacity between 4,000 kg H_2 to 12,500 kg H_2 leads to a wide range of potential station counts. Lower station utilization can also greatly affect the number of stations needed to meet a set amount of hydrogen fueling demand. For the year 2025, where about five percent of the drayage and long haul fleets have transitioned to ZEVs, station counts range between 4 and 17 stations. In 2045, when hydrogen demand is 36x hydrogen demand in 2025, the range of values is between 125 and 626.

Hydrogen station counts based solely on total hydrogen demand will miss the spatial constraints that may affect actual station utilization. These initial station counts will be compared to the results of the spatial analysis in Section 4.3 and should not be taken as final results.

Figure 41. Projected Number of Hydrogen Stations based on Drayage and Long Haul Fuel Demand



4.2.1.3 Transit Fleet Stations

Appendix C, Table C-1 details the planned transit charging and hydrogen station deployments under the ICT rollout plans and other public announcements. At the time of this report, 10 hydrogen stations are planned between 2023 and 2040, 25 charging stations, and two undefined stations. Planned hydrogen stations are expected to support between 33 and 245 FCEBs, depending on location. Assuming buses travel an average of 100 miles per day at an average fuel efficiency of 8 mi/kg H2,[8] estimated station capacity ranges between 400 and 3 thousand kg of H_2 dispensed per day. The charging stations are expected to support approximately 3,500 buses. At a 1:2 charger to vehicle ratio, that equates to about 1750 chargers. Estimations based on the aggregated data (bottom-up approach) are lower than the regional estimates (top-down approach) reported below due to data gaps for some transit agencies.

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[8] Estimate is based on CARB's EMFAC tool: year 2025 daily miles traveled per electric bus.

Figure 42 and Figure 43**Figure *44*** present the estimated count of fleet-based chargers and hydrogen stations needed to support fleet operations for scenarios explored, respectively. These results assume that transit agencies rely solely on fleet-based infrastructure. Agencies may elect to coordinate with public stations and/or other transit agencies to have access to additional stations in the case of a fleet station outage.

The difference between the transit scenarios explored is primarily for the year 2035, as growth in 2025 is already set by budget plans and both scenarios assume 100% zero-emission by 2045. The accelerated adoption of ZEBs to achieve 100% ZEBs by 2035 requires about 32% more chargers compared to the current ICT plans. The ratio of vehicles-to-chargers has the greatest impact on the total number of chargers. The influence of charger power capacity, cost, and the number of chargers per vehicle is explored more in the cost section of the Blueprint.

The total number of chargers is highly dependent on the ratio of chargers to vehicles. By 2045, the explored scenarios required 3.8 to 7.6 thousand chargers. The number of chargers is also dependent on the number of battery electric buses versus fuel cell electric buses. Several transit agencies have yet to decide between the two ZEV types.

Figure 42. Projected Number of Chargers for Transit Buses, Years 2025, 2035, and 2045

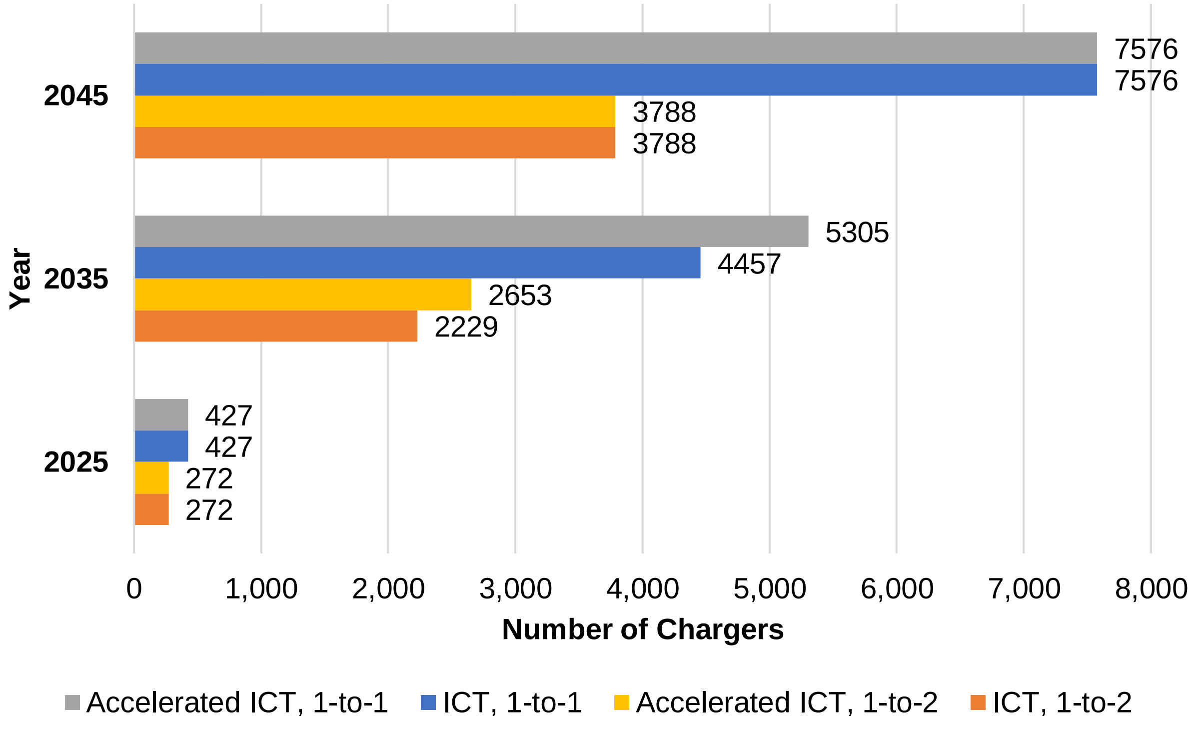
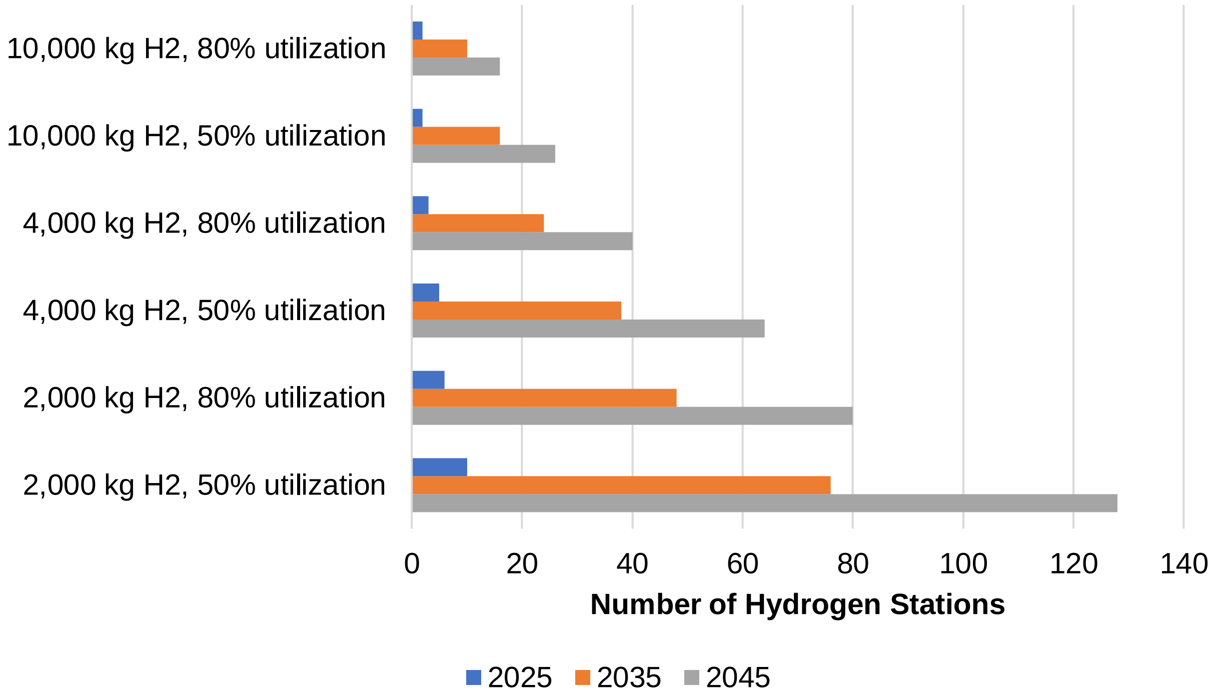


Figure 43. Projected Number of Hydrogen Stations based on Transit Bus Fuel Demand under ICT Scenario



Transit agencies have committed to 10 hydrogen stations to meet FCEV fueling demand out to the 2035 timeline. Based on planned fuel cell electric bus deployment, 10 stations are sufficient to cover estimated daily hydrogen demand for 2025. However, additional stations may be needed between 2035 and 2045 if transit VMT increases, as predicted by EMFAC. The final number of required stations is dependent on station sizing as well as redundancy measures.

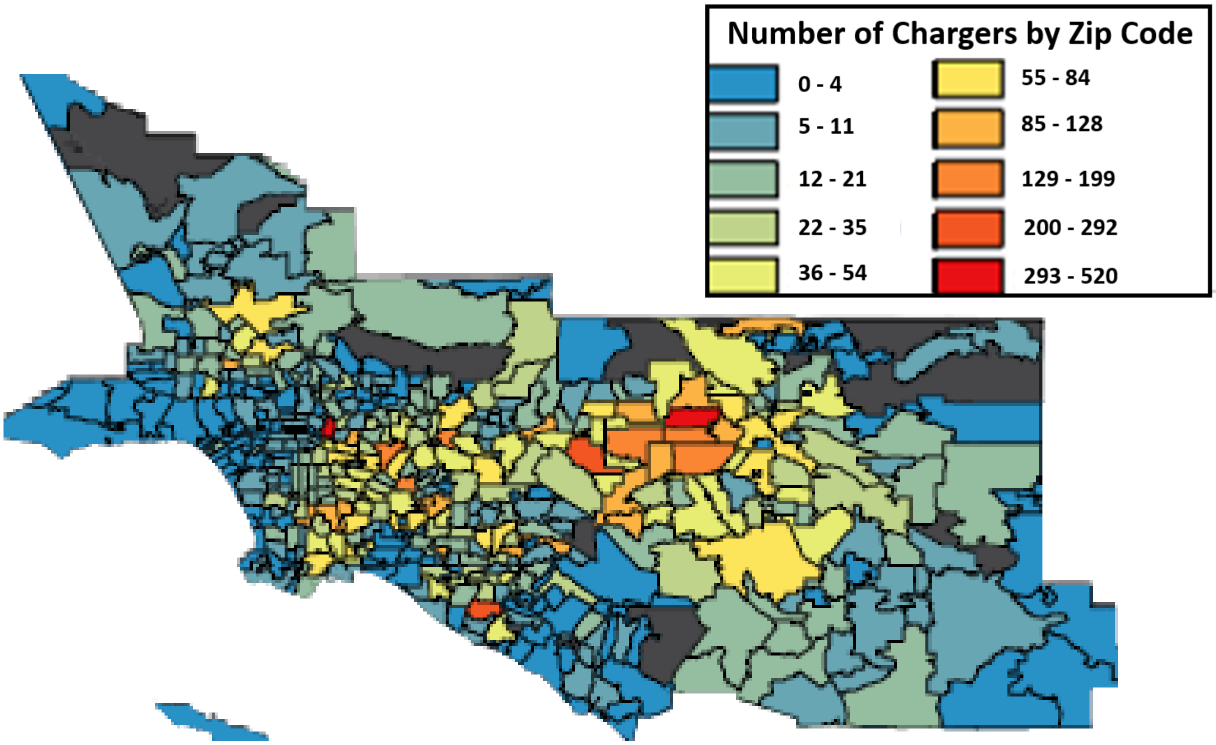
4.2.2 Spatial Allocation of Stations

4.2.2.1 Drayage and Long Haul Trucks

Charging Stations

For this analysis, charging stations for drayage and long haul trucks are assumed to be located where the vehicles are registered, as reported by EMFAC (data from the California DMV). Due to limited data on where fleets may operate moving forward, the current zip code data are used for the future years. Figure 44 presents the density of drayage and long haul chargers within the SoCAB region, assuming the CAAP drayage scenario and optimistic long haul scenario projections with a charger to vehicle ratio of 1:2 for the year 2035.

Figure 44. Charging Station Density for Drayage and Long Haul Trucks



Public Hydrogen Stations

This section covers the siting of public hydrogen refueling stations in SoCAB for drayage and long haul trucks for the years 2025, 2035, and 2045. The modeled scenario combines the TRACE scenario for drayage trucks and the optimistic scenario for long haul trucks. Figure 45 presents the 2025 hydrogen station siting results. The model selected five stations in SoCAB. One of the five stations is located in a DAC. Figure 46 presents the 2035 station siting results. 42 stations were sited, 19 of which are in DACs (about 45% of stations). Between 2035 and 2045, the number of required stations increases to 127 stations sited in 2045, see Figure 47. 53 of the stations (42%) are in DACs.

Figure 45. SoCAB Drayage and Long Haul Hydrogen Refueling Station Siting for the Year 2025

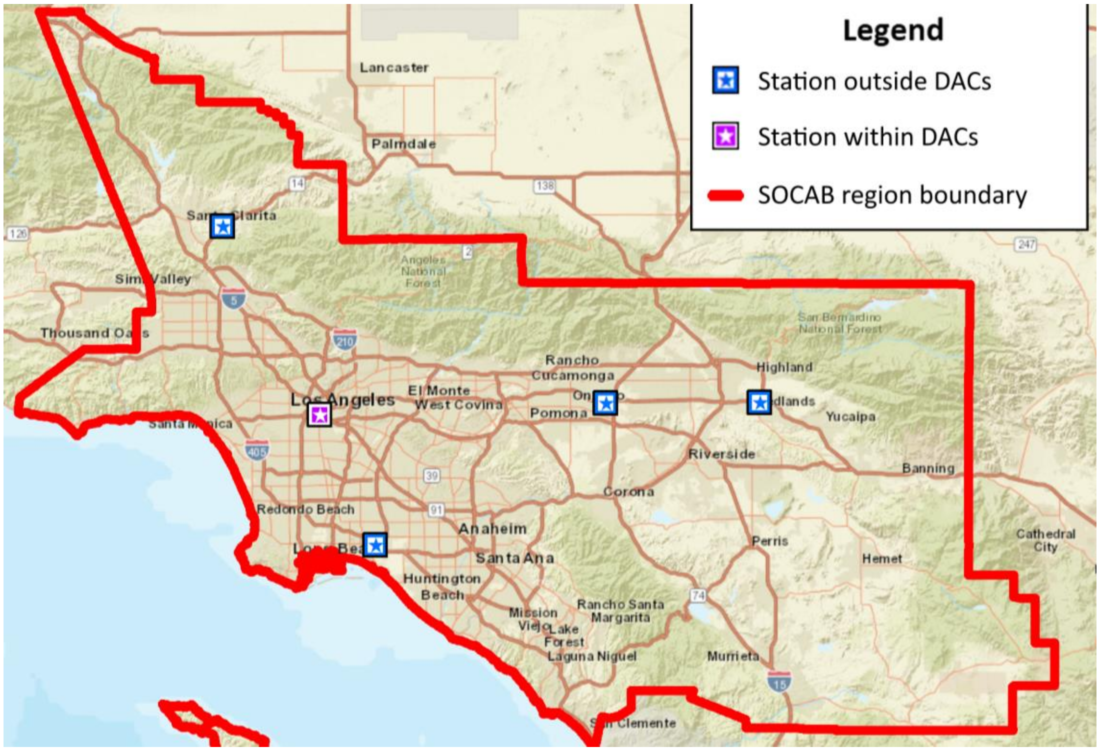


Figure 46. SoCAB Drayage and Long Haul Hydrogen Refueling Station Siting for the Year 2035

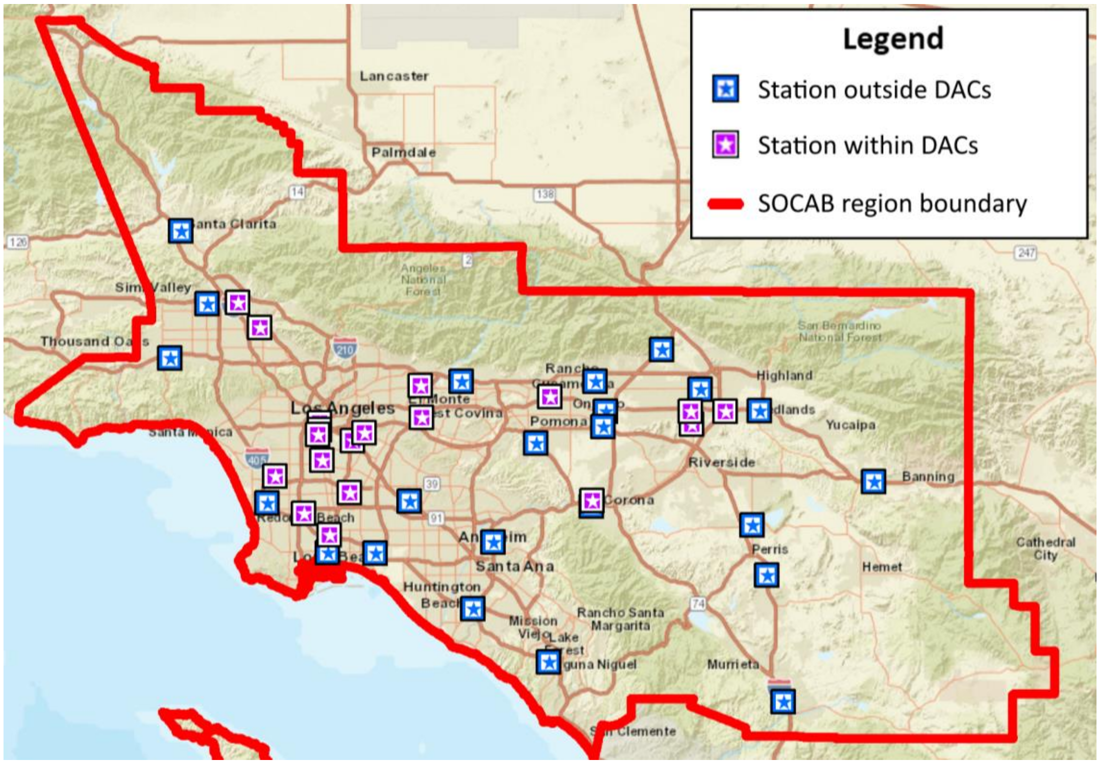
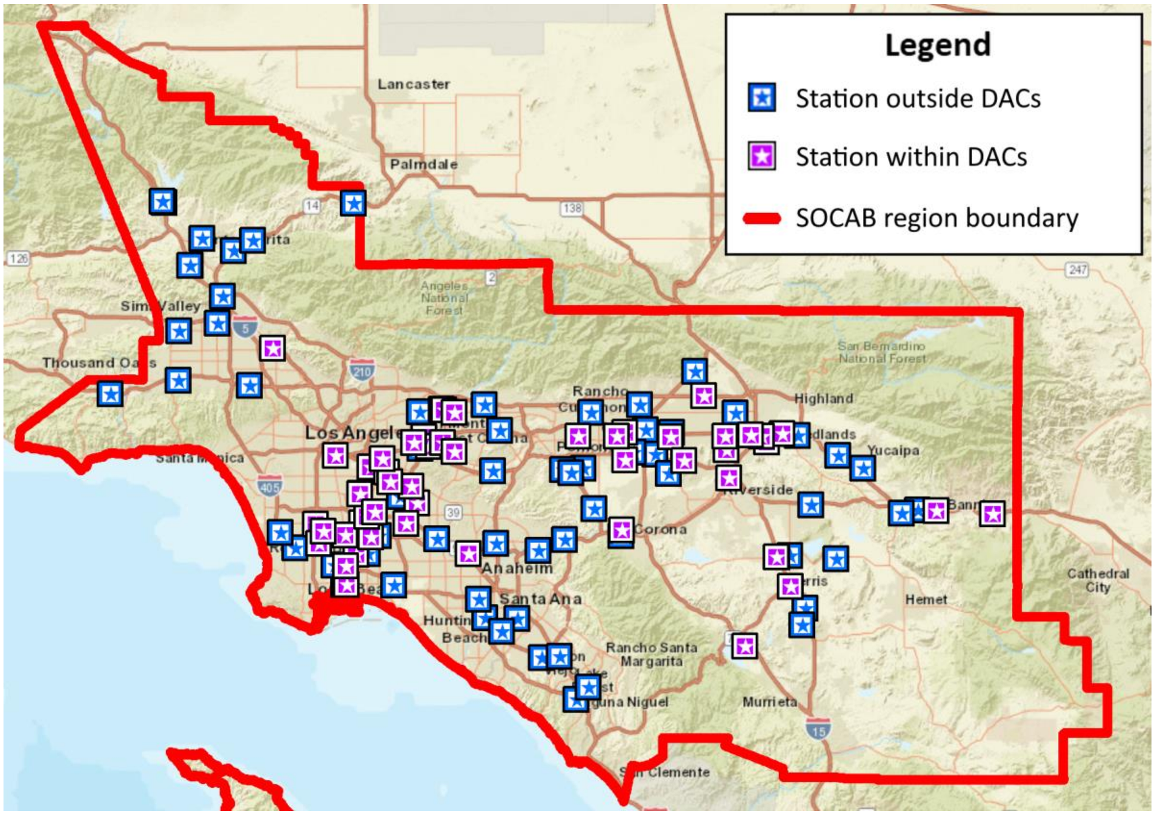


Figure 47. SoCAB Drayage and Long Haul Hydrogen Refueling Station Siting for the Year 2045



While BEV fleets are expected to rely primarily on home base charging, public stations can provide an additional back-up network for opportunity, en route charging. One solution is to co-locate charging and hydrogen fueling solutions as both vehicle types are expected to follow similar travel patterns along highways. Key limiting factors in co-location are space and access to electricity. Public stations would be well situated for higher power charging (350 kW to 1 MW+ charging), which can provide 20 – 100 miles of range under 20 minutes. For the hydrogen station siting results presented, adding 5 – 7 chargers per station could support 20% of the regional drayage and long-haul BEV charging demand projected for 2025, 2035, and 2045.

4.2.2.2 Transit Fleet Stations

While some details are undecided, the ICT rollout plans project the required charging and hydrogen stations (including timeline and capacity) to support transit agencies. A full list of announced stations is provided in Appendix C, Table C-1. 20 of the proposed stations are planned to be online by 2025 and the remainder (total of 38) will be online before 2035. 28 of the planned stations are located within DACs. Figure 48 presents the proposed stations in 2035 and their proximity to the diesel truck stops used as candidate stations for the drayage and long haul scenarios.

Figure 48. Major Transit Hubs for SoCAB Region under ICT Rollout in 2035

4.3 Costs

4.3.1 Infrastructure and Fuel Costs

For BEVs, total electricity cost is a function of total electricity demand, when the BEVs charge (on-peak versus off-peak), and maximum charging demand ("demand charge"). While the major utilities currently have a demand charge "holiday," this is expected to expire within the next year (March 1, 2024). As a result, station operators will need to account for peak charging demand when calculating fuel costs moving forward.

Southern California Edison and San Diego Gas and Electric both offer TOU rates for BEV charging. SCE has established three rates based on the peak power demand a facility is expected to have. The three SCE rates are as follows: TOU-EV-7 for peak charging demand of 20 kW or less, TOU-EV-8 for between 20 and 500 kW, and TOU-EV-9 for over 500 kW. SDGE's Commercial and Industrial EV-Only, EV-HP Rate has subscription levels, allowing for monthly demand charges to be set in increments of 10 kW for demand levels under 150 kW and 25 kW increments for over 150 kW [63]. The current TOU rates, delineated by time bins previously presented in Figure 25, range from approximately $0.08-0.10/kWh for super off peak times in winter to $0.55-0.60/kWh for peak times in summer, depending on the utility and rate plan [64]. These energy prices do not include additional interconnection and service fees that may apply.

Charging equipment and installation costs vary by charger type (and capacity) as well as total number of planned chargers at a facility. CALSTART's INSITE tool provides a detailed equipment catalog for both charging and hydrogen infrastructure. Prices can range from under $1,000 (7.2 kW, Level 2 AC) to over $200,000 (350 kW DC) [65]. Prices do not include installation costs, interconnection fees, and other electric grid upgrades that may be required. As mentioned in Section 1.4.2, utilities may have programs that provide charger rebates and partially cover installation and upgrade costs.

Regarding hydrogen fuel, retail hydrogen prices ($/kg) are currently in flux due to rising natural gas prices, inflation following the pandemic, and the drop in LCFS credit price drop from a high of $200 to less than $80 [66], [67]. The current average dispensing price at retail stations is $26, up sharply from about $16 in 2021. Reed et al. (2020) projects that hydrogen fuel prices will decline as technologies mature and production capacity increases [68].

Hydrogen refueling station costs are uncertain due to the limited number of large capacity MD/HD stations built. Nikola recently announced six new MD/HD hydrogen stations with a total project cost estimated at $85.6 million, or 14.3 million per station [69]. Each station is anticipated to fuel up to 100 FCEVs per day. Construction is anticipated to begin before 2024, establishing this price range as reasonable for the 2025 scenarios in this analysis. As more stations are designed and the market matures, it is possible to reduce costs per station.

4.3.2 Government Funding Opportunities

Investing in MD/HD ZEVs, whether battery electric or fuel cell electric, costs today considerably more than internal combustion vehicles. Direct government funding helps offset the higher capital costs of alternative fueled MD/HD-ZEVs, making price less of a consideration for early adopters. Subsidized purchases increase demand, and increased sales will typically increase supply. Several federal, state, and regional funding programs provide funding for MD/HD ZEVs as well as the required fueling infrastructure. Available programs vary in terms of funding structure and include point-of-sale vouchers, grants, and rebates, some of which allow for "stacking" –combining multiple program funds to support a single project and/or procurement for equipment. Examples of programs include:

- **Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)**: Funded by the California Climate Investment programs, HVIP provides point-of-sale vouchers for eligible vehicles from approved vendors. Eligible vehicles include medium-duty vans, MD/HD trucks (including refuse), buses (including school buses), refuse trucks, and electric power take-off [70].

- **Carl Moyer Memorial Air Quality Standards Attainment Program**: Voucher incentive program to purchase on-road, low carbon vehicles or convert polluting vehicles (greater than 14,000 lbs.) to lower carbon power trains for small fleets (10 or fewer vehicles) [71].
- **Volkswagen Diesel Emissions Environmental Mitigation Trust**: Administered by Air Quality Management/Control Districts, the trust funds both zero-emission vehicle and infrastructure deployments, spanning light-duty to heavy-duty applications [37].
- **Energy Infrastructure Incentives for Zero- Emission Commercial Vehicles (EnergIIZE Commercial Vehicles):** Newly launched program to partially fund fueling equipment for MD/HD BEVs and FCEVs. The program offers four "funding lanes," including a fast-track lane for fleets that already have purchased a vehicle [36].
- **Low Carbon Fuel Standard**: Tradeable credits program with the goal of reducing the carbon intensity of transportation fuels, including electricity and hydrogen. Eligible fuel providers receive credits based on volume and the calculated carbon intensity of the certified fuel pathway [72].
- **Discretionary Grant Program for Charging and Fueling Infrastructure:** Established under the Bipartisan Infrastructure Law, this program focuses on deploying ZEV fueling infrastructure along identified corridors. At least 50 percent of the benefits (are earmarked for low- and moderate-income communities [73].
- **Zero and Near Zero-Emission Freight Facilities (ZANZEFF):** This program provides funding for "pre-commercial" deployments that demonstrate emerging, zero- and near-zero emission technologies [74].
- **Sustainable Transportation Equity Project (STEP):** Program funded under the California Climate Investments, focuses on community-level investment in sustainable transportation, encompassing public transit and other clean mobility initiatives [75].
- **Zero-Emission Truck and Bus Pilot Projects:** A subprogram under the California Climate Investments, administered by the California Air Resources Board, that funds pilot projects [74].
- **Targeted Airshed Grants program:** program by U.S. Environmental Protection Agency to address degraded air quality within communities [76].

Funding for pilots and other "pre-commercial" deployments is important for proof-of-concept designs that will inform broader deployment of ZEV infrastructure to meet State goals. For example, the current ZANZEFF projects at the Ports are creating a test bed for the development of the next generation of heavy-duty fuel cell electric trucks and hydrogen refueling stations [13], [77].

The major California investor-owned utilities have also implemented charging infrastructure funding programs. In the SoCAB region, Southern California Edison's Charge Ready Transport program is an example which supports some of the costs of the design, installation, and maintenance of charging infrastructure, including transformer upgrades [78].

In addition to technology funding, the California Energy Commission recently awarded funding to support workforce development, under grant funding opportunity GFO-21-602 IDEAL ZEV Workforce Pilot, to multiple recipients within the SoCAB region [79].

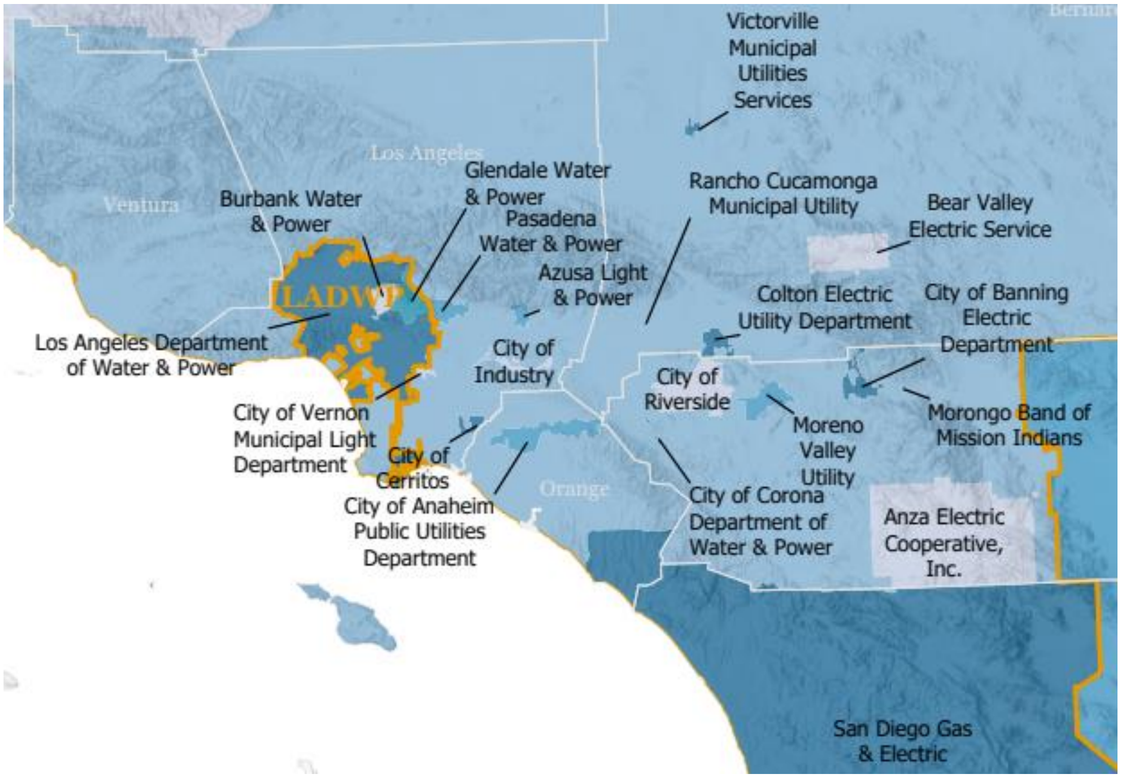
4.3.3 Utility Programs

The SoCAB region is divided into several electric utilities (see Figure 49). Each utility operates independently and may have distinct rules for permitting and operating of EVCS. They also may offer different programs to help plan the infrastructure design and offset initial costs.

The two investor-owned utilities (IOUs) within the SoCAB region, Southern California Edison (SCE) and SDG&E, have infrastructure funding programs that coordinate the design and construction of hardware, in front of and behind of the meter, required to support EVCS. A summary of the programs is provided in Table 13. Each IOU funding program is 5 years. Applicants must commit to support at least 2 EVs, operate and maintain the vehicles and chargers for a minimum of 10 years, and provide data on charger use for 5 years. SCE has specified that new EVSE should be near a new or existing transformer, with all project EVSE within a single location. EVs should be expected to arrive within 18 months of applying to the program [78]. The utilities also require applicants to rely on eligible or approved product lists in order to ensure safety and performance [28], [78].

The other utilities also have programs that cover infrastructure for ZEVs. Some have specific tiers or separate programs for MD/HD ZEVs, whereas others only define charging level. In the SoCAB region, only the Los Angeles Department of Water and Power (LADWP), in addition to SCE and SDGE, has a MD/HD ZEV specific program, although others have "commercial" programs. Commercial-oriented programs are oriented towards light-duty vehicles but may have the potential to support some medium- or heavy-duty vehicle needs. Suitability will depend on the charging level, site design (e.g., ingress, egress, height clearance, EVSE spacing, parking spot size), and utility restrictions.

Figure 49. Electric Utility Territories in the SoCAB Region



Source: California Energy Commission. 2017 California Electric Utility Service Territories and Balancing Authorities. https://cecgis-caenergy.opendata.arcgis.com/documents/2017-california-electric-utility-service-territories-balancing-authorities/explore

Table 13. Investor-Owned Medium- and Heavy-Duty Vehicle Electric Infrastructure

	Southern California Edison	**San Diego Gas and Electric**
Program Name	Charge Ready Transport	Make-Ready Charging Infrastructure
Start Year	2019	2020
Budget	$356.4 million	$107 million
Already Funded	Not reported	1,034 MDHDVs; 47 projects
Total Budgeted	Up to 8,490 MDHDVs; 870 sites	Up to 3,000 MDHDVs; 300+ sites

Sources: Southern California Edison; San Diego Gas and Electric

It is important to coordinate with the local utility to ensure that the planned EVCS follows all applicable codes and regulations as well as all eligibility requirements for funding/rebates. Also, independent of the utility, companies may be eligible for State and/or federal funding. Table 14 provides an overview of utility programs within the

SoCAB region. Appendix D, Table D-1 presents an overview of the approved vendors and maximum EVSE power ratings for their MH-ZEV infrastructure funding programs.

Table 14. SoCAB Utility ZEV Infrastructure Funding Programs and Rebates

Utility	**Funding**	**MD/HD Program**
Anza Electric Co-op	None	No
Azusa Light and Power	Only residential level 2 chargers: $150 per charger	No
Bear Valley Electric Service [80]	Bear Ready Commercial: • 50 level 2 EV chargers	No
Burbank Water and Power [81]	Commercial Electric Vehicle Charging Station Rebate Program: • Up to $15,000 per charging station • Without utility upgrade o $4,000 if in DAC or public access o $1,800 if not • With utility upgrade o $7,500 if in DAC or public access o $3,500 if not • Limit 40 rebates per commercial customer	No
City of Anaheim Public Utilities Department [82]	Only residential level 2 chargers: up to $400 or $1,000 depending on utility rate	No
City of Banning Electric Department	None	No
City of Cerritos	None; may be eligible for SCE programs	No
City of Corona Department of Water and Power	None; may be eligible for SCE programs	No
City of Industry	None	No
City of Riverside	EV rebates, but not EVSE.	No
City of Vernon Municipal Light Department	None	No
Colton Electric Utility Department [83]	Electric Vehicle Charger Rebate • $5,000 for charger with separate meter • $2,500 for standard connection Electric Forklift Rebate • $2,000 for forklifts	Forklifts
Glendale Water and Power	Commercial rebate • $6,000 for charger	No
LA Department of Water and Power [84]	Rebate up to $125,000 for DC fast charging EVSE	**Yes**

Moreno Valley Utility	Residential customers with EVs eligible for reduced electricity rate	No
Morongo Band of Mission Indians	None	No
Pasadena Water and Power [85]	Commercial rebate: • $6,000 for charger	No
Rancho Cucamonga Municipal Utility	Commercial rebate: • Up to $5,000 for charger (level 2 or DCFC)	No
San Diego Gas and Electric	Make-Ready Charging Infrastructure <u>50% of cost or listed value (whichever is less)</u> • $3,000 for up to 19.2 kW • $15,000 for 19.3 – 50 kW • $45,000 for 50.1 – 150 kW • $75,000 for 150.1 kW or greater	**Yes**
Southern California Edison	Charge Ready Transport • $1,700 for up to 19.2 kW • $6,800 for 19.3 kW – 49.9 kW • $20,100 for 50-149.9 kW • $37,000 for 150 kW or greater	**Yes**
Victorville Municipal Utilities Service	None	No

4.4 Emissions Results

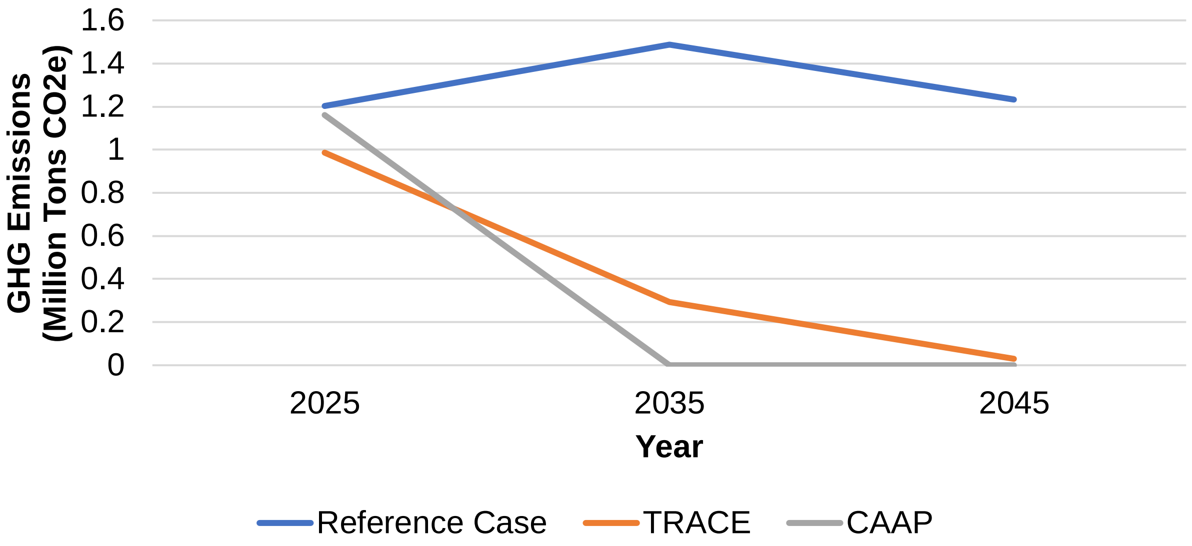
In all cases, adopting ZEVs results in a reduction in GHG and CAP emissions compared to the reference case. Total reductions achieved depend on the rate of ZEV adoption as well as changes in other vehicle fuel types. 100% reduction in GHG tailpipe emissions are achieved in cases where vocations are able to transition to 100% ZEVs. 100% reduction in CAPs is not achieved even in the 100% ZEV cases due to PM emissions associated with brake and tire wear. NOx and ultrafine particulate matter ($PM_{2.5}$) results are reported in the section. Additional CAP results (PM_{10}, SOx, and CO) are reported in Appendix E.

4.4.1 Drayage

Figure 50 presents the GHG emissions reduction for the two drayage scenarios compared to the reference case. In the reference case, emissions increase between 2025 and 2035 due to the increase in drayage VMT, despite modest increases in vehicle fuel efficiency. Between 2035 and 2045 for the reference case, GHG emission decline back to around 2025 levels, associated with an improvement in fuel efficiency paired with minimal growth in VMT. In the two ZEV scenarios, GHG emissions reduce significantly between 2025 and 2035, associated with the adoption of ZEVs. Adopting 100% ZEVs reduces tailpipe GHG emissions to zero in 2035 for the CAAP case. For the

TRACE scenario, drayage trucks are 97% ZEV and so there are still a small amount of GHG emissions in 2045. By having a faster transition to ZEVs in the CAAP case compared to the TRACE scenarios, total GHG emissions between 2025 and 2045 are lower.

Figure 50. SoCAB Drayage GHG Emissions Results for Years 2025, 2035, and 2045



Criteria pollutant emissions also decrease for the ZEV scenarios. NOx emissions reduce significantly for both scenarios explored, see Figure 51. CAAP scenario results in zero NOx emissions in 2035 and 2045. The TRACE scenario still has some diesel drayage trucks on the road accounting for approximately 28 million miles in 2045. $PM_{2.5}$ decreases under the increased ZEV scenarios but is not eliminated due to the increase in ZEV brake and tire wear, see Figure 52. Comparing the TRACE and CAAP scenarios, CAAP results in 29% lower $PM_{2.5}$ emissions in 2035 and 4.5% lower in 2045. 100% ZEV in 2045 still results 24 tons of $PM_{2.5}$ emitted in per year.

Figure 51. SoCAB Drayage NOx Emissions Results for Years 2025, 2035, and 2045

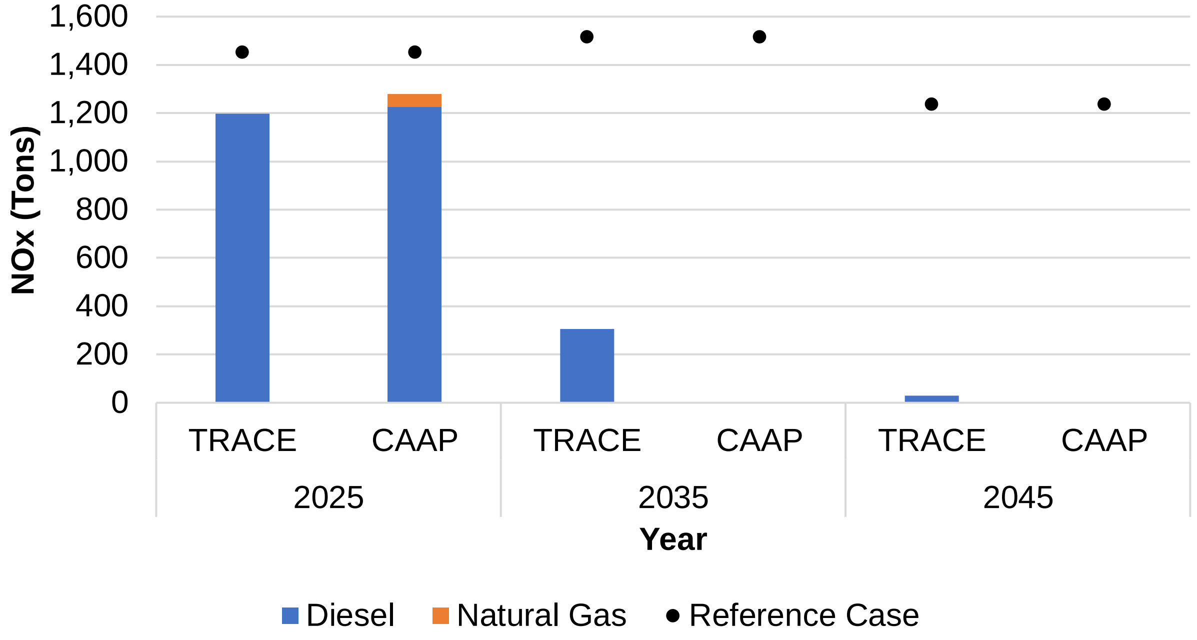
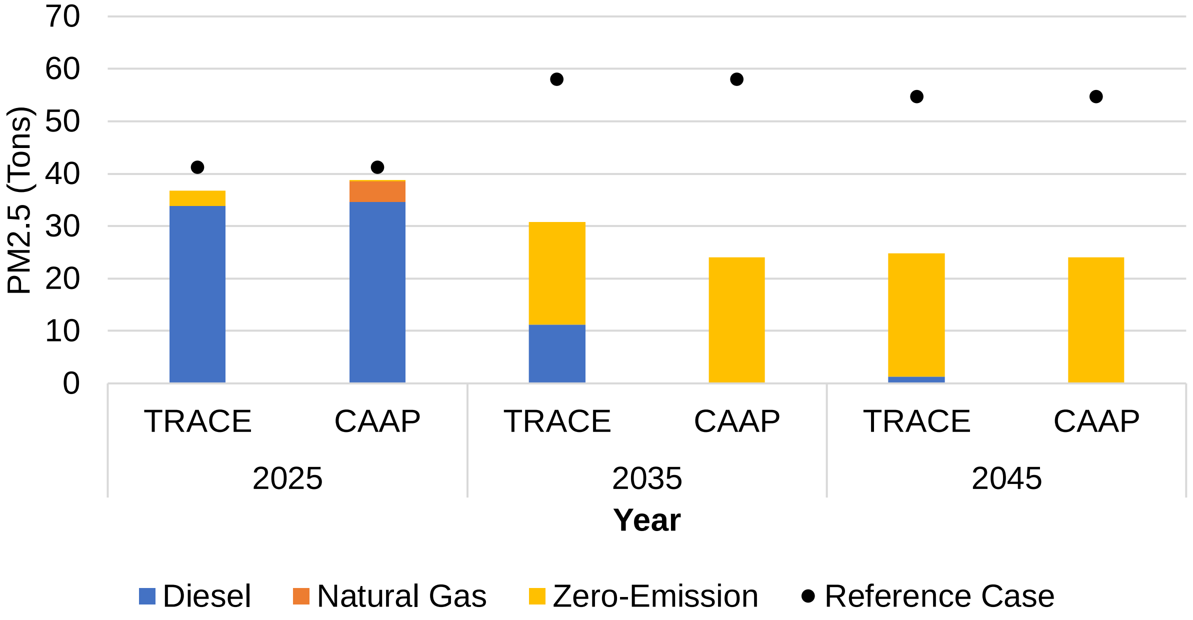


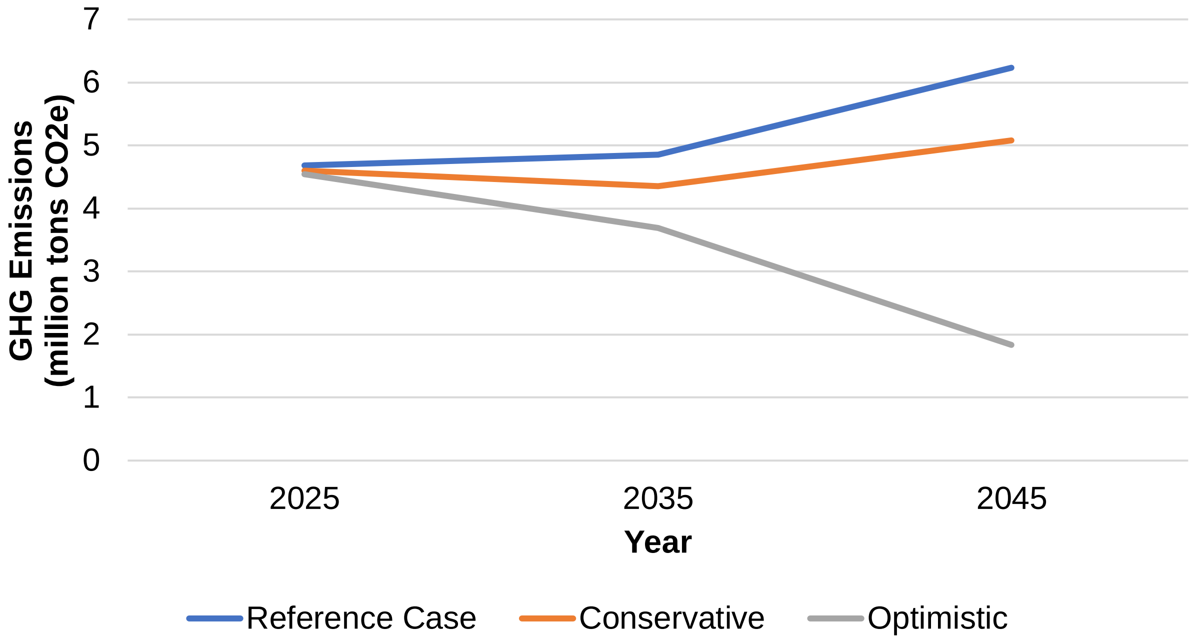
Figure 52. SoCAB Drayage PM2.5 Emissions Results for Years 2025, 2035, and 2045



4.4.2 Long Haul

Long haul GHG emissions increase in the reference case between 2025 and 2045 associated with vehicle population and VMT growth, see Figure 53. Under the conservative scenario, GHG emissions also increase, but less rapidly than in the reference case. In the conservative scenario, only in-state long haul trucks transition to ZEVs. In the optimistic scenario, both in-state and out-of-state long haul trucks transition to ZEVs, although long haul trucks transition more slowly. The net impact is an overall reduction in GHG emissions, 57% reduction compared to the reference in 2035 and 89% in 2045.

Figure 53. SoCAB Long Haul GHG Emissions Results for Years 2025, 2035, and 2045



NOx emissions decline compared to the Reference case in both the conservative and optimistic scenarios, see Figure 54. For the conservative scenario, improvements in NOx emissions factors result in a decrease even when total VMT increases over time. The optimistic scenario that has out-of-state vehicles transitioning to ZEVs sees a 64% greater reduction in NOx emissions in 2035 and 85% greater in 2045 compared to the conservative scenario.

$PM_{2.5}$ emissions also decline in both ZEV scenarios compared to the reference case, see Figure 55. Again, transitioning out-of-state vehicles in addition to in-state vehicles leads to greater PM reductions. $PM_{2.5}$ emissions increases in both scenarios between 2035 and 2045 related to a 38% increase in VMT. Emissions remain lower compared to the reference case, 15% lower than the reference in 2045 for the conservative scenario and 35% lower for the optimistic scenario.

Figure 54. SoCAB Long Haul NOx Emissions Results for Years 2025, 2035, and 2045

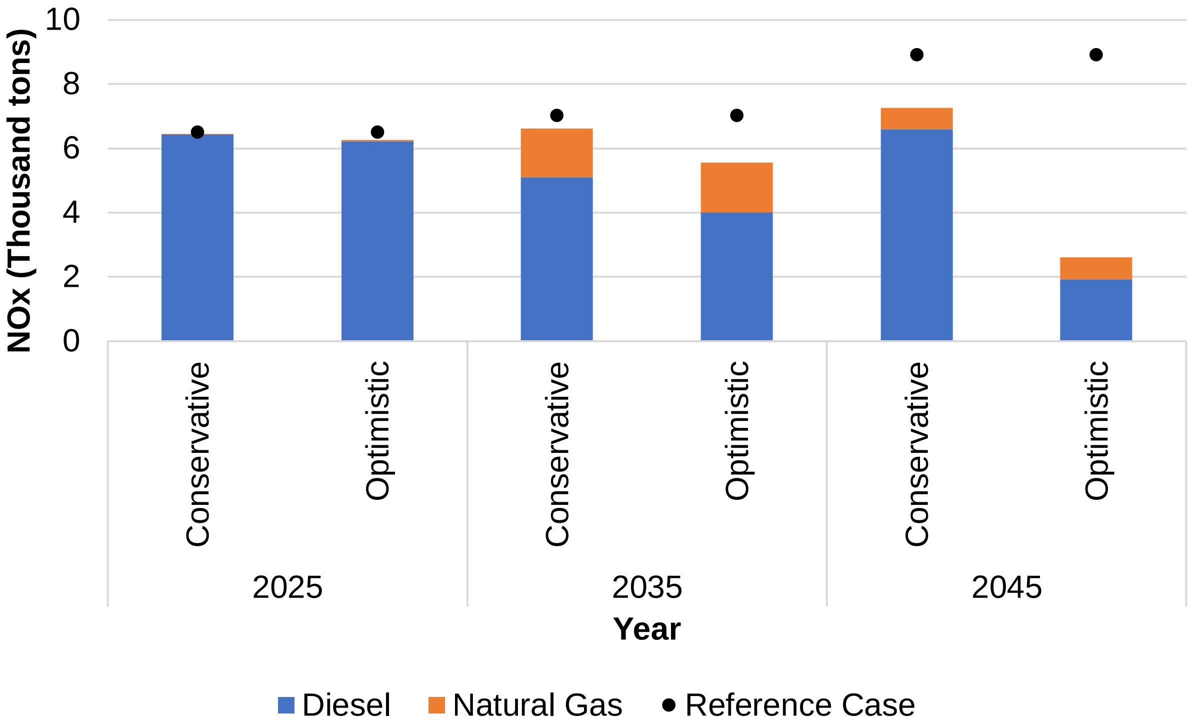
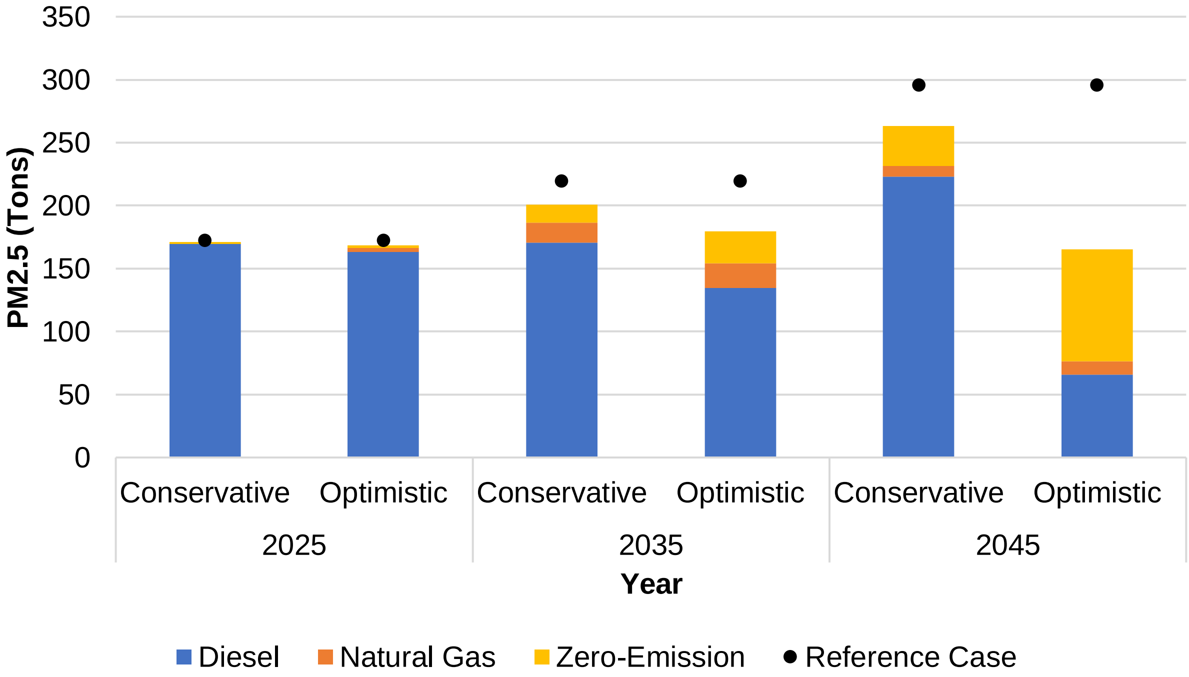


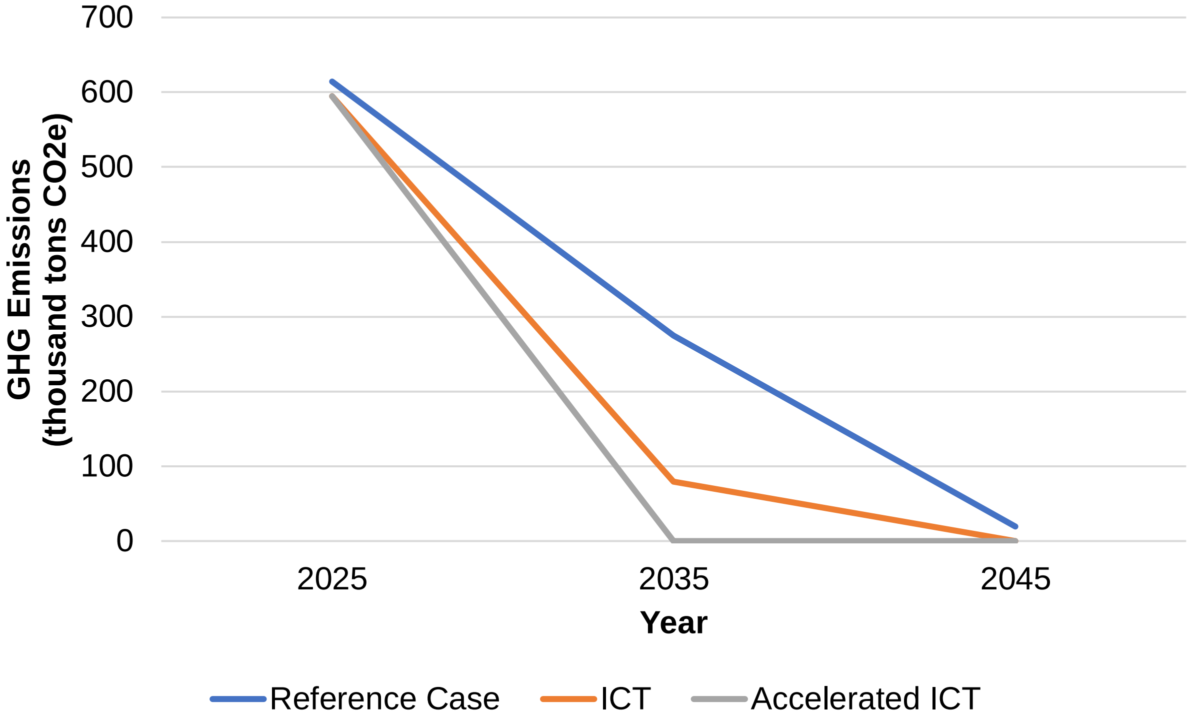
Figure 55. SoCAB Long Haul PM2.5 Emissions Results for Years 2025, 2035, and 2045



4.4.3 Transit

Transit GHG emissions decline for all scenarios including the reference case, see Figure 56. This decline reflects the strong Transit commitments already imbedded in the reference case. In 2035, accelerating the adoption of ZEV compared to the ICT scenario results in reducing GHG emissions by 79 thousand tons CO_2e.

Figure 56. SoCAB Transit GHG Emissions Results for Years 2025, 2035, and 2045



CAP emissions are lower compared to the reference for all scenarios. NOx emissions decrease to zero with 100% ZEB, see Figure 57. Accelerating the ICT to 100% ZEBs in 2035 reduces NOx by 6.2 tons for that year. $PM_{2.5}$ emissions decrease between 2025 and 2035 for both ZEV scenarios but increase again between 2035 and 2045 due to a 43% increase in VMT, see Figure 58. The two ZEV scenarios both assume 100% ZEBs in 2045 and therefore have the same emissions results for that year.

Figure 57. SoCAB Transit NOx Emissions Results for Years 2025, 2035, and 2045

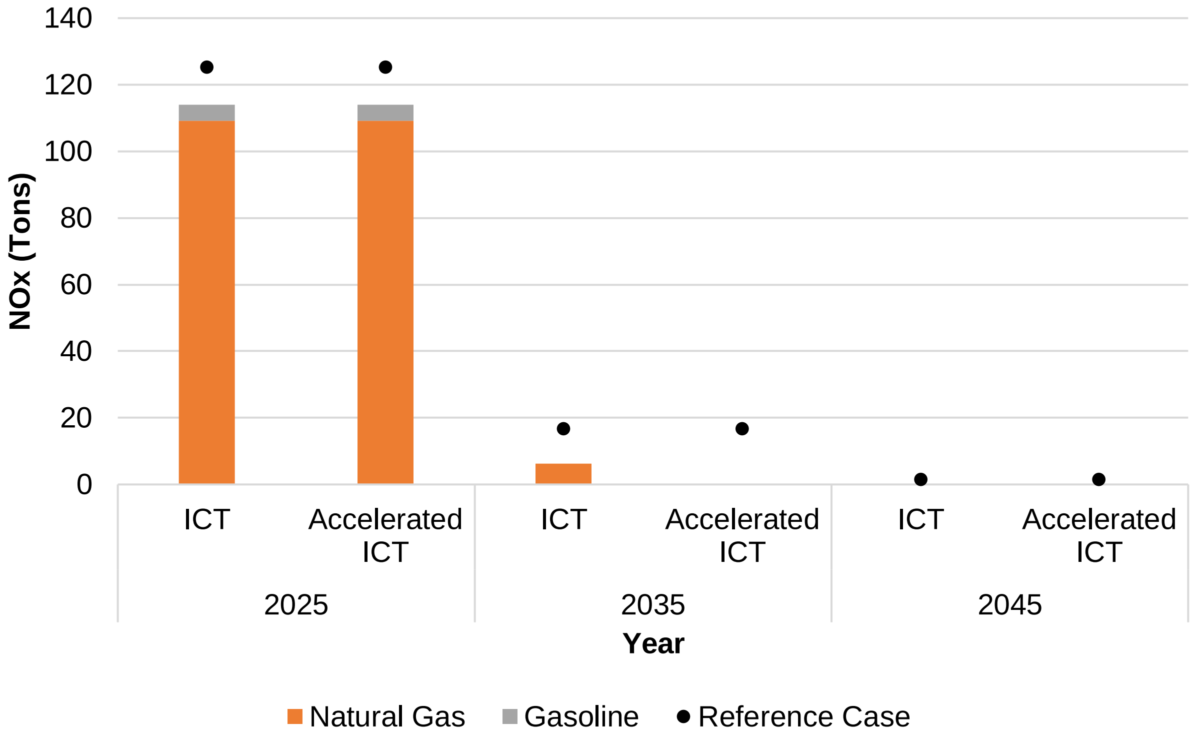
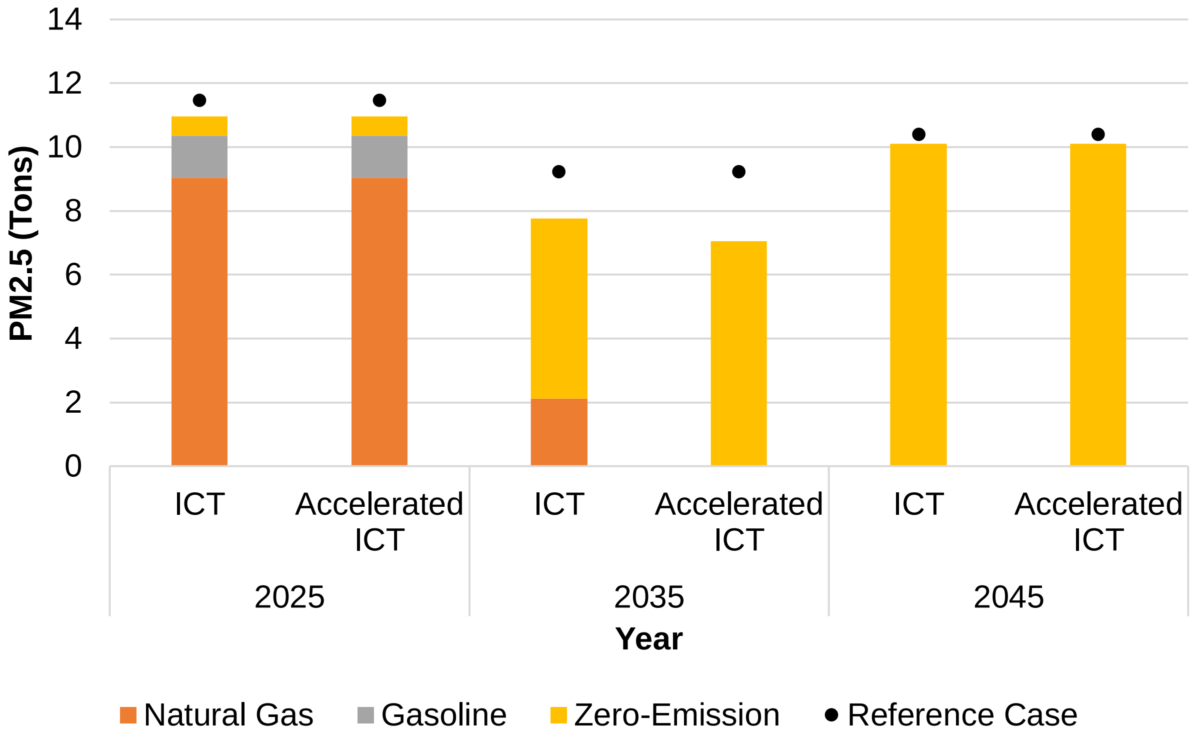


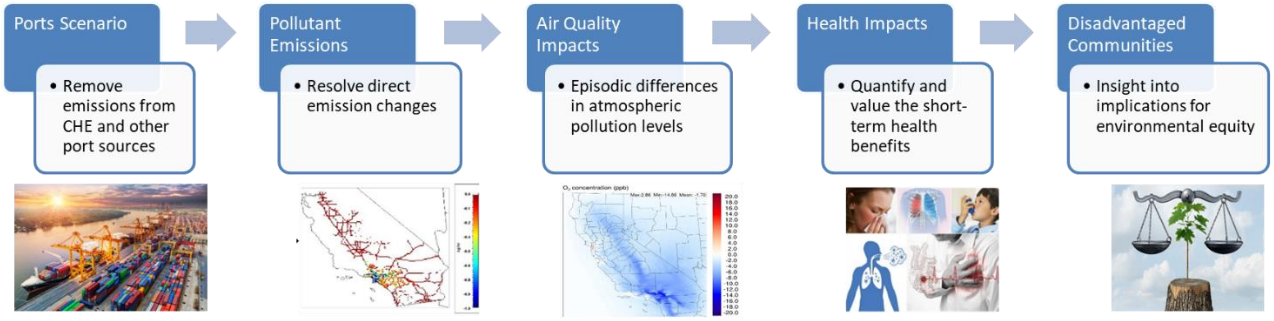
Figure 58. SoCAB Transit PM2.5 Emissions Results for Years 2025, 2035, and 2045



4.5 Regional Air Quality Impacts

This analysis leverages the air quality work in past work, including Forrest et al. (2023) and the 2022 Scoping Plan to assess the likely impact of adopting MD/HD-ZEVs in the SoCAB region. Both past works employed an integrated modeling approach to evaluate the effects of reducing emissions on air quality and public health, comparing it to a "Reference Case" representing the usual business-as-usual scenario, see Figure 59. The Reference Case serves to provide a relative understanding of the advantages that can be achieved by adopting ZEVs instead of taking no action.

Figure 59. Overview of the Air Quality and Public Health Assessment Approach

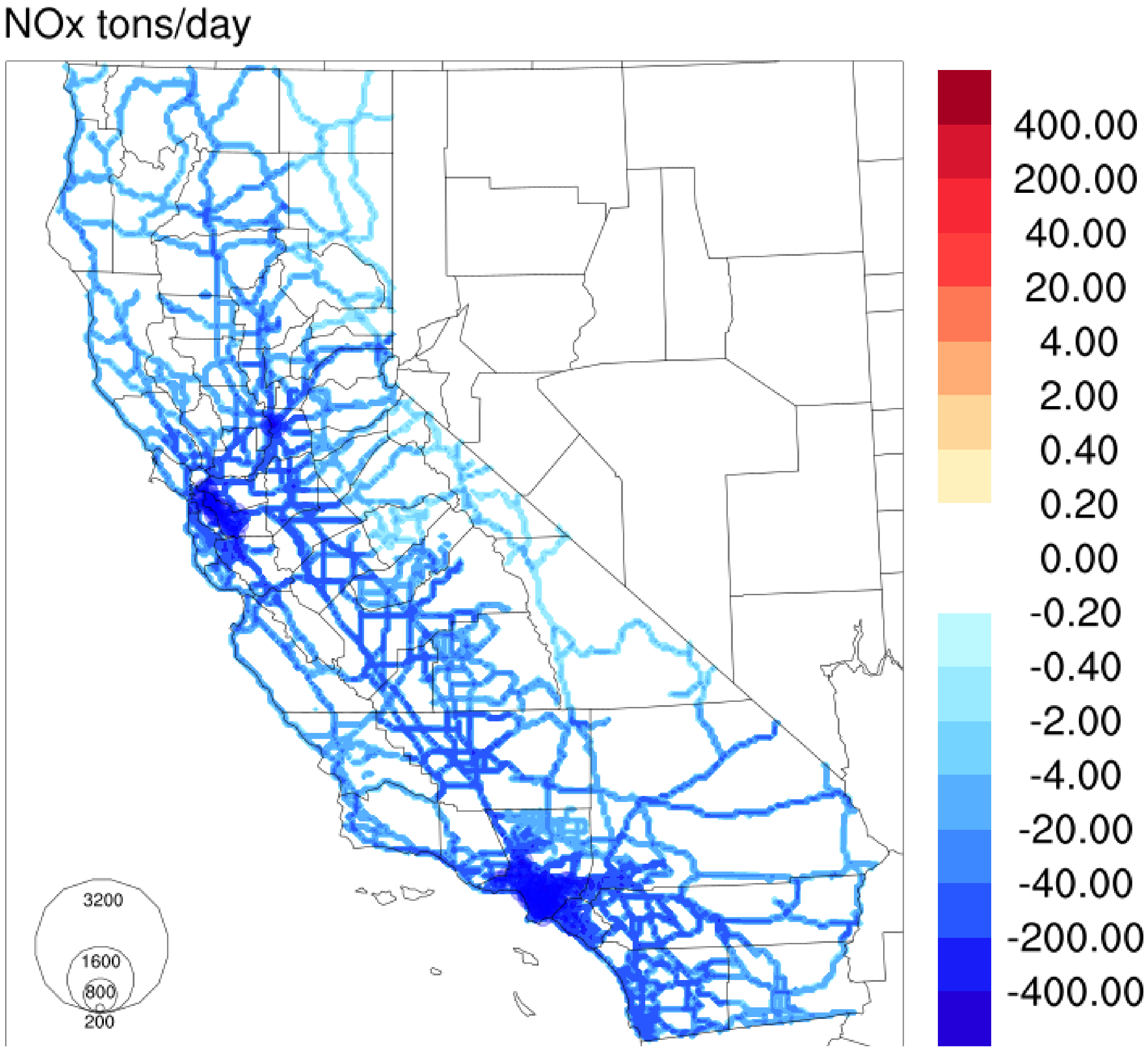


Credit: UCI APEP

To create the Reference Case, emissions of criteria pollutants were projected until 2035 using CARB's pollutant emissions inventory, starting from a detailed base year. The spatial and temporal distribution of emissions was determined using the Sparse Matrix Operator Kernels Emissions version 4.7 (SMOKE) model [86]. The next step involved translating changes in emissions into impacts on atmospheric pollution levels, specifically ground-level ozone and $PM_{2.5}$, using an advanced photochemical air quality model called the Community Multiscale Air Quality version 5.3.2 (CMAQ) model, which accounts for atmospheric chemistry and transport [87], [88]. It models both primary (emitted) and secondary (formed) pollutant species, including ground-level ozone and $PM_{2.5}$ [89]. This approach focused on evaluating the differences in ground-level ozone and PM2.5 between the Reference Case and the Scoping Plan’s zero-emission scenario. Changes in on-road vehicle emissions are modeled spatially along roadways, as shown in Figure 60.

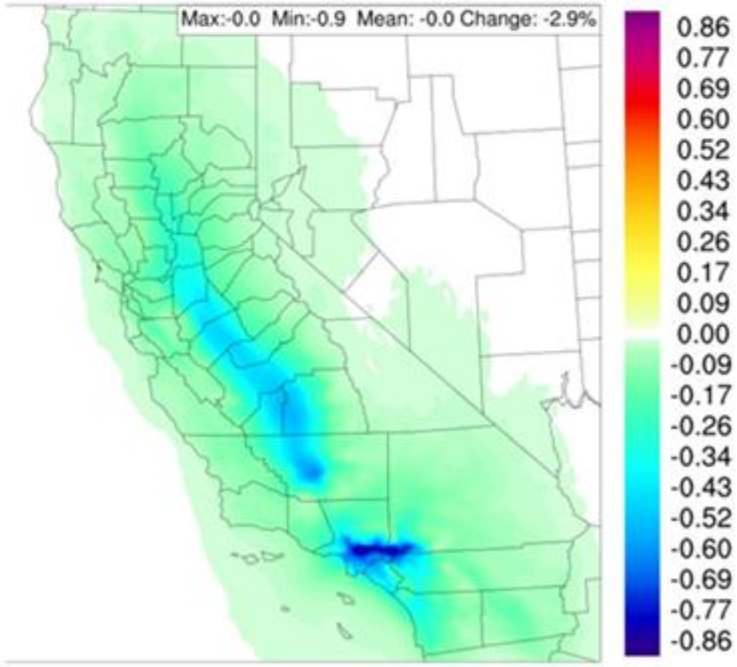
The statewide change in $PM_{2.5}$ concentrations under a carbon neutral transportation system in 2045 is presented in Figure 61. The illustrated scenario is less stringent than the MD/HD vocational scenarios explored in this current work, but it illustrates the potential air quality benefits of transitioning to ZEVs. Furthermore, the economywide change in CAP concentrations under the 2022 Scoping Plan scenario is shown in Figure 62. State level reduction in CAP emissions, including those from the transportation sector, lead to significant improvement in air quality, especially within the SoCAB region.

Figure 60. Example of NOx reductions from On-Road Vehicles



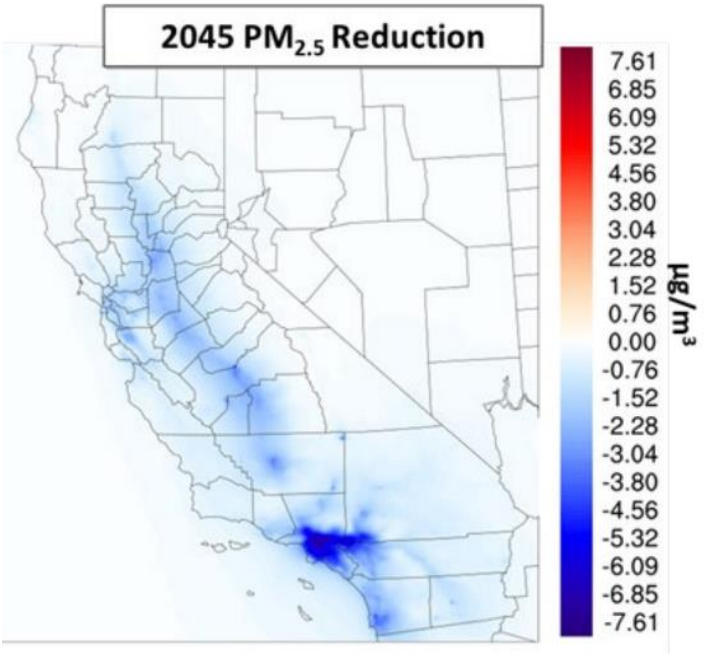
Source: UCI APEP

Figure 61. PM2.5 Concentration Change for the Adoption of Carbon Neutral Transportation Sector in 2045



Source: Forrest et al. (2023)

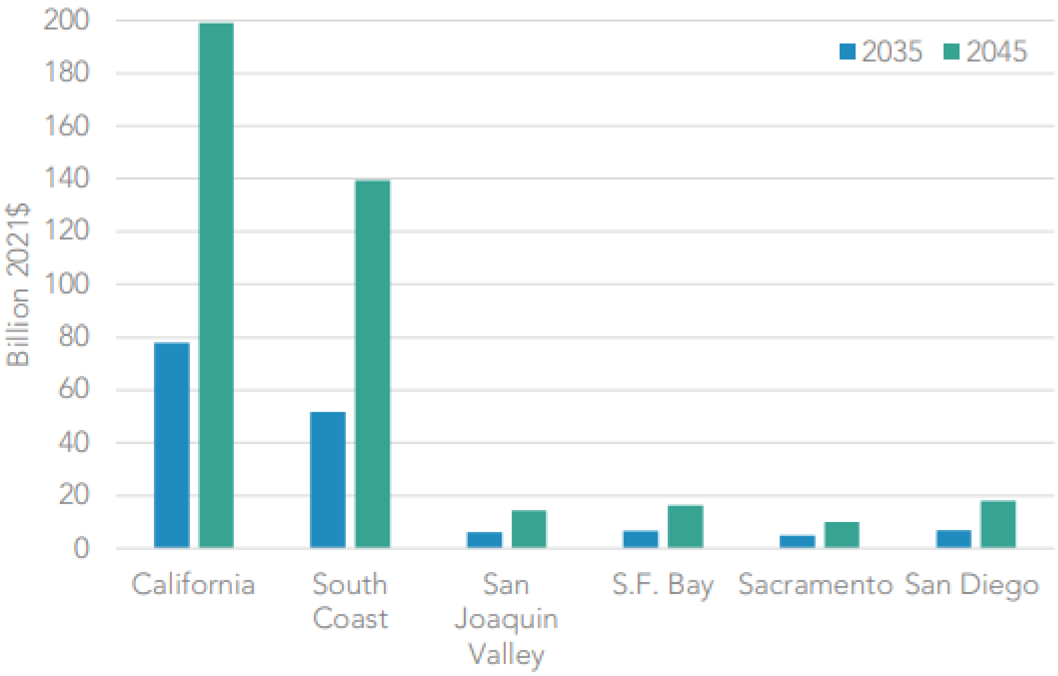
Figure 62. Change in PM2.5 Concentrations in 2045 for the 2022 Scoping Plan Scenario



Credit: CARB

The Scoping Plan conducted a health impact assessment based on changes in air quality through the Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP) [90]. BenMAP provides a quantitative estimate of the occurrence and value of avoided adverse health outcomes associated with air pollution. The Scoping Plan found that (1) significant health benefits of adopting the Scoping Plan, with the greatest benefit in terms of avoided costs anticipated in the SoCAB region (see Figure 63), and (2) DACs realize roughly 36% of health benefits in 2035 and in 2045 in terms of costs avoided.

Figure 63. Total Estimated Annual Health Benefits in the Scoping Plan Scenario



Credit: CARB

5 Workforce Requirements and Opportunities

Job growth related to ZEVs and their associated infrastructure is spurred in part by California's progressive ZEV mandates and overarching climate goals. Recent federal actions have propelled further expansion through updated policies, direct funding, and other research, development, and deployment initiatives.

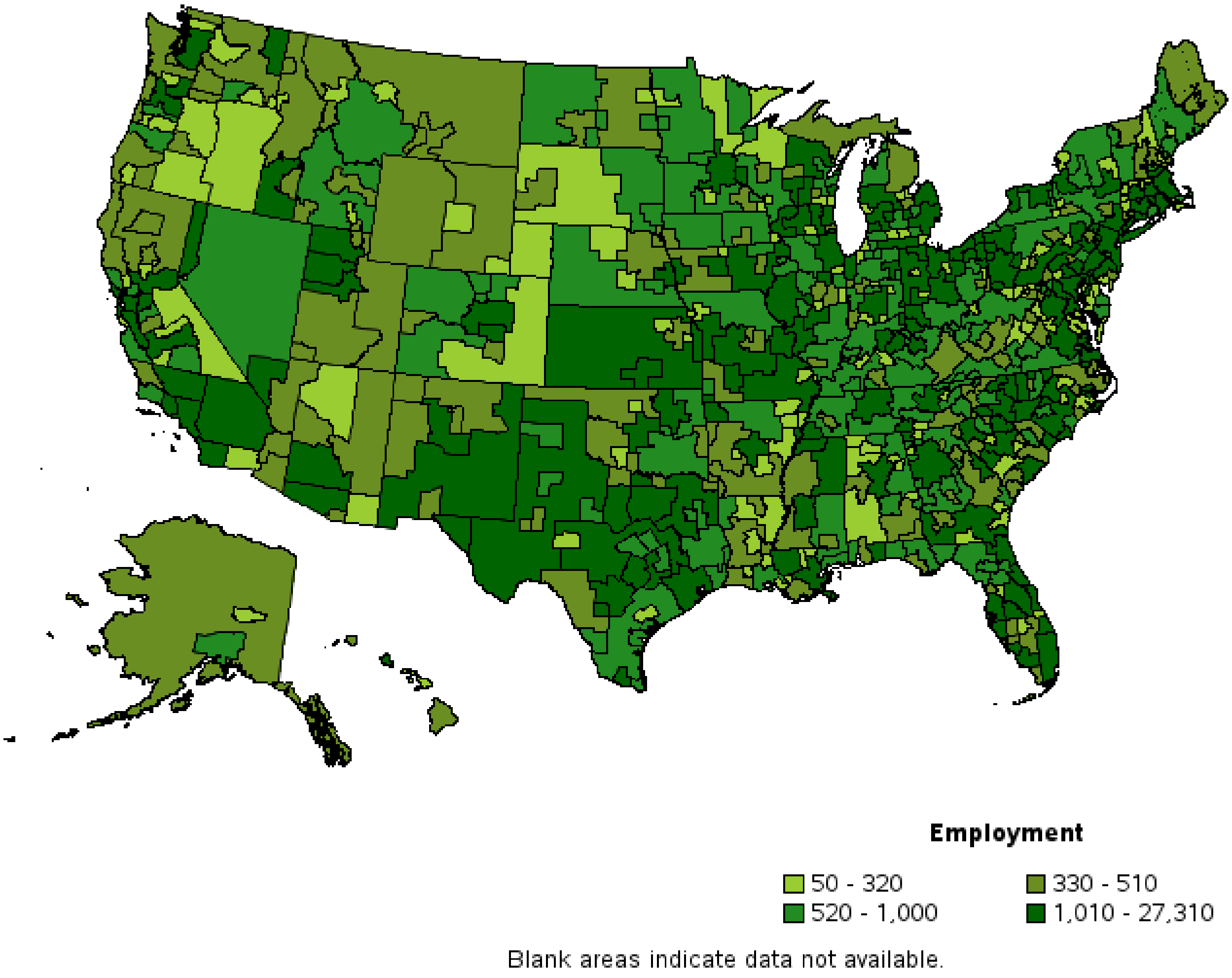
Numerous jobs are associated with the manufacturing, sale, and maintenance of ZEVs, in addition to the manufacturing, installation, operation, and maintenance of the related fueling infrastructure [91], Including:

- Research: material scientist, chemist, engineer (mechanical, electrical, chemical, etc.)
- Design and Development: regional planners, electrical power-line technicians, electricians, engineers
- Manufacturing: machinists, machine tool operators, assemblers, production managers
- Sales and Support: salespersons, customer service representatives
- Maintenance: automotive service technicians, mechanics, electric Infrastructure technicians, electricians

In the U.S., there are roughly 664,000 automotive technicians and mechanics, encompassing both conventional internal combustion engine (ICE) vehicles and clean vehicles [92]. According to the sixth annual Clean Jobs America report, in the U.S. there are approximately 273,630 jobs in the clean vehicles sector and 37,000 in clean fuels, 15% of which were in California [93]. Jobs in this sector span construction, manufacturing, and professional services. U.S. clean vehicle employment grew 14.6 percent annually between 2017 and 2020, averaged across jobs in hybrid, electric, and fuel cell vehicle categories [93].

Of particular focus is the availability of automotive technicians and mechanics who can service electric vehicles. Figure 64 presents the employment of automotive service technicians and mechanics across the U.S. as of mid-2022. California employs roughly 60,500 people in these positions [92]. Only a subset of these workers has been trained to service electric vehicles, which have new and different vehicle systems that need to be maintained. These systems include complex software systems and high voltage systems, such as the electric motor and battery management system. As the number of electric vehicles grows, so does the need for workers with EV-specific expertise.

Figure 64. Employment Automotive Service Technicians and Mechanics by Sub-Area, May 2022



Reproduced from U.S. Bureau of Labor Statistics. Occupational Employment and Wage Statistics. Automotive Service Technicians and Mechanics. https://www.bls.gov/oes/current/oes493023.htm#st

At the same time, transitioning to ZEVs by extension means phasing out ICE vehicles and the jobs associated with them. Thousands of workers, from auto mechanics to gas station attendants could be affected. One estimate forecasts that by 2040 nearly 32,000 diesel and gasoline mechanics would lose jobs [94]. However, many ICE vehicle and infrastructure workers have skills that can be utilized by the emerging clean vehicle market. To transition, additional training may be required for professionals who have previous work experience in related ICE vehicles or fueling infrastructure applications (e.g., mechanics and engineers).

Manufacturing jobs for ZEVs and infrastructure are anticipated to increase. The Build America Buy America Act, included in the 2021 Infrastructure Investment and Jobs Act, requires the use of domestically sourced materials and products for public infrastructure projects when available, in order to qualify for public funding [95]. Several vehicle OEMs have announced plans to expand investments in U.S. manufacturing facilities [96].

Job prospectives are challenging to predict also due to uncertainty around electric vehicle repair. Overall, electric vehicles require less maintenance than ICE vehicles. Also, repairs tend to require more technical expertise and may involve proprietary parts, systems, software, and tools. These complexities may impact the degree to which independent repair shops[9] can perform maintenance on electric vehicles versus dealerships. Currently, there are no laws at the federal or California state level requiring that vehicle OEMs make these systems available to independent repair shops.[10]

5.1 Education Credentials and Skill Requirements

Educational credentials and skill requirements for ZEV-related jobs vary by sub-sector. In research applications, such as chemists and engineers, workers require a bachelor's degree or higher from an accredited college or university. Similarly, for many positions in design and development. Technicians, mechanics, and machinists often require specialized training at a trade school or community college. Further training may be provided on the job with certifications preferred or required to operate certain equipment and/or offer more specialized services [91]. For example, at least one electrician who has completed the Electric Vehicle Infrastructure Training Program certification must be present when installing electric vehicle supply equipment [97]. Relevant certificates include those covering electrical fundamentals, electrical systems, energy systems, hydrogen energy, green hydrogen, hydrogen safety, and electric vehicle powertrains.

California has a vast network of colleges and universities that provide higher educational instruction and research that are relevant to ZEVs and infrastructure. The University of California consists of 10 university campuses located throughout the State, and the California State University System has 23 campuses. The California Community College System is comprised of 116 colleges. There are also approximately 85 private universities and colleges in California.

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[9] Note: California's Bureau of Automotive Repair regulates automotive repair. Repair technicians, dealers, and Smog Check stations all require licenses to operate in the state. https://www.bar.ca.gov/laws-and-regulations

[10] In 2012, Massachusetts passed the "Right to Repair" law that guarantees the right to take one's vehicle to the repair shop of their choice. There is a push to enact similar laws across states and at the federal level. https://www.autocare.org/government-relations/current-issues/right-to-repair

Within the spheres of research, design and development, manufacturing, sales and support, and maintenance, numerous degrees are applicable to ZEV and infrastructure deployment. Common technical degree programs include engineering (electrical, mechanical, chemical, environmental, civil), computer science, materials science, chemistry, and physics. For trade positions, mechanic or technician certifications may be required in lieu of a four-year degree. For sales and support positions, marketing, accounting, and business degree programs are most relevant.

Several special partnerships and collaborations have been established across colleges, universities, and high schools to advance alternative fuel vehicles and automotive education. One such the Advanced Transportation and Logistics (ATL) initiative [98]. A collaboration between the California Community Colleges and high schools within disadvantaged communities, ATL focuses on developing the workforce through targeted automotive programs at local high schools. These programs include as listed:

- Electric, Hybrid, and Hydrogen Fuel Cell Programs
- Gaseous Fuel Programs for Heavy Duty Vehicles
- Gaseous Fuel Programs for Light Duty Vehicles
- Intelligent Transportation Systems Programs
- Railroad Operation Programs
- Aeronautics and Flight Technology Programs
- Motorcycle Maintenance Programs
- Automotive Clean Air Car, Emissions Programs
- Photo Voltaic, Concentrated Solar, Geothermal, and Wind Technology Renewable Energy Programs

5.2 Curriculum Development

For this project, UCI APEP is collaborating with Saddleback Community College in the development of curriculum to train a growing workforce in alternative fuel vehicles and infrastructure. Saddleback College is a regional leader in developing and promoting workforce development in emerging industry sectors through the Los Angeles and Orange County Regional Consortium of community colleges, and specifically responsible for automobile technology. Saddleback Community College currently offers an Alternative Fuel Vehicle Technician Certification and is planning to expand course offerings to include electronics repair, advanced driver assistance systems (ADAS) repair, and fuel cell vehicle technologies. Saddleback Community College is also coordinating with the broader Orange County community college community regarding automotive courses.

Saddleback has three core degree and certificate routes: associate of science, certificate of achievement, and stackable certificate. The Associate of Science (A.S.) and Certificate of Achievement both require the same core courses, but the associate degree also requires the completion of General Education courses. Five A.S. specialist/technician tracks are offered:

- Alternative Fuel Vehicle Specialist
- Automotive Chassis Specialist
- Automotive Engine Performance Specialist
- Automotive Engine Service Specialist
- General Automotive Technician

Most relevant to this work is the Alternative Fuel Vehicle Specialist track. All core classes as listed in Table 15 and at least one elective course is required.

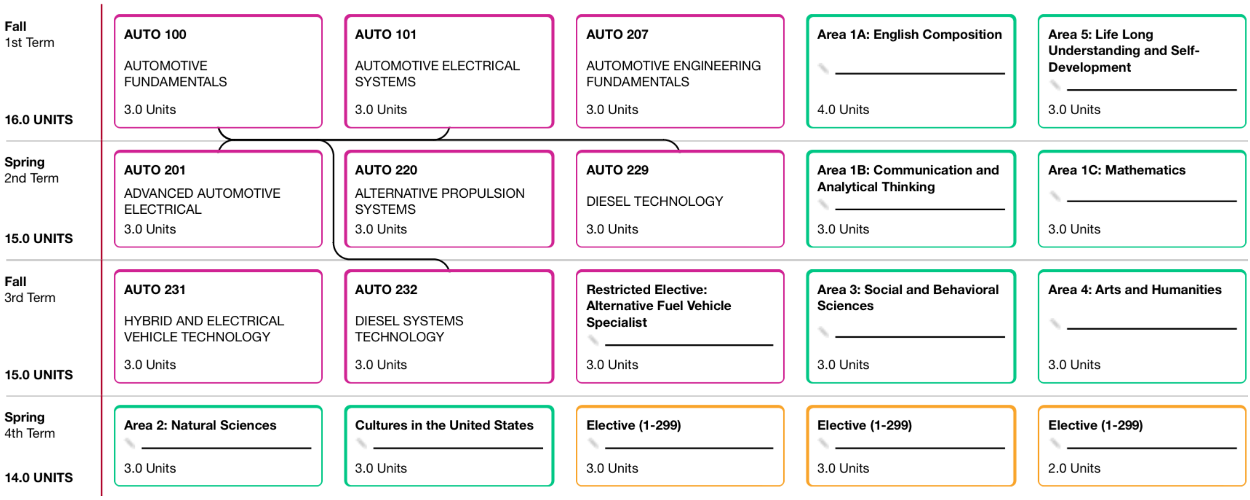
Table 15. Alternative Fuel Vehicle Specialist Course List

Required Core	**Electives**
Automotive Fundamentals	Automotive Engine Performance Electronics and Ignition
Automotive Electrical Systems	Automotive Engine Performance-Fuel and Emission Systems
Advanced Automotive Electrical	Automotive Powertrain
Automotive Engineering Fundamentals	Automotive Suspension and Alignment
Alternative Propulsion Systems	Automotive Brake Systems
Diesel Technology	Automatic Transmission
Hybrid and Electrical Vehicle Technology	Automotive Air Conditioning
Diesel Systems Technology	Advanced Engine Performance Diagnosis
	Automotive Service Consultant
	Automotive Service Management
	Co-OP ED-Auto (Cooperative Work Experience)

Stackable certificates are achieved when students complete a specified subset of courses listed above, which can then serve as a standalone certificate or a stackable unit for a broader Certificate of Achievement. Example stackable certificates include automotive engine diagnostics technician, automotive technician fundamentals, automotive electric vehicle technician, and automotive chassis systems.

Courses are offered in the Fall and Spring semesters, such that a student can complete a Certificate of Achievement or A.S. degree within two years, if studying full-time. A sample schedule based on course availability in 2022 is presented in Figure 65.

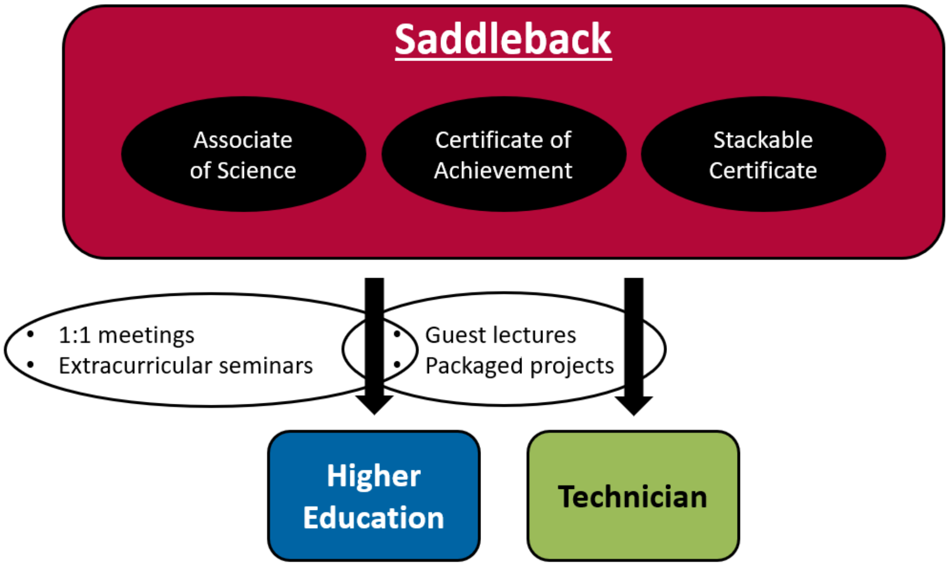
Figure 65. Sample Course Schedule for Automotive Technology A.S. Degree at Saddleback College



Fall 1st Term **16.0 UNITS**	**AUTO 100** AUTOMOTIVE FUNDAMENTALS 3.0 Units	**AUTO 101** AUTOMOTIVE ELECTRICAL SYSTEMS 3.0 Units	**AUTO 207** AUTOMOTIVE ENGINEERING FUNDAMENTALS 3.0 Units	**Area 1A: English Composition** 4.0 Units	**Area 5: Life Long Understanding and Self-Development** 3.0 Units
Spring 2nd Term **15.0 UNITS**	**AUTO 201** ADVANCED AUTOMOTIVE ELECTRICAL 3.0 Units	**AUTO 220** ALTERNATIVE PROPULSION SYSTEMS 3.0 Units	**AUTO 229** DIESEL TECHNOLOGY 3.0 Units	**Area 1B: Communication and Analytical Thinking** 3.0 Units	**Area 1C: Mathematics** 3.0 Units
Fall 3rd Term **15.0 UNITS**	**AUTO 231** HYBRID AND ELECTRICAL VEHICLE TECHNOLOGY 3.0 Units	**AUTO 232** DIESEL SYSTEMS TECHNOLOGY 3.0 Units	**Restricted Elective: Alternative Fuel Vehicle Specialist** 3.0 Units	**Area 3: Social and Behavioral Sciences** 3.0 Units	**Area 4: Arts and Humanities** 3.0 Units
Spring 4th Term **14.0 UNITS**	**Area 2: Natural Sciences** 3.0 Units	**Cultures in the United States** 3.0 Units	**Elective (1-299)** 3.0 Units	**Elective (1-299)** 3.0 Units	**Elective (1-299)** 2.0 Units

In support of the current project, the following collaboration framework has been developed, see Figure 66. To support current courses, UCI APEP has committed to providing guest lectures on on-going research on the topics of ZEVs and infrastructure. Second, it is working with Saddleback to develop small, packaged research projects that can be used within courses to teach advanced topics, such as automated and connected vehicles and managed charging strategies. Next, UCI APEP is planning on providing additional support and guidance for students who are interested in transferring to four-year degree programs and pursuing engineering by providing one-on-one meetings with students and providing community college students the opportunity to attend off-campus events such as seminars and tours hosted at UC Irvine.

Figure 66. UCI APEP and Saddleback Collaboration Framework



The last two semesters (Fall 2022 and Spring 2023), UCI APEP provided guest lectures in two of Saddleback's automotive courses: AUTO 207 - Automotive Engineering Fundamentals and AUTO 220 - Alternative Propulsion Systems. The guest lectures covered UCI APEP's current research on ZEV infrastructure deployment related to this project, in addition to other, related research topics relevant to the courses.

UCI APEP is also serving in an advisory role in the development of future resources at the Advanced Technology and Education Park (ATEP) in Tustin, CA. Construction for Saddleback @ ATEP broke ground on March 1, 2023. The future compound will house its Advanced Automotive program with four classrooms as well as laboratory facilities, including an automotive technology high bay laboratory.

UCI APEP continues to work with Saddleback to identify additional collaboration opportunities, including future coursework development, guest lectures, and hands-on research options. Critical topic areas for coursework expansion include hydrogen fuel cell electric vehicle technologies and ZEV infrastructure. This collaboration includes exploring future grants to fund expanding ZEV and infrastructure curriculum throughout the Orange County and Los Angeles Community colleges.

6 Summary and Recommendations

With increased zero-emission vehicle adoption, all vocations show a reduction in GHG and CAP emissions. CAP emissions fall to zero levels with 100% zero-emission vehicle adoption except for PM which is emitted due to brake and tire wear. For the scenarios examined, all vocations require both charging and hydrogen fueling infrastructure to support zero-emission vehicle deployment. The following are findings from this study:

- **Multiple zero-emission infrastructure options are available to meet MD/HD fleet requirements.**
  Based on the literature and background review, several infrastructure options are available today that can support ZEV deployment. MD/HD BEV charging stations and 350 bar HDV hydrogen stations are relatively mature, whereas MD/HD hydrogen refueling stations for trucks (700 bar) are closer to the early commercial phase.

- **Technologies currently being developed will serve a major role in facilitating widescale deployment of MD/HD ZEVs.**
  Megawatt charging and high flow hydrogen refueling are currently in development with standardized commercial product timelines between two and five years. It is possible that proprietary solutions may become available sooner.

- **Meeting zero-emission MD/HD vehicle targets by 2045 is critical to achieve GHG and CAP emissions reduction goals.**
  MD/HD vehicles contribute disproportionately to GHG and CAP emissions in the SoCAB region compared to their population size, making up roughly 15% of transportation GHG emissions, over 50% of transportation NOx emissions, and over 30% of $PM_{2.5}$ emissions. ZEVs provide an opportunity to significantly reduce these emissions, with 100% ZEV adoption eliminating tailpipe emissions of GHGs, NOx, SOx, and CO. $PM_{2.5}$ and PM_{10} remain emitted due to brake and tire wear, but at lower levels due to regenerative braking.

- **Supporting MD/HD ZEV deployment will require significant investment in MD/HD charging and hydrogen fueling networks.**
  This analysis projected at least 127 public hydrogen refueling stations are needed with the SoCAB region to support drayage and long haul trucks in 2045. Full buildout of this network could cost roughly 1.8 billion dollars, depending on how station costs evolve in the future. Supporting the BEV fraction of drayage and long haul trucks will require about 7.5 to 17 thousand chargers, depending on BEV adoption and the ratio of chargers to vehicles. The estimated cost for the chargers, excluding grid upgrade and installation costs, range between $1.5 to $3.4 billion.

- **The number of charging and hydrogen stations to support MD/HD ZEVs is dependent on adoption rates and preference between ZEV types, assumed station capacity, station siting, and network resiliency/redundancy measures.**

  The ratio of BEVs to FCEVs is expected to vary by vehicle vocation as well as over time related to economic and operational variables. It is likely that MD/HD fleets will rely on DC fast charging (150 kW+) and larger capacity hydrogen fueling station (4,000 kg+) solutions.

- **Fleets transitioning to ZEVs should incorporate resiliency in overall infrastructure planning.**

  Charging and hydrogen stations are not immune to issues causing station downtime with several approaches available to increase system resiliency. For example, deploying back-up or "redundant" stations can provide network resiliency in the case of station downtime. Creating and executing a microgrid in parallel with charging and hydrogen fueling infrastructure can establish the capability to maintain uninterrupted operations during power outages.

- **Air quality improvements with zero-emission technology adoption can lead to significant health benefits.**

  As demonstrated in past analyses, including the 2022 Scoping Plan, adopting ZEVs results in significant improvements to air quality which in turn provide significant health benefits. Implementing the Scoping Plan could result in almost $140 billion in health benefits, 36% of those benefits realized within DACs.

- **Accelerating adoption of ZEVs can provide additional climate, air quality, and human health benefits.**

  Current State mandates dictate rapid adoption of ZEVs. Adopting ZEVs at a faster rate above these mandates can lead to additional benefits but the feasibility of earlier adoption is limited by numerous factors including technology maturity, cost, fleet vehicle turnover, infrastructure construction timelines, and vehicle purchase timelines.

- **Coordinated planning can help optimize the placement of public stations to support MD/HD vehicle hydrogen demand.**

  Public stations placed in MD/HD demand hotspots can maximize utilization across fleets. Fleet-restricted and/or uncoordinated station planning can result in overbuilding of an underutilized network. Coordinated planning can provide more cost-effective deployment, especially in the early and mid-term hydrogen markets.

- **More work is needed to determine the long-term benefits and trade-offs of placing ZEV infrastructure in disadvantaged communities.**

> Ideally, the buildout of ZEV infrastructure within disadvantaged communities will displace diesel traffic within these communities, reduce local CAP emissions, and retain economic and workforce opportunities locally. However, these benefits may be offset maybe an increase in local truck traffic, which can increase traffic congestion, contribute to noise pollution, and increase safety concerns.

In conclusion, while transitioning to ZEVs offers significant environmental and health benefits, careful planning and investment in charging and hydrogen fueling infrastructure are required to support and accelerate the deployment of MD/HD ZEVs.

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Appendix A.
2022 Scoping Plan Vehicle Projections

Figure A-1. Light-Duty Vehicle Stock as Projected by the 2022 Scoping Plan

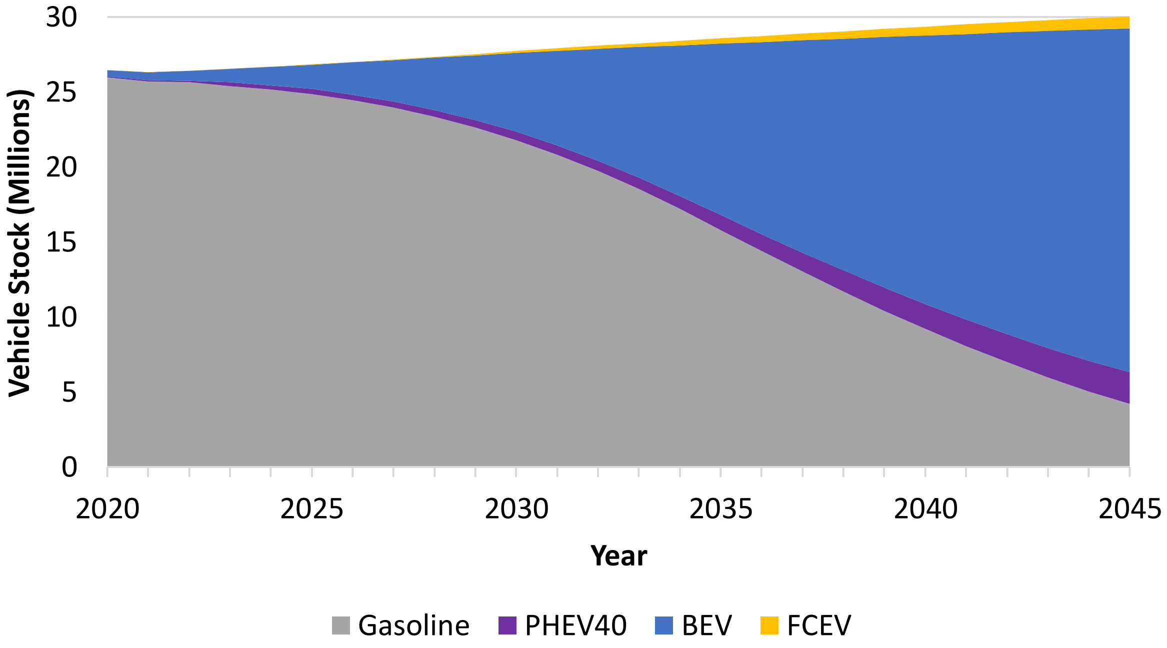


Figure A-2. Medium-Duty Vehicle Stock as Projected by the 2022 Scoping Plan

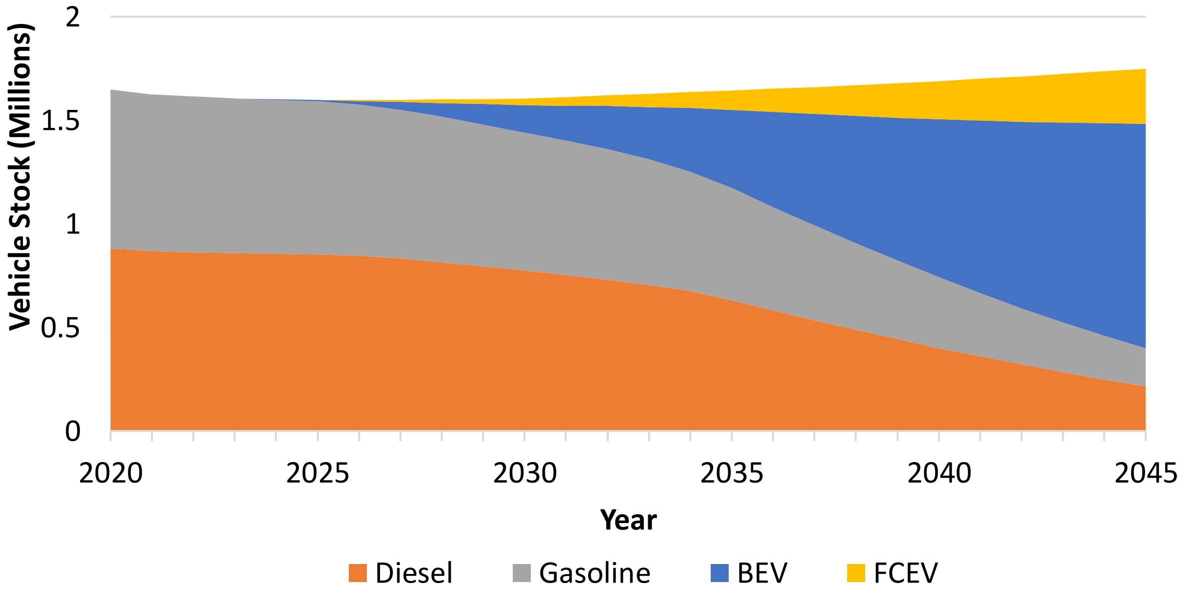


Figure A-3. Heavy-Duty Vehicle Stock as Projected by the 2022 Scoping Plan

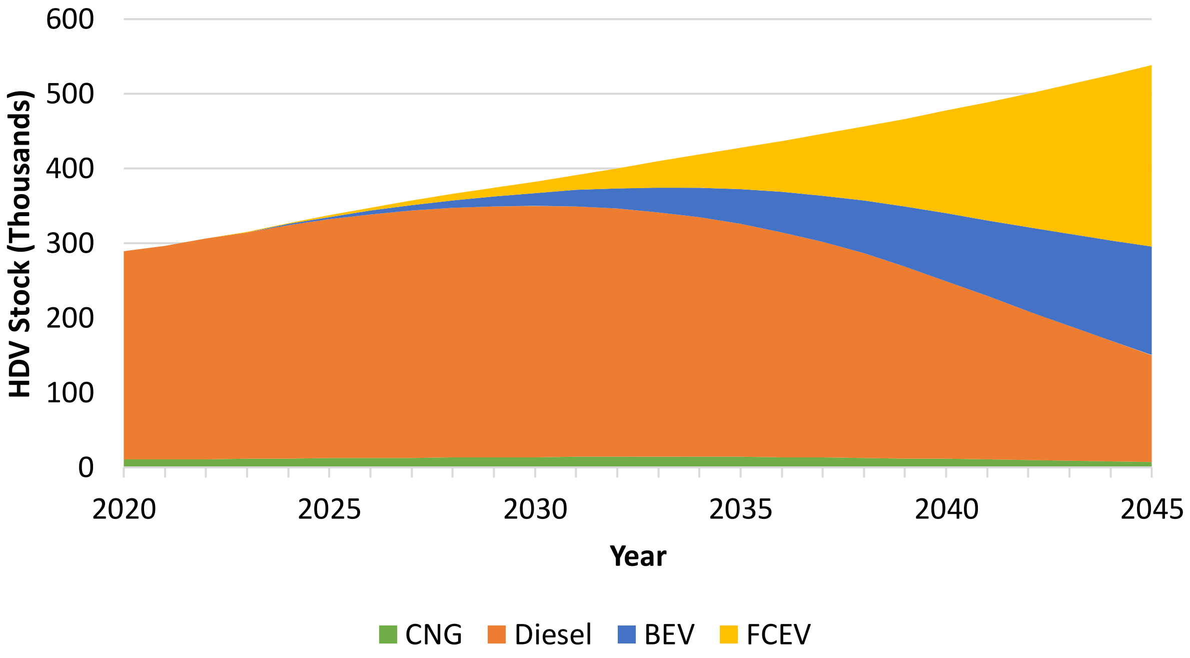
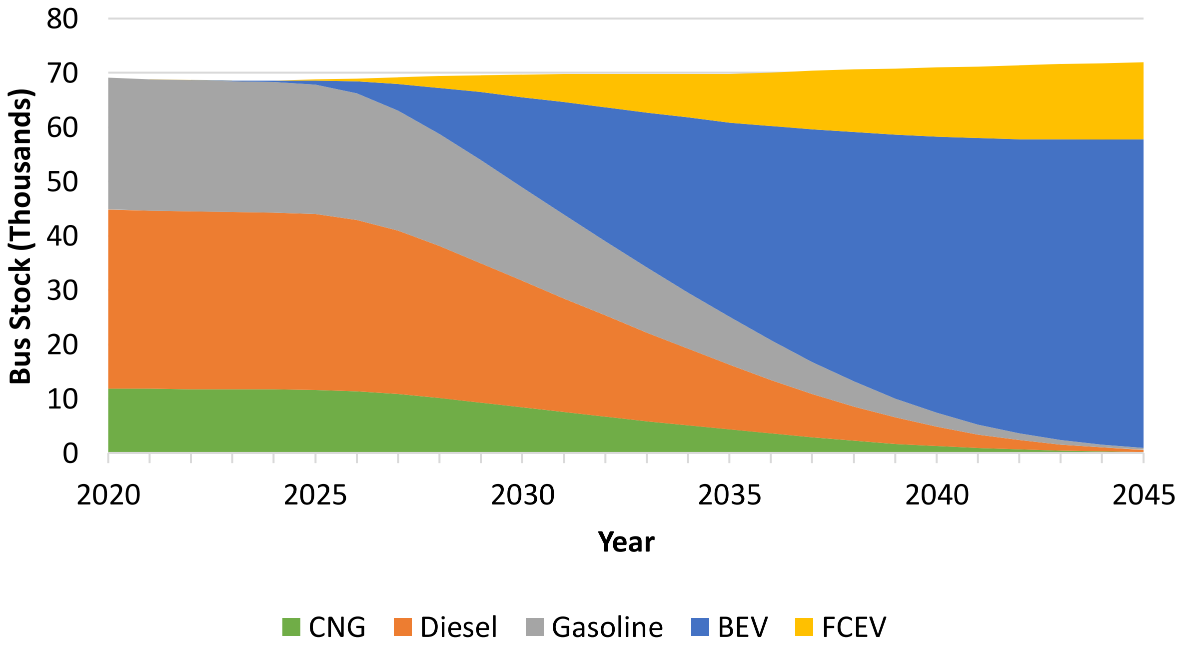


Figure A-4. Bus Stock as Projected by the 2022 Scoping Plan



Appendix B.
SoCAB Transit Agency List for Zero-Emission Bus Rollout

Table B-1. Transit Agency Zero-Emission Bus Rollout for the Year 2035

Transit Agency	% of Fleet Zero-Emission by 2035	Fleet Total Bus Count	ZEB Total in 2025	ZEB Total in 2035	Battery Electric Bus (2035)	Fuel Cell Electric Bus (2035)	CNG (2035)	Diesel (2035)
Antelope Valley Transit Authority	100%	57	57	57	57	0	0	0
City of LA DOT	100%	492	395	492	492	0	0	0
Culver CityBus	100%	54	6	54	54	0	0	0
Foothill Transit	100%	353	148	353	320/TBD	at least 33	0	0
GTrans (Gardena MBL)	100%	52	At least 2	52	52	0	0	0
Glendale Beeline	34%	80	0	27	27	0	53	0
Glendora	100%	4	4	4	TBD	TBD	0	0
LA Metro	100%	2194	300	2194	2194 (est.)	TBD	0	0
Long Beach Transit	100%	225	165	225	100	125	0	0
Montebello Bus	71%	66	8	47	0	47	19	0
Orange County TA	56%	470	20	263	20	243	207	0
Santa Clarita Transit	11%	289	10	31	13	18	244	10
Santa Monica Bus	100%	195	109	195	at least 19	TBD	0	0
Omnitrans	63%	186	12	117	at least 29	TBD	TBD	0
Riverside TA	43%	339	5	145		145	194	0
Pasadena	57-100%	44	2-9	at least 25	TBD	TBD	TBD	0

Appendix C.
Transit Agencies Proposed Stations

Table C-1. Planned Transit Agency ZEV Infrastructure

Agency	Zip Code	Infrastructure Type	Capacity (Bus)	Est. Year	In DAC?
OCTA	92806	hydrogen	150	2030	YES
OCTA	92843	hydrogen	150	2021	YES
OCTA	92843	battery	TBD	2021	YES
OCTA	92618	hydrogen	125	2030	YES
OCTA	92606	battery	250	2024	NO
OCTA	92704	hydrogen	245	2030	YES
LA DOT	90021	battery	150	2025	YES
LA DOT	90012	battery	82	2027	YES
LA DOT	91342	battery	94	2024	YES
LA DOT	90059	battery	130	2022	YES
Foothill	91006	battery	180	2030	NO
Foothill	91766	battery	140	2031	YES
Foothill	91766	hydrogen	TBD	2023	YES
LA Metro	90021	battery	189	2029	YES
LA Metro	90021	battery	172	2027	YES
LA Metro	90065	battery	177	2029	YES
LA Metro	90062	battery	193	2029	YES
LA Metro	90069	battery	233	2030	NO
LA Metro	91311	battery	202	2024	YES
LA Metro	91731	battery	223	2026	YES
LA Metro	90012	battery	163	2026	YES
LA Metro	91352	battery	241	2025	YES
LA Metro	90248	battery	252	2026	YES

Long Beach	90813	battery	141	2034	YES
Long Beach	90805	hydrogen	141	2025	YES
Montebello	90640	hydrogen	70	2040	YES
Santa Clarita	91355	battery	TBD	TBD	NO
Santa Clarita	91355	hydrogen	60	2020	NO
Santa Monica	90401	Undetermined ZEB	195	2020	YES
OMNITRANS	91763	battery	74	2021	YES
OMNITRANS	92411	battery	120	2021	YES
Riverside	92507	hydrogen	112	2026	YES
Riverside	92545	hydrogen	33	2024	NO
Culver CityBus	90232	battery	56	2022	NO
Glendale	91204	battery	TBD	TBD	YES
Pasadena	91107	Undetermined ZEB	44	TBD	NO
Glendora	91741	battery	4	TBD	NO

Appendix D.
Utility Approved EVSE Vendors

Table D-1. SCE and SDGE Approved Vendors

Supplier	EVSE Charging Rate			
	< 19.2 kW	19.3 – 50 kW	50 – 150 kW	>150 kW
ABB	✓	✓	✓	✓
Advanced Charging Technologies	X	X		
Blink	✓	✓		
BTCPower	✓	✓	✓	✓
BYD Coach & Bus	X			
Charge America				✓
ChargePoint	✓	✓		
Clipper Creek	✓			
Cyber Switching	✓			
Delta	✓	✓	✓	✓
EcoTec	X			
EFACEC	✓	✓		✓
Electrify America				✓
Enatel	X	X		
Enel X	✓			
Enersys	X	X		
EverCharge	✓			
EV Passport	✓			
EVRange	✓			
Freewire Technologies			✓	
Heliox				✓
InCharge		✓	✓	✓
ioTecha	✓			
JuiceBox	✓			
KIGT Inc.	✓			
Konnectronix	✓			
Loop	✓			
Noodoe	✓			✓
Nuuve	✓			
Phihong	✓	✓	✓	✓
Power Designers Sibex	X	X		
Power Electronics				✓
PowerFlex	✓			
Proterra			✓	
Rhombus			✓	
SemaConnect	✓			
Siemens	✓	✓		✓
Signet HP				✓
Stryten	X	X		
Tellus Power		✓	✓	✓
Tritium		✓	✓	✓
TurnOnGreen		✓		
Wallbox	✓			
Webasto	✓			

✓ = rebate eligible, X = not rebate eligible, black = SCE, yellow = SDGE, green = SCE & SDGE

Appendix E.

SoCAB Additional Criteria Pollutant Scenario Results

Figure E-1. SoCAB Drayage PM10 Emissions Results for Years 2025, 2035, and 2045

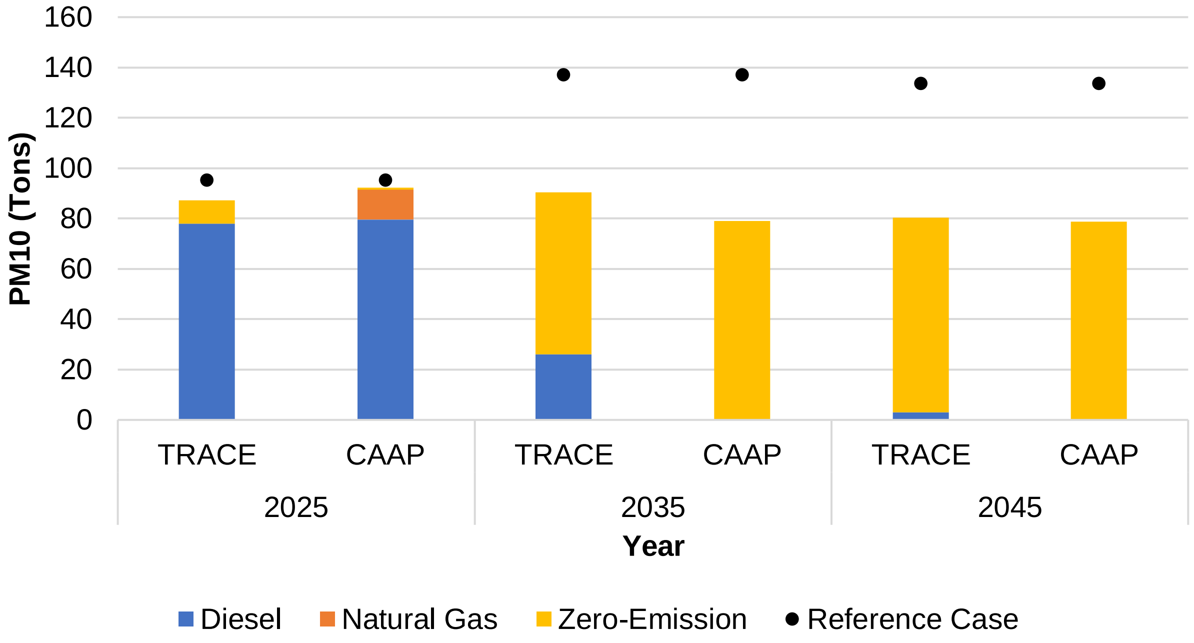


Figure E-2. SoCAB Drayage CO Emissions Results for Years 2025, 2035, and 2045

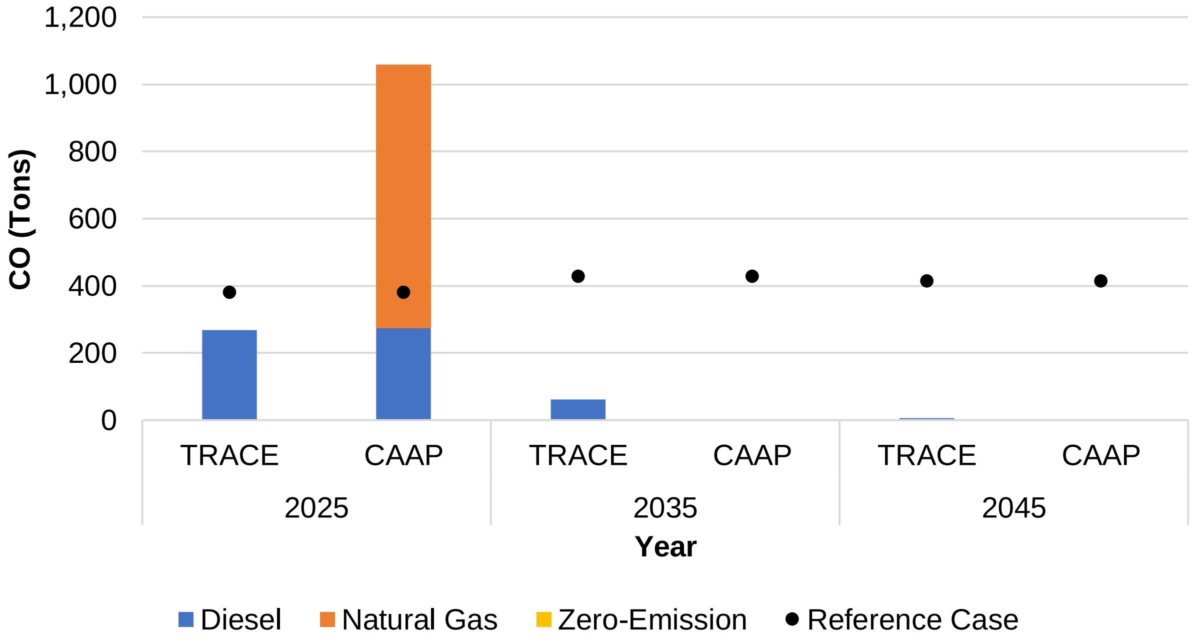


Figure E-3. SoCAB Drayage SOx Emissions Results for Years 2025, 2035, and 2045

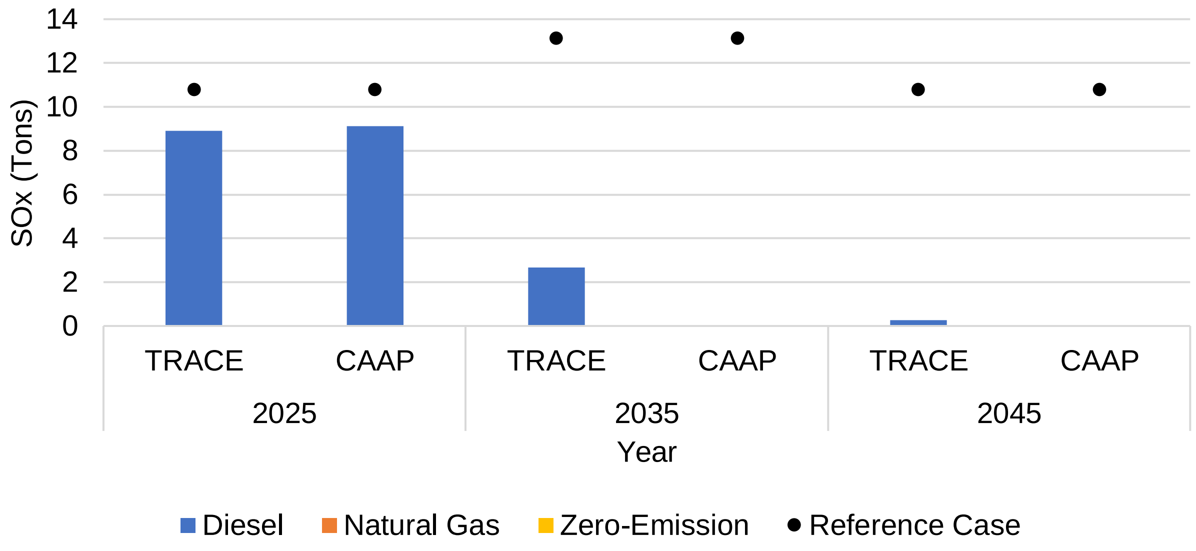


Figure E- 4. SoCAB Long Haul PM10 Emissions Results for Years 2025, 2035, and 2045

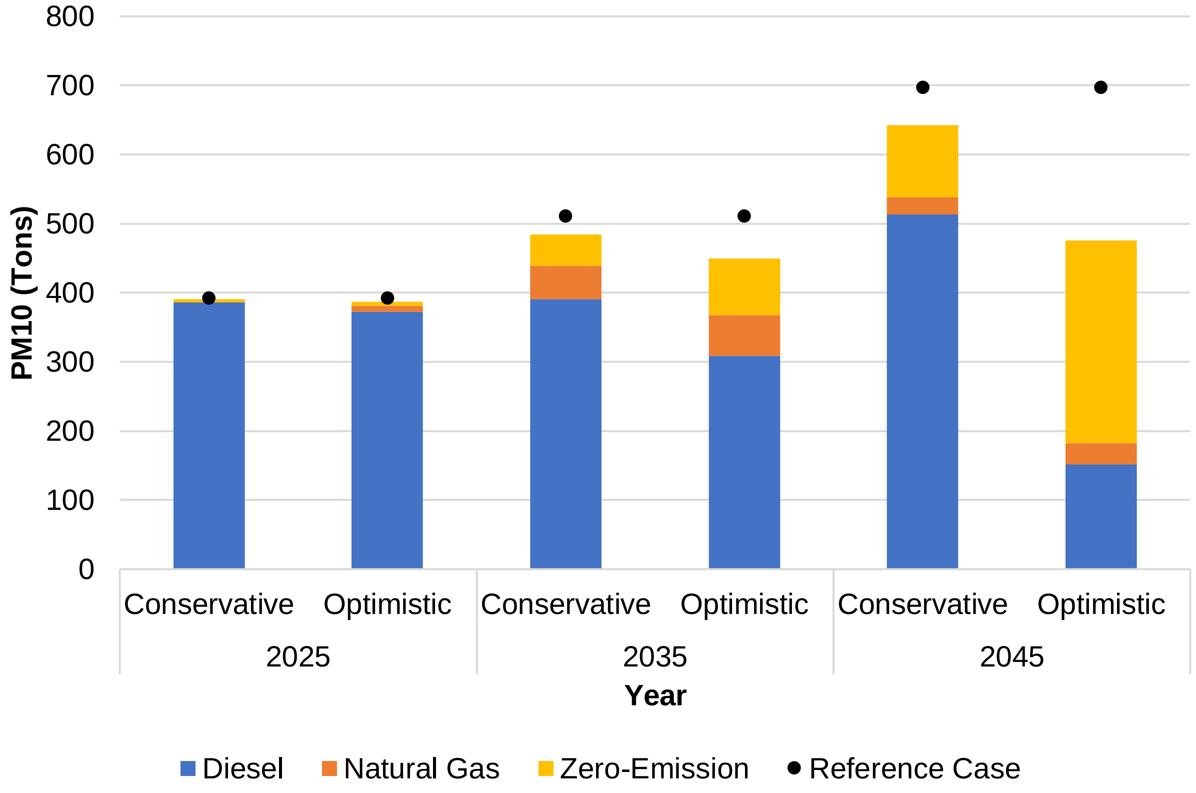


Figure E-5.SoCAB Long Haul CO Emissions Results for Years 2025, 2035, and 2045

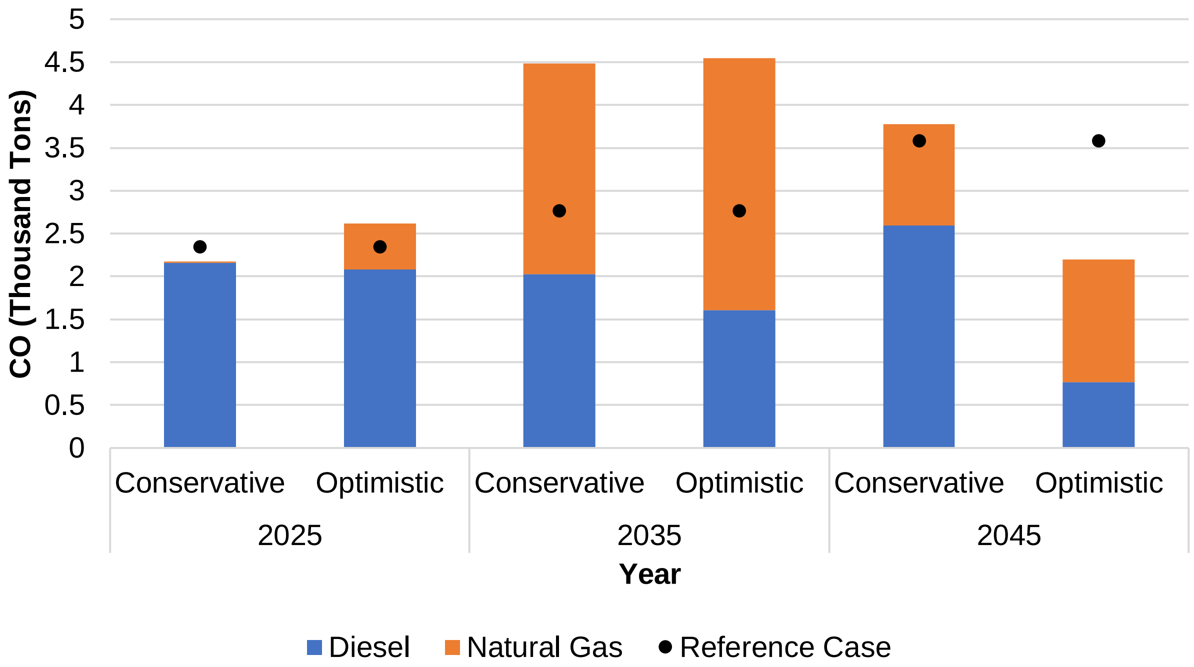


Figure E-6. SoCAB Long Haul SOx Emissions Results for Years 2025, 2035, and 2045

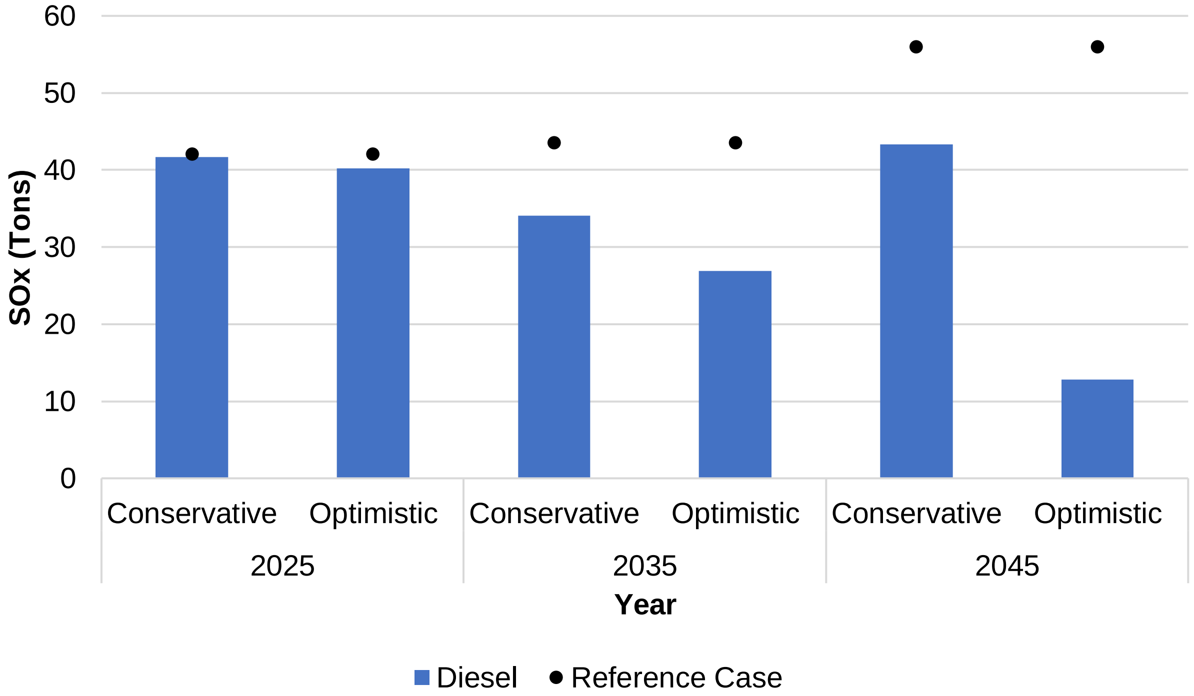


Figure E- 7. SoCAB Transit PM10 Emissions Results for Years 2025, 2035, and 2045

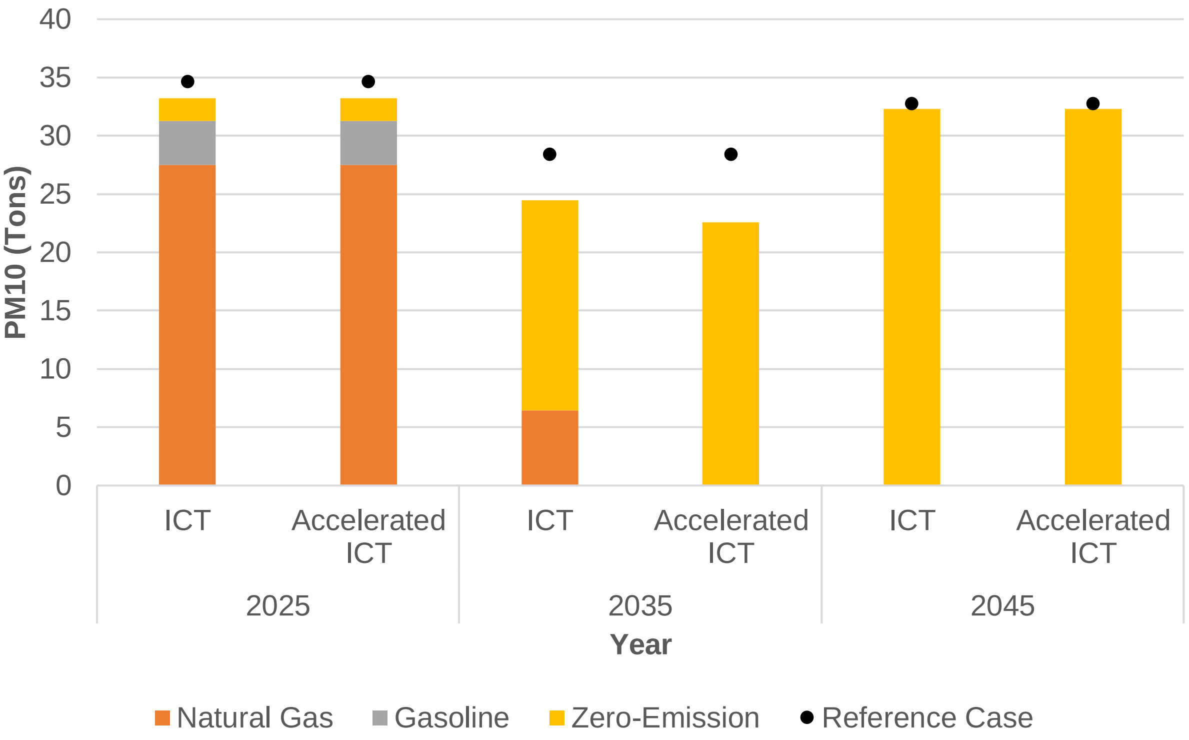


Figure E- 8.SoCAB Transit CO Emissions Results for Years 2025, 2035, and 2045

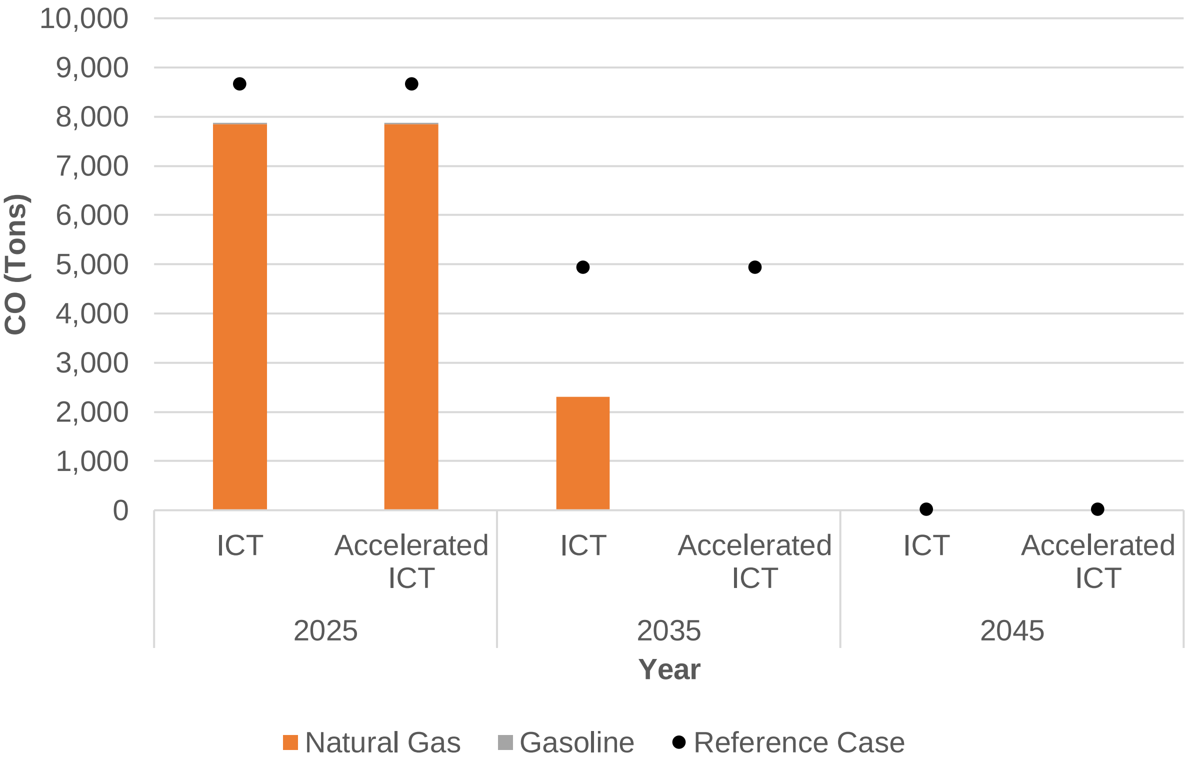
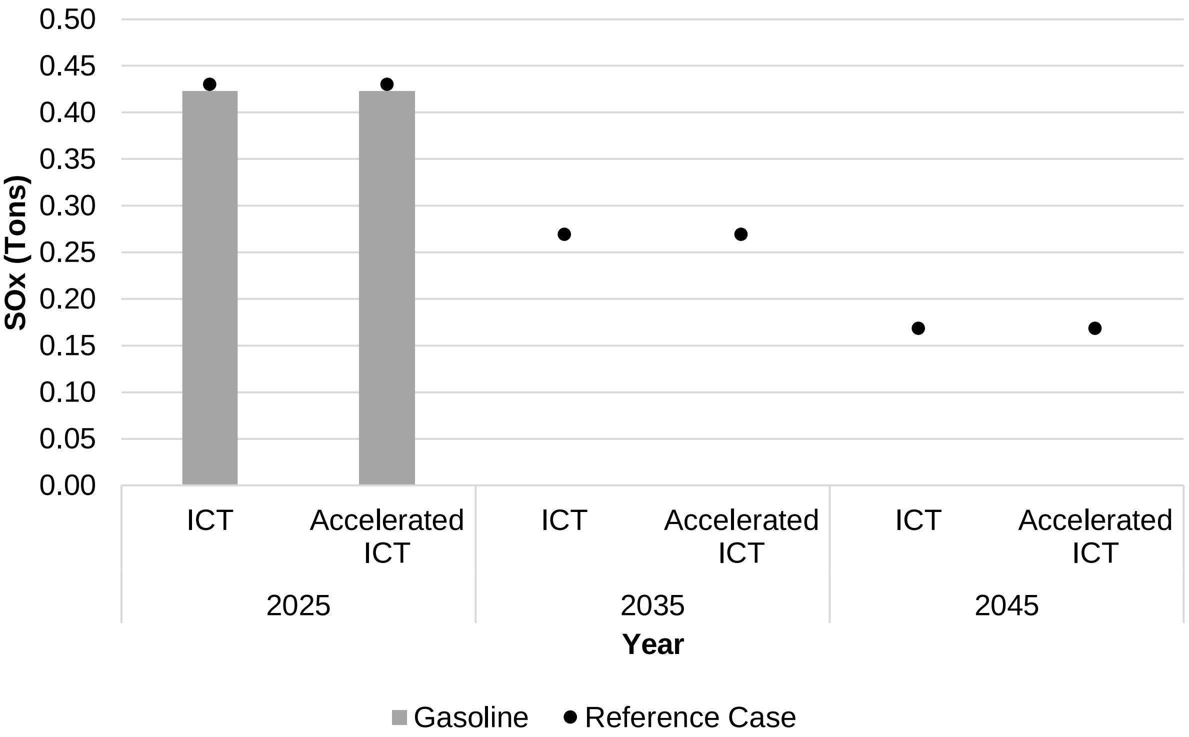


Figure E-9. SoCAB Transit SOx Emissions Results for Years 2025, 2035, and 2045


0.50
0.45
0.40
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0.05
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SOx (Tons)
ICT
Accelerated ICT
ICT
Accelerated ICT
ICT
Accelerated ICT
2025
2035
2045
Year
Gasoline
Reference Case