California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

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

Prepared for: California Energy Commission

Prepared by: Advanced Power and Energy Program, University of California, Irvine

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PREFACE

Assembly Bill (AB) 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program (CTP). The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Most recently, AB 126 (Reyes, Chapter 319, Statutes of 2023) reauthorized the CTP through July 1, 2035.

The CTP has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies
- Produce sustainable alternative and renewable low-carbon fuels in California
- Expand alternative fueling infrastructure and fueling stations
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies

To accelerate the shift toward cleaner, sustainable transportation for medium- and heavy-duty (MDHD) zero-emission vehicles, the CEC issued a grant funding opportunity (GFO) in November 2020. GFO-20-601: "Blueprints for Medium- and Heavy-Duty Zero-Emission Vehicle Infrastructure," offering grant funding to develop planning "Blueprints." In response to this opportunity, the University of California, Irvine (UCI) Advanced Power and Energy Program (APEP) submitted an application which was proposed for funding in the CEC's notice of proposed awards on April 8, 2021. The agreement was executed on September 28, 2021.

ABSTRACT

The goals of the *Replicable Zero-Emission Blueprint for Medium-and Heavy-Duty Fleets in the South Coast Air Basin* (Blueprint) were to develop a replicable Blueprint for medium- and heavy-duty (MDHD) zero emission vehicle (ZEV) charging and hydrogen infrastructure within the South Coast Air Basin (SoCAB) with a focus on transit, drayage, and long-haul trucking. Through this effort, stakeholder input was gathered and considered. The Blueprint is available to the public, industry and community stakeholders. This report is the first step in developing a SoCAB regional blueprint for MDHD ZEV charging and fueling infrastructure. The goal of this Blueprint is to outline a replicable framework for the build-out of MDHD ZEV infrastructure that can result in a cost-effective, reliable, and resilient charging and fueling network with consideration to disadvantaged communities. This is the final project report for the Blueprint.

The goal of the Blueprint was to outline a replicable framework for the buildout of a cost-effective, reliable, and resilient charging and fueling network with consideration to disadvantaged communities. 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, this analysis estimates that at least five 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. Private, fleet-based stations were also investigated using registration data and other publicly available data. Fleet-based stations are expected to be located at depot locations at or near fleet facilities.

This report also outlines the job potential and workforce training requirements for the rollout of MDHD ZEVs and their associated infrastructure in California. Job positions for a zero-emission future span numerous specializations and sectors, including but not limited to education, research, engineering, design and development, manufacturing, sales, and technical support.

Keywords: Blueprint, Medium- and Heavy-Duty Vehicles, Charging, Hydrogen, Infrastructure, South Coast Air Basin, Zero-Emission Vehicles

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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, has historically experienced degraded air quality. The degradation of air quality stems from a combination of a high concentration of economic activity, such as goods movements to and from the Los Angeles and 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 involves the adoption of zero-emission vehicle (ZEV) technologies.

The transition to medium- and heavy-duty (MDHD) ZEVs requires an overhaul of the transportation sector in both vehicle deployment and fueling infrastructure. Limited guidance on the rollout of charging and hydrogen refueling infrastructure, costs, and limited deployment has hindered adoption of MDHD ZEVs. 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 MDHD infrastructure implementation and 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. To this end, the University of California, Irvine (UCI) Advanced Power and Energy Program (APEP) has developed a replicable infrastructure Blueprint for MDHD ZEVs in SoCAB.

Project Purpose

The goals of this project were to:

- Develop a replicable blueprint for MDHD ZEV charging and hydrogen infrastructure within SoCAB with a focus on transit, drayage, and long-haul trucking
- Gather and consider stakeholder input on the Blueprint
- Ensure that the Blueprint is available to the public, and to industry and community stakeholders.

The Blueprint is intended to facilitate the adoption of MDHD ZEVs by reducing uncertainty and risk for MDHD fleets seeking to transition to ZEVs in response to grant incentives, education, and climate change, and urban air quality goals.

Project Approach

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. In addition, the spatial distribution of potential private, fleet-based stations was mapped based on zip code registration data and announced fleet plans.

The research team established decarbonization scenarios for three MDHD vocations – transit, drayage, and long haul. The technical metrics for assessing the scenarios included:

- Vehicle demand in terms of vehicle miles traveled, vehicle fuel consumption, station capacity, and general station siting within the region
- Economic metrics including fuel and station cost
- Environmental metrics were reduction in GHG emissions, reduction in criteria air pollutant (CAP) emissions, change in regional air quality, and change in local air quality associated with disadvantaged communities.

In parallel to the development of the Blueprint, the team conducted outreach to multiple stakeholders within the community and industry to solicit input and gauge feedback on the Blueprint as well as the development of workforce training to support the deployment of ZEVs and their related infrastructure. Outreach included regular meetings with identified stakeholders as well as guest lectures to automotive students at Saddleback Community College.

Conclusions and Recommendations

The Blueprint demonstrates that ZEV adoption can reduce GHG and CAP emissions within the SoCAB region. The findings from this study include:

- **Multiple zero-emission infrastructure options are available:** Several zero-emission infrastructure options are available today to support MDHD ZEV deployment.
- **Emerging technologies will play an important role:** Promising technologies like megawatt charging and high-flow hydrogen refueling are under development, with standardized commercial timelines of two to five years, possibly sooner with proprietary solutions.
- **Adopting MDHD ZEVs is critical:** Achieving MDHD ZEV targets by 2045 is crucial for reducing GHG and CAP emissions as MDHD vehicles contribute significantly to emissions in the region.
- **Significant investment in MDHD charging and hydrogen fueling networks is needed:** Full buildout of a hydrogen network for drayage and long

haul trucks could cost roughly $1.8 billion dollars, depending on how station costs evolve in the future. The estimated cost for the chargers, excluding grid upgrade and installation costs, ranges between $1.5 to $3.4 billion, depending on battery electric vehicle (BEV) adoption and the ratio of chargers to vehicles.

- **Station deployment depends on adoption rates and preferences:** The number of charging and hydrogen stations will vary by vehicle type, as well as the timing of commercial readiness, and economic and operational variables.
- **Resiliency planning can improve station performance:** Establishing a microgrid in parallel with charging and hydrogen fueling infrastructure can support uninterrupted operations during power outages. Deploying back-up or "redundant" stations can provide network resiliency in the case of station downtime.
- **ZEVs provide significant air quality improvements and health benefits:** As demonstrated in past analyses, including the *2022 Scoping Plan for Achieving Carbon Neutrality* (*2022 Scoping Plan*),[1] adopting ZEVs results in significant improvements to air quality which in turn provide significant health benefits.
- **Accelerating adoption of ZEVs can provide additional benefits:** Adopting ZEVs at a faster rate above State 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 station placement:** Public stations placed in MDHD demand hotspots can maximize utilization across fleets. 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 by an increase in local truck traffic, which can increase traffic congestion, contribute to noise pollution, and increase safety concerns.

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[1] California Air Resources Board. December 2022. *2022 Scoping Plan for Achieving Carbon Neutrality*. https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents.

In conclusion, while transitioning to ZEVs offers substantial environmental and health advantages, careful planning and infrastructure investment are necessary to support MDHD ZEV deployment.

CHAPTER 1: Introduction

Project Goals and Objectives

The goals of the project were to (1) develop a replicable Blueprint for medium- and heavy-duty (MDHD) charging and hydrogen infrastructure within the South Coast Air Basin (SoCAB) 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, industry and community stakeholders. The Blueprint is intended to facilitate the adoption of MDHD ZEVs by reducing uncertainty and risk for fleets seeking to transition in response to grant incentives, education, climate change, and urban air quality goals.

To achieve the goals of the project, the following objectives were met:

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

Approach

To achieve the goals and objectives of the project, the project team developed and addressed the following tasks:

Task 1: Administration

This task included all activities related to the administrative implementation of the project, including cost and reporting. This final report is a product of this task.

Task 2: Establish Blueprint Breadth Within Existing Plans and Policies

The goal of this task was to outline the technical, economic, and environmental metrics for the Blueprint within SoCAB based on existing private and public policies and plans.

Task 3: Assess Charging and Fueling Infrastructure Needs

The goal of this task was to develop a written guide detailing the decision-making steps in the deployment of electric charging and hydrogen refueling stations that can be easily adapted for fleets and local jurisdictions.

Task 4: Establish Infrastructure Demand Within the SoCAB Region for Transit, Drayage, and Long Haul

The goal of this task was to analyze future region-specific charging and refueling demands focusing on transit, drayage, and long-haul requirements and the corresponding charging and refueling station configurations.

Task 5: Stakeholder and Community Outreach and Engagement

The goal of this task was to engage industry stakeholders (e.g., ZEV manufacturers, fleets, utilities, hydrogen providers, fueling station owners, charger manufacturers, and certified electric truck conversion specialists) and community stakeholders (e.g., local governments, community colleges, environmental non-profit organizations, disadvantaged communities, financial institutions) and solicit input for inclusion in the development of the Blueprint document.

a) Prepare for stakeholder input

b) Outreach to stakeholders to inform the creation of a replicable Blueprint and thereby facilitate the adoption of MDHD ZEVs within the SoCAB region

Task 6: Project Fact Sheet

The goal of this task was to develop both an initial and final project fact sheet that describes the CEC-funded project and the benefits resulting from the project for the public and key decision makers.

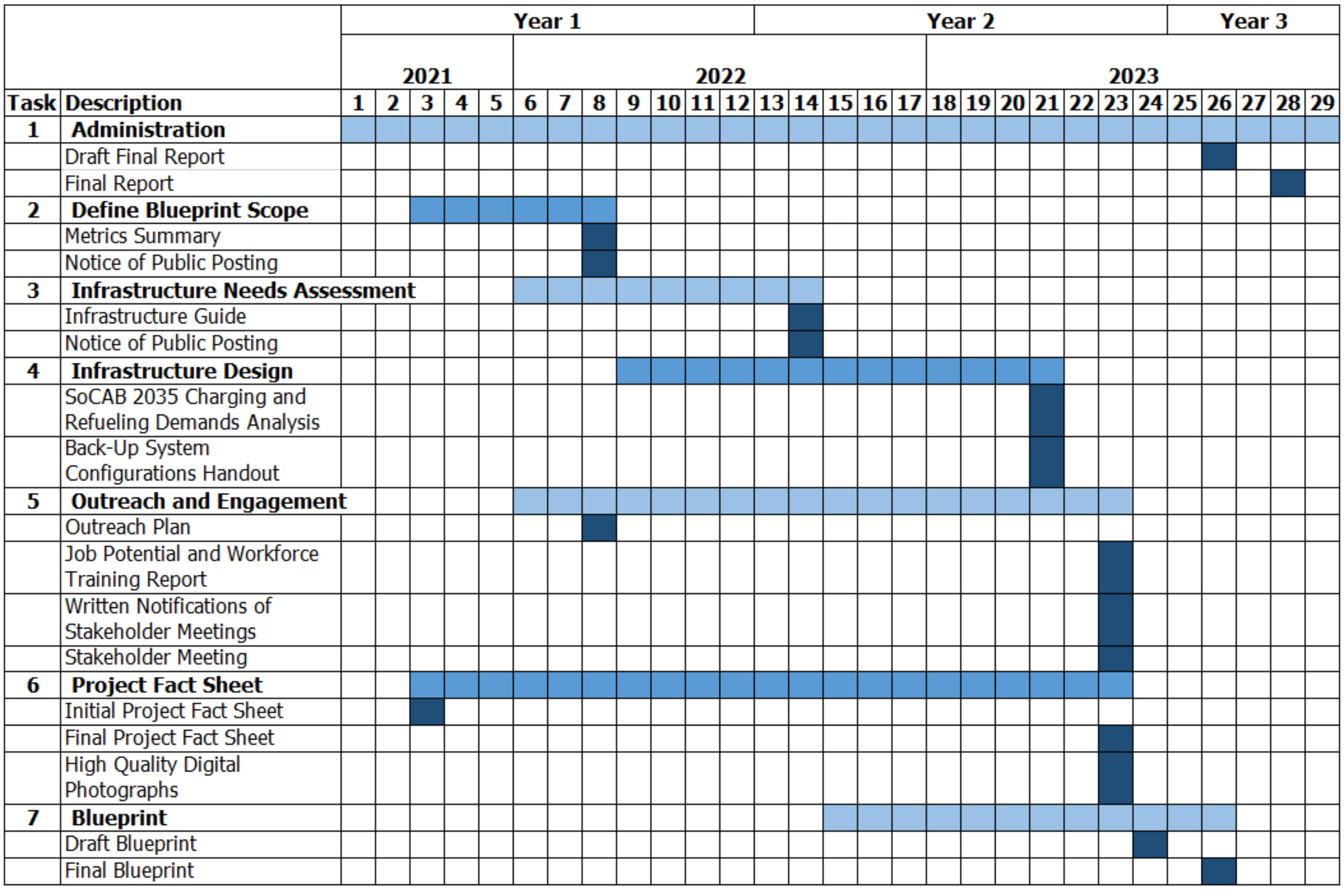
Task 7: Blueprint

The goal of this task was to develop a replicable Blueprint for SoCAB MDHD ZEV charging and hydrogen infrastructure that reduces uncertainty and risk for fleets seeking to transition to ZEV.

Project Schedule

Figure 1 shows the project schedule and deliverables.

Figure 1: Project Timeline



		Year 1												Year 2												Year 3				
		2021					2022												2023											
Task	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
1	**Administration**	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░
	Draft Final Report																										█			
	Final Report																												█	
2	**Define Blueprint Scope**			▒	▒	▒	▒	▒	▒																					
	Metrics Summary								█																					
	Notice of Public Posting								█																					
3	**Infrastructure Needs Assessment**						░	░	░	░	░	░	░	░	░															
	Infrastructure Guide														█															
	Notice of Public Posting														█															
4	**Infrastructure Design**									▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒								
	SoCAB 2035 Charging and Refueling Demands Analysis																					█								
	Back-Up System Configurations Handout																					█								
5	**Outreach and Engagement**						░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░						
	Outreach Plan								█																					
	Job Potential and Workforce Training Report																							█						
	Written Notifications of Stakeholder Meetings																							█						
	Stakeholder Meeting																							█						
6	**Project Fact Sheet**			▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒						
	Initial Project Fact Sheet			█																										
	Final Project Fact Sheet																							█						
	High Quality Digital Photographs																							█						
7	**Blueprint**															░	░	░	░	░	░	░	░	░	░	░	░			
	Draft Blueprint																								█					
	Final Blueprint																										█			

Source: University of California, Irvine Advanced Power and Energy Program (UCI APEP)

CHAPTER 2: Medium- and Heavy Duty Zero-Emission Infrastructure Blueprint for SoCAB Region

Blueprint Scope

SoCAB is a large economic hub within California responsible for goods movement to and from the San Pedro Bay ports. The region is in nonattainment for several National Ambient Air Quality Standards (NAAQS) and California Ambient Air Quality Standards (CAAQS) due in part of these activities. MDHD ZEVs are crucial for reducing regional criteria air pollutants (CAP) and greenhouse gas (GHG) emissions. Investing in MDHD ZEVs, whether battery electric vehicles (BEVs) or fuel cell electric vehicles (FCEVs), is a significant expense and requires careful planning and long lead times for both vehicles and infrastructure. MDHD vehicle operators need assurance that the development of electric charging and hydrogen fueling infrastructure will meet their operational needs. The developed Blueprint provides regional guidance on the deployment of ZEV infrastructure to inform fleets of planning considerations to reduce risk and uncertainty. The Blueprint focuses on three vehicle types – transit, drayage, and long-haul, illustrating a range of heavy-duty vehicle applications with variable operational requirements.

Baseline and Future Regional Demand

This analysis focuses on MDHD vehicles and in particular transit buses, drayage trucks (Class 8), and long haul trucks (Class 8). Despite making up 4 percent of the regional vehicle miles traveled, MDHD vehicles produce percent of on-road transportation GHG emissions. They also disproportionately contribute to CAP emissions, most notably 53 percent of on-road NO_x emissions and 34 percent of on-road $PM_{2.5}$ emissions [1].

All three vehicle categories—transit, drayage, and long haul—are projected to grow in terms of population and vehicle miles traveled (VMT) between now and 2045. Without ZEV adoption, emissions associated with these vehicles will also grow. Between 2022 and 2045, we expect the drayage truck population to increase by 26 percent, transit to increase by 47 percent, in-state long haul by 139 percent, and out-of-state long haul by 83 percent [1]. It is important to note that while long haul truck growth remains consistent during this period, drayage truck and transit growth fluctuates. Most drayage growth is expected before 2025, while transit growth is concentrated between 2035 and 2045. These trends will influence the timing and quantity of ZEV stations needed to meet vocational ZEV demand.

Addressing out-of-state vehicle emissions is essential for decreasing overall emissions from MDHD vehicles due to their significant contribution to emissions. However, enforcing zero-emission mandates on out-of-state trucks necessitates the implementation of new measures to verify compliance. The state can broaden the reach of current programs or establish new ones to enforce these measures.

Zero-Emission Technologies and Infrastructure

Two zero-emission vehicle choices exist for complying with zero-emission requirements – BEVs and FCEVs. Both types employ an all-electric power system. In a BEV, electricity is generated and used to power the vehicle through chemical energy stored in its battery. A FCEV utilizes hydrogen as its energy source, which is electrochemically split by an onboard fuel cell to produce electricity to power the electric motor. Several BEV and some FCEV models exist for MDHD vehicle applications, with more BEV options available across more vehicle weight classes.

ZEVs require access to refueling, either charging or hydrogen stations, depending on the vehicle type. The frequency and quantity of refueling depends on the vehicle fuel efficiency and how far it travels. When fleets decide on whether to adopt one or both ZEV technologies, they need to consider how they plan to use the vehicles, including vehicle travel distances, time of dwell periods, and dwell locations.

Electric Vehicle Charging Stations

Charging rates can vary by charger and may be limited by the vehicle itself. 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 per charger. SAE International is developing a standard for a megawatt charging system. Lower charging rates may be suitable for MDHD ZEVs that travel short distances, but as the daily travel distance increases, so will the necessary charging rate.

Hydrogen Refueling Stations

Two pressure levels are available for delivering gaseous hydrogen to FCEVs in the United States, 350 bar and 700 bar. Transit agencies that have already embraced fuel cell buses typically opt for the more cost-effective 350 bar fueling option, as the lower state-of-charge (SOC) it offers is adequate for their operational requirements. Class 8 trucks currently use 700 bar fueling.

Several fueling protocols designed specifically for heavy-duty vehicles are currently in development and undergoing standardization within SAE (J2601-5) and ISO (ISO 19885-3). These new standards aim to achieve a refueling rate nearly three times faster than the current 700 bar fueling protocol. It is anticipated that future heavy-duty hydrogen refueling stations will adopt these advancements to offer quicker refueling for the next generation of MDHD FCEVs.

Charging stations and hydrogen stations have the same general station development stages:

(1) Planning, including design review and engineering
(2) Permitting, including local and regional permits as well as any utility required steps
(3) Construction
(4) Station commissioning

Station development timelines are dependent on the station location, size, and type. Estimating the time needed to finish a project is particularly challenging due to the unpredictability of design and construction schedules, coordination with the utilities, along with variations in permitting processes by different Authorities Having Jurisdiction (AHJ). Smaller projects tend to progress more swiftly at each stage, while larger projects, or those requiring utility upgrades, can substantially lengthen the duration of any given phase. The timeline also can vary depending on the proposed location of the station, with permitting requiring more time with AHJs that do not have previous experience with ZEV stations.

Distributed Energy Resources and Microgrids to Support Station Resiliency

Distributed energy resources (DERs) and microgrids provide additional resiliency in the face of the increased frequency of extreme weather events under climate change. DERs include solar photovoltaics (PV), wind turbines, battery storage, fuel cells, and thermal systems. Microgrids, local networks of loads and DERs capable of operating independently from the main grid, improve local electric reliability and resilience. "Islanding" the microgrid – disconnecting it from the main grid – allows it to continue functioning during grid outages. Microgrids can enhance reliability and resilience at charging and hydrogen refueling stations, while also offering potential cost savings and greater use of renewables.

The choice and size of DERs depend on energy management objectives, including identifying critical loads during emergencies, determining outage support duration, and assessing emissions from DER operation. Designing the microgrid should also consider the trade-off between load support, cost, and equipment footprint. Embracing a mix of BEVs and FCEVs can decrease dependence on the electric grid and DER assistance. Further, reducing the permissible charging rate or restricting the number of active chargers during an outage can ease the load on the microgrid, although it might impact operational capabilities during microgrid isolation.

Station Count and Siting Methodology

This analysis examined two station types – private fleet-based stations and public stations for charging BEVs and refueling FCEVs. The Blueprint assumed that BEVs primarily charge at fleet facilities, while fuel cell electric buses (FCEB) and trucks (FCET) refuel principally at public stations along routes. It is possible that while BEVs primarily rely on fleet-based charging, they may also use public charging stations as back-up or for enroute charging for longer trips. The distribution of private fleet charging stations was mapped based on available zip code registration data from EMFAC[2], as well as available data from the Innovative Clean Transit (ICT) rollout plans. The methodology for locating such public stations can follow the same approach presented here for hydrogen fueling.

Regarding charging, the Blueprint considered two scenarios – deploying chargers at a 1:1 ratio (one charger per vehicle) and a 1:2 ratio (one charger per two vehicles). Charger power ratings are expected to range from 150 to 350 kW per charger. Previous research has examined the charger-to-vehicle ratio, suggesting a range between 1:1 and 1:2 [2], [3].

For hydrogen refueling stations, the Blueprint explored station capacities ranging from 4,000 to 10,000 kg of hydrogen. Additionally, a sensitivity analysis on daily utilization demonstrated that varying use between 50-80 percent of the dispensing capacity can significantly affect the total number of stations needed to support the MDHD ZEV population. A station with a 100 percent daily utilization rate would have required daily hydrogen replenishment and might have led to a poor user experience due to fuel shortages and long queues. Lower station utilization could have offered a more reliable and user-friendly experience for users.

Candidate locations for public MDHD stations must meet two essential criteria. Firstly, these stations must be accessible to MDHD vehicles, considering that not all roads in California can accommodate large vehicles. If a site lacks truck-accessible routes or a viable connection to highways, it cannot function as an MDHD ZEV station. Secondly, the station must be in an area zoned for commercial purposes. The Blueprint uses existing truck stop locations as candidate sites for public stations as they meet both criteria and are already used for fueling MDHD trucks.

For the spatial analysis, the study used the Freight Analysis Framework 5 (FAF5), a collaborative effort between the Bureau of Transportation Statistics and the Federal Highway Administration. FAF5's network of roadways defines available routes and

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[2] CARB. 2021 EMFAC Emissions Model. https://ww2.arb.ca.gov/our-work/programs/msei/on-road-emfac

accessibility. To create a spatial fuel demand weighting, the Blueprint mapped county vehicle miles traveled from EMFAC to the FAF5 network.

Regional Infrastructure Deployment for Future Demand

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 1percent of the population for the year 2025, 7.3 percent for the year 2035, and 15percent for the year 2045 (Figure 2). For in-state long haul trucks, ZEV adoption is less than 1 percent for 2025, 8.5 percent for 2035 and 15 percent for 2045 (Figure 3). For out-of-state long haul trucks, ZEV adoption is lower for each year, 0.5 percent, 7.4 percent, and 9.8 percent for each target year, respectively (Figure 4). For transit buses, the adoption rate is 7.5 percent for 2025, 5.8 percent for 2035, and 4.3 percent for 2045 (Figure 5).

Figure 2: Reference Case Projected Drayage Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

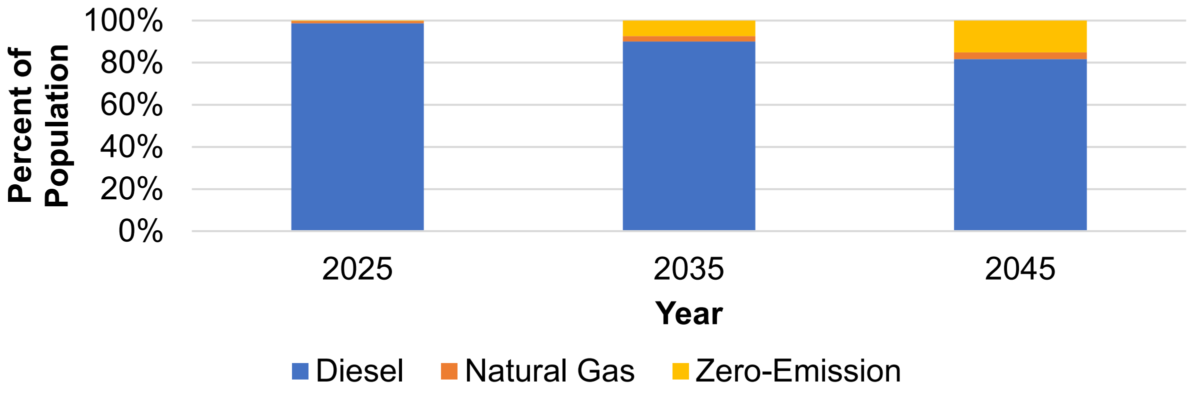


Figure 3: Reference Case Projected In-State Long Haul Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

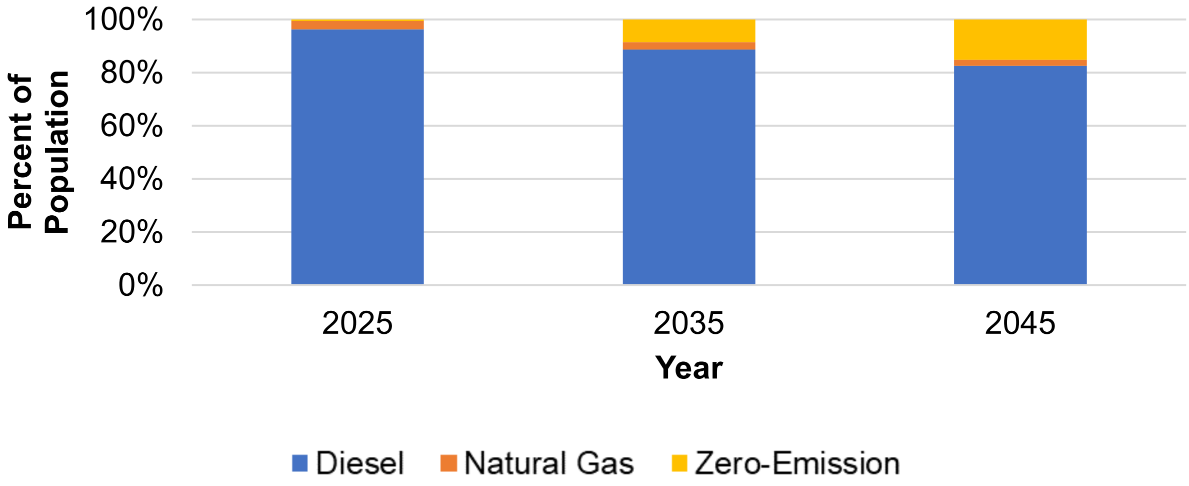


Figure 4: Reference Case Projected Out-of-State Long Haul Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

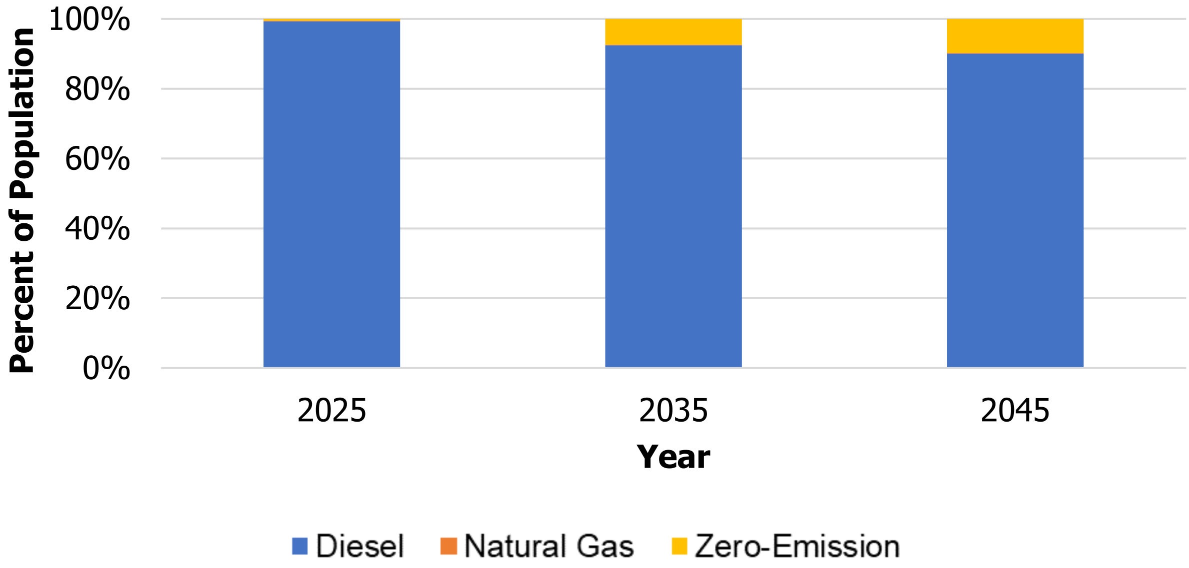
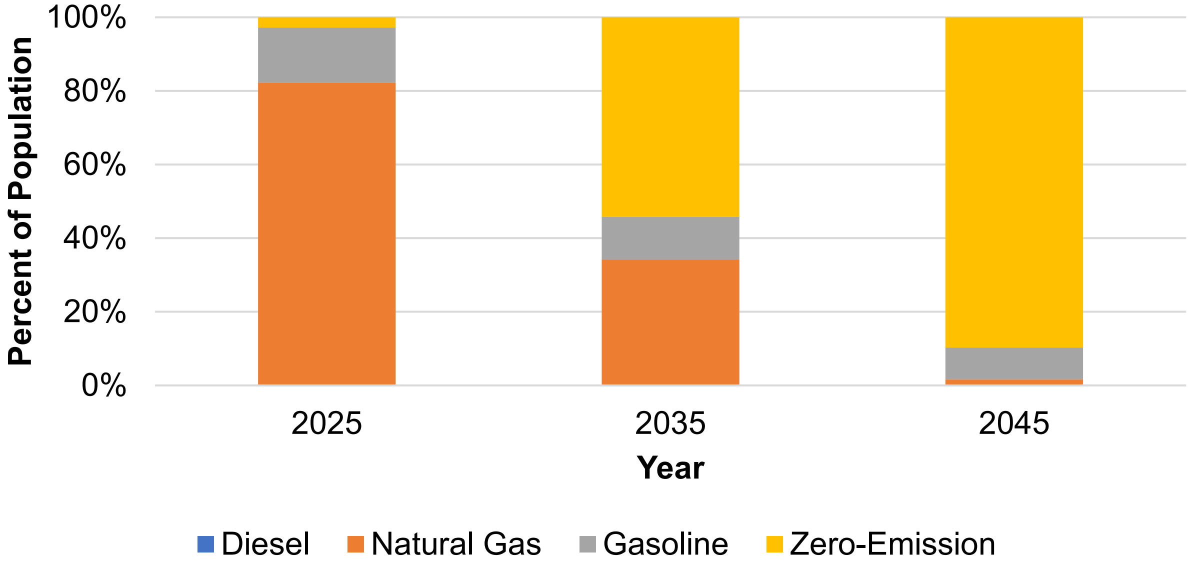


Figure 5: Reference Case Projected Transit Bus Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045



Zero-Emission Scenarios

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 [4]. The scenario projects about 18 percent of drayage trucks are zero-emission by 2025, about 82 percent will be zero-emission by 2035 and 98 percent by 2045 (Figure 6). TRACE further delineates the number of BEVs versus FCEVs across the years. The Clean Air Action Plan scenario ("CAAP scenario") assumes about 1.4percent 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 7) [5]. The ratio of BEVs and FCEVs from TRACE are applied to the CAAP scenario as well.

Figure 6: TRACE Scenario Projected Drayage Distribution by Vehicle Fuel Type for Years 2025, 2035, and 2045

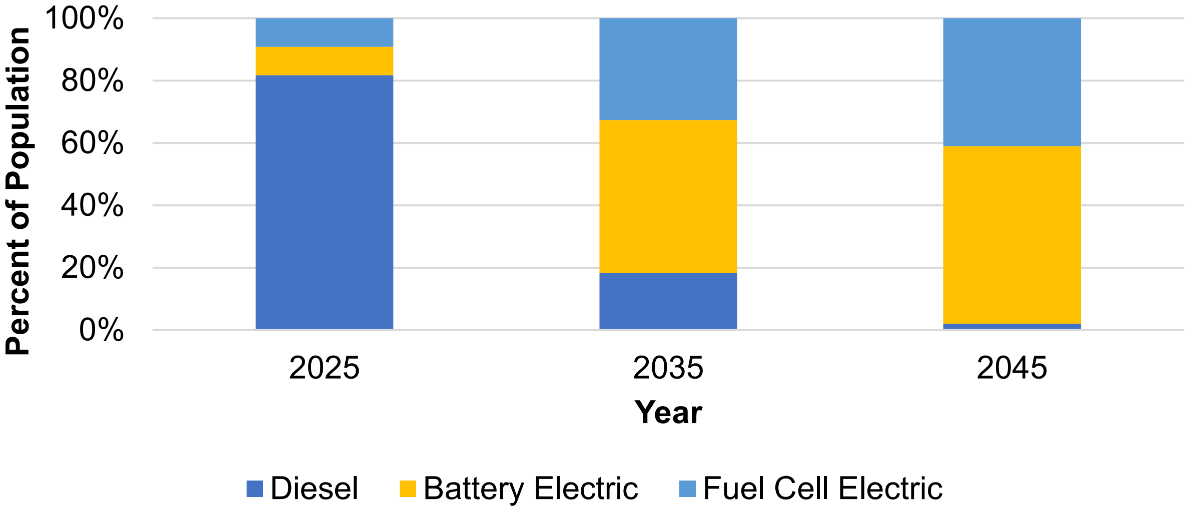
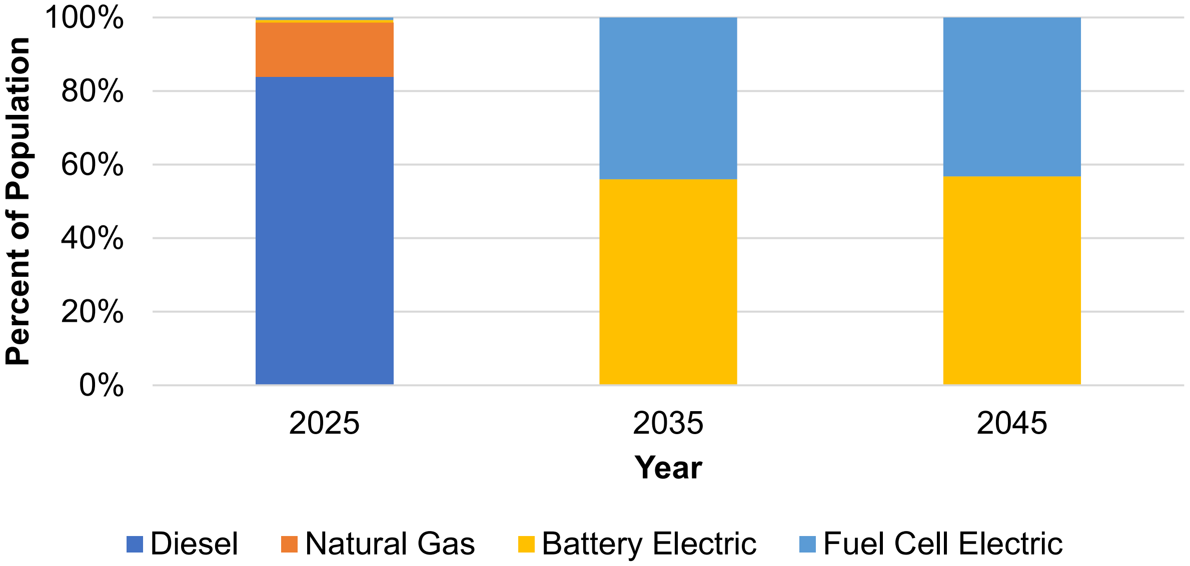


Figure 7: CAAP Scenario Projected Drayage Vehicle Distribution by Fuel Type for Years 2025, 2035, and 2045



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 8). 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 9). In both figures, in-state and out-of-state vehicle populations are combined.

Figure 8: Conservative Scenario Projected Long Haul Vehicle Distribution by Fuel Type for Years 2025, 2035, and 2045

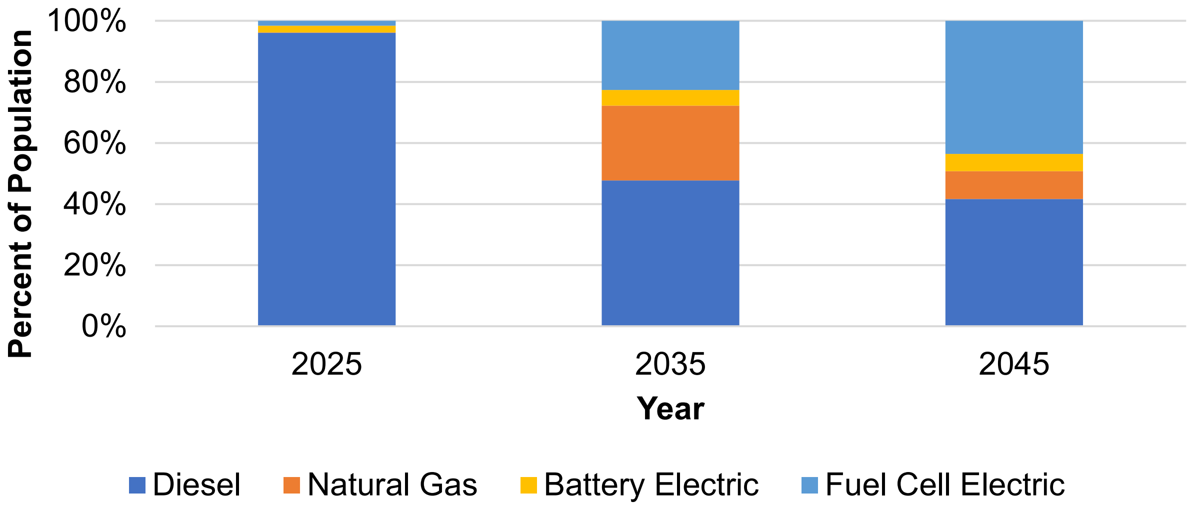
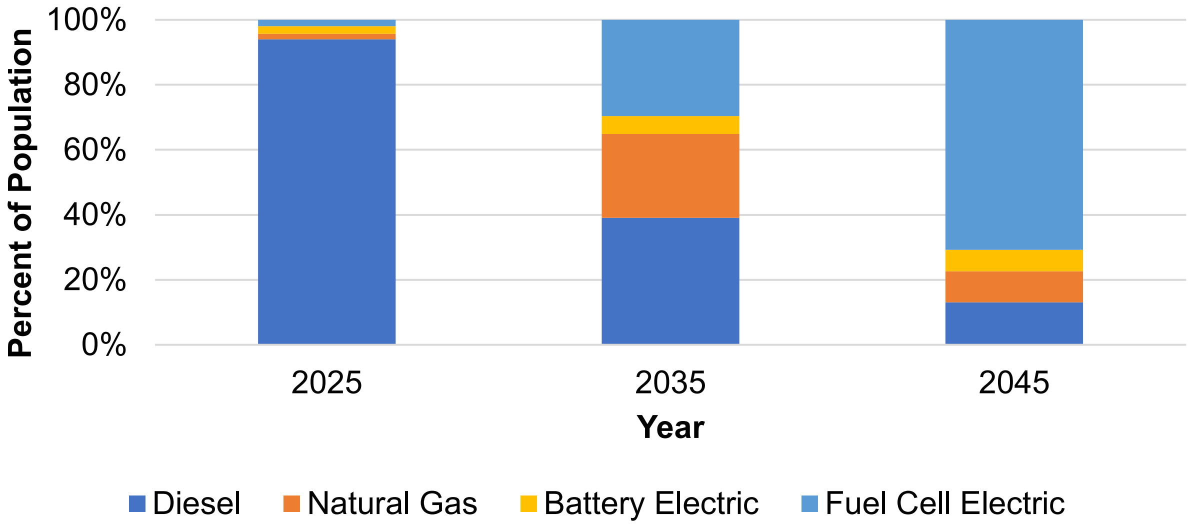


Figure 9: Optimistic Scenario Projected Long Haul Vehicle Distribution by Fuel Type for Years 2025, 2035, and 2045



Transit

While the 2022 Scoping Plan statewide estimates that 64 percent of buses will be zero-emission by 2035 in the SoCAB region, transit agencies have committed to transition to roughly 84 percent zero-emission by 2035 and 100 percent 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 [6].

For transit, two zero-emission bus adoption scenarios are modeled, ICT and 100 percent ZEB. The ICT Scenario assumes adoption that meets the commitments made by Transit agencies in the SoCAB region (about 10 percent ZEB in 2025, 84 percent in 2035, and 100 percent by 2035) (see Figure 10). The 100 percent ZEB Scenario assumes that transit agencies have transitioned early, reaching 100 percent zero-emission options by the year 2035 (Figure 11).

Figure 10: ICT Scenario Projected Transit Bus Distribution by Fuel Type for Years 2025, 2035, and 2045

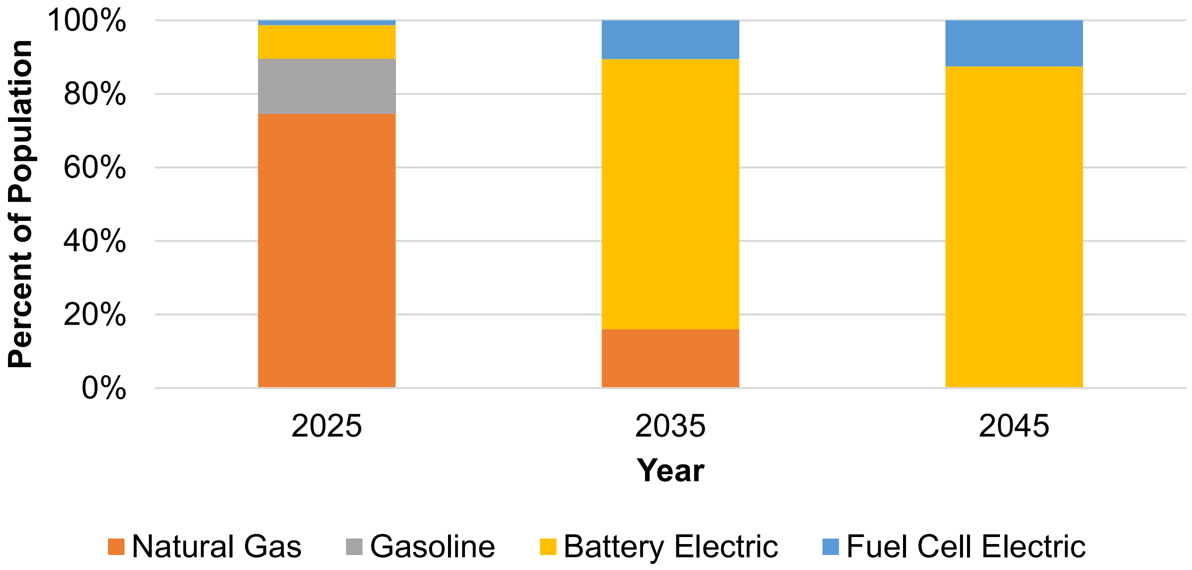
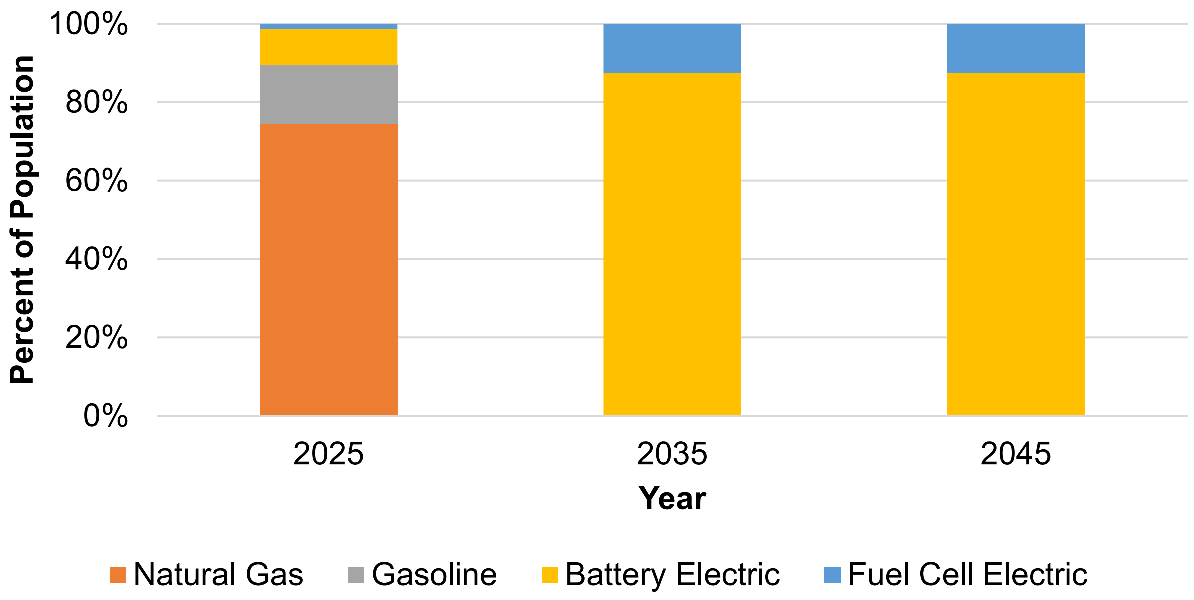


Figure 11: Accelerated ACT Scenario Projected Transit Bus Distribution by Fuel Type for Years 2025, 2035, and 2045



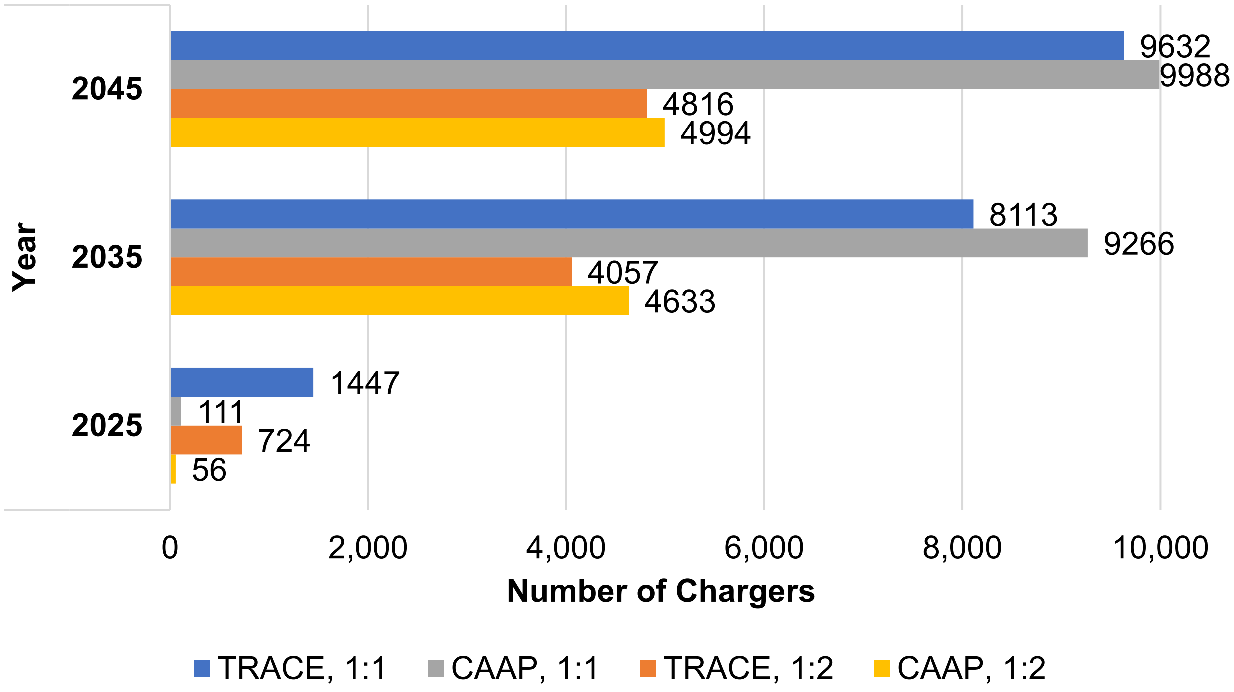
Station Counts

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.

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 percent 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, as shown in Figure 12. This ratio will also greatly affect the capital cost of deploying chargers for battery electric drayage trucks. Overall, transitioning to 100 percent drayage trucks by 2035 requires between 4,600 to 9,300 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 percent 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 1,500 chargers needed by 2045.

Figure 12: 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 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.

Long Haul

Figure 13 presents the number of chargers needed to support battery electric long haul trucks under the conservative and optimistic scenarios. Despite long trucks making up a larger share of MDHD vehicles compared to drayage, a smaller portion is anticipated to be battery electric due to longer average travel demands and higher payloads.

Figure 13: Projected Number of Chargers for Long Haul Trucks, Years 2025, 2035, and 2045

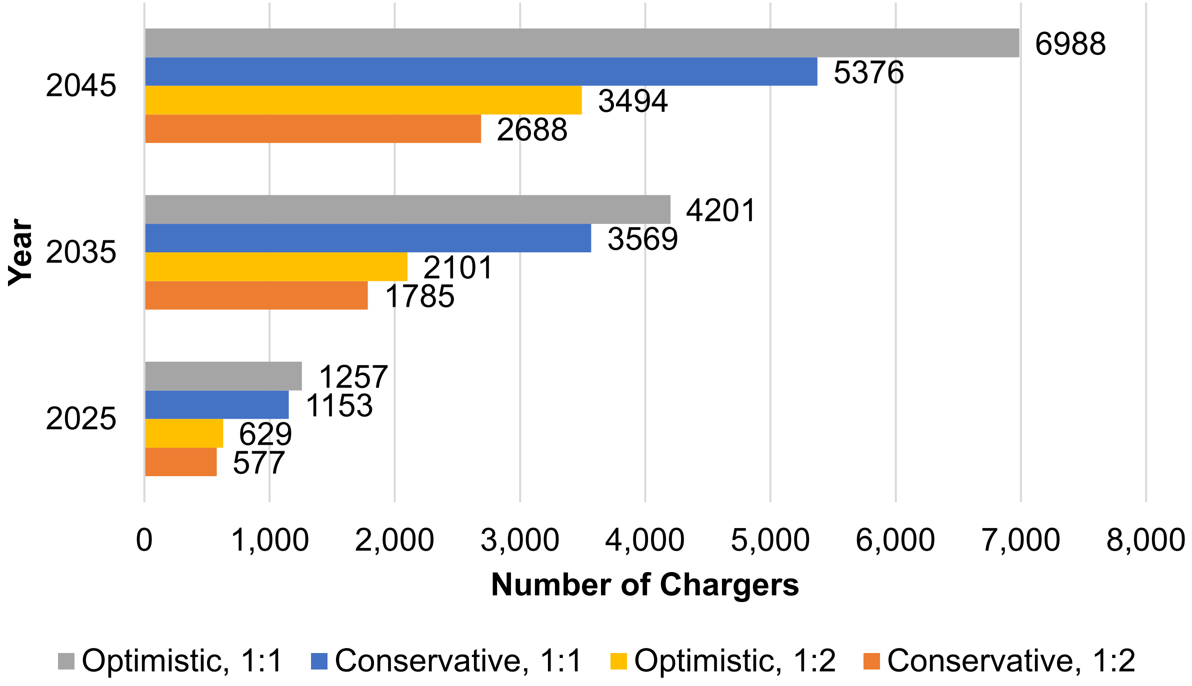
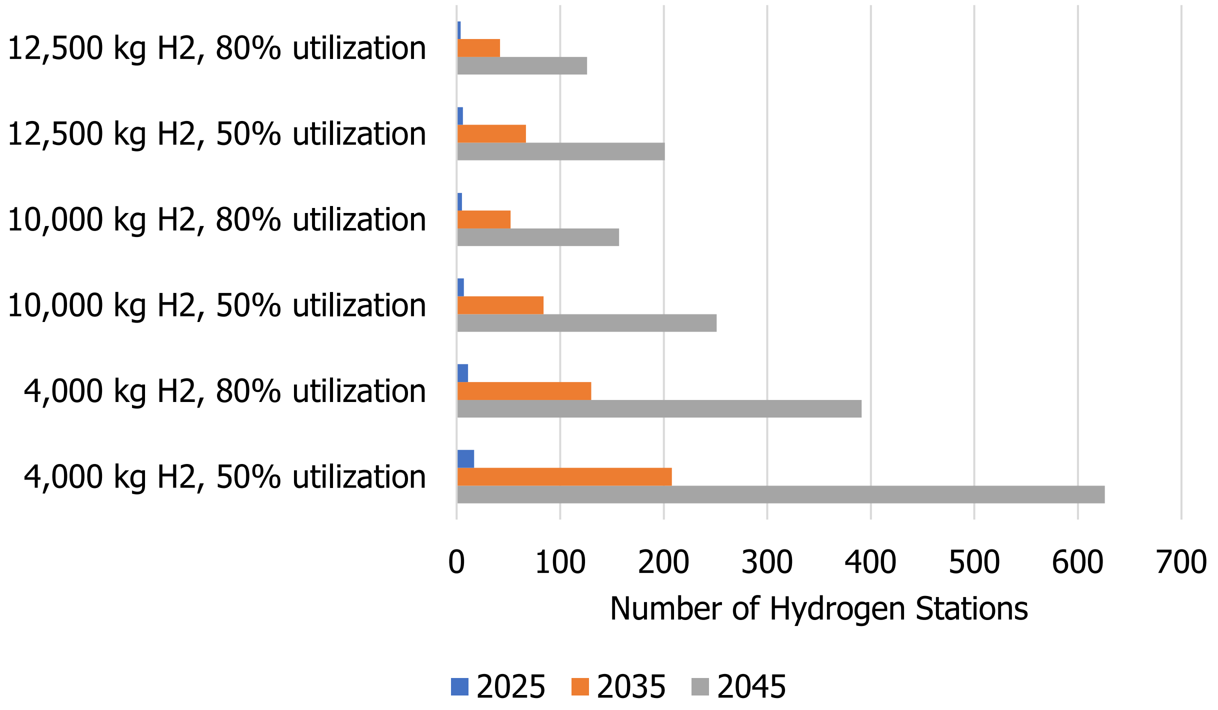


Figure 14 presents the projected number of hydrogen stations needed to support drayage and long haul fueling demands for the years 2025, 2035, and 2045 with different station capacity and utilization assumptions. The range of station sizes explored is based on a combination of available data on future 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, when 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 36 times the 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 14: Projected Number of Hydrogen Stations based on Drayage and Long Haul Fuel Demand



Transit Fleet Stations

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 miles/kg H2,[3] estimated station capacity ranges between 400 and 3,000 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 1,750 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.

Figure 15 and Figure 16 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 percent zero-emission by 2045. The accelerated adoption of ZEBs to achieve 100 percent ZEBs by 2035 requires about 32 percent 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

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

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 scenarios explored required 3,800 to 7,600 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 ZEB types.

Figure 15: Projected Number of Chargers for Transit Buses, Years 2025, 2035, and 2045

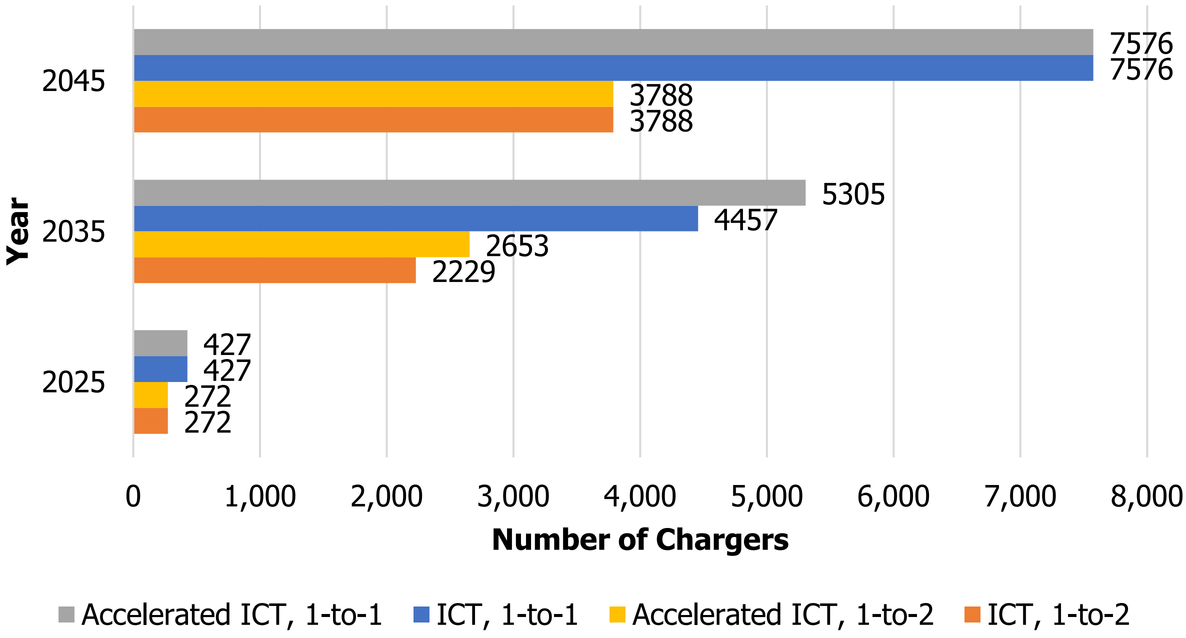
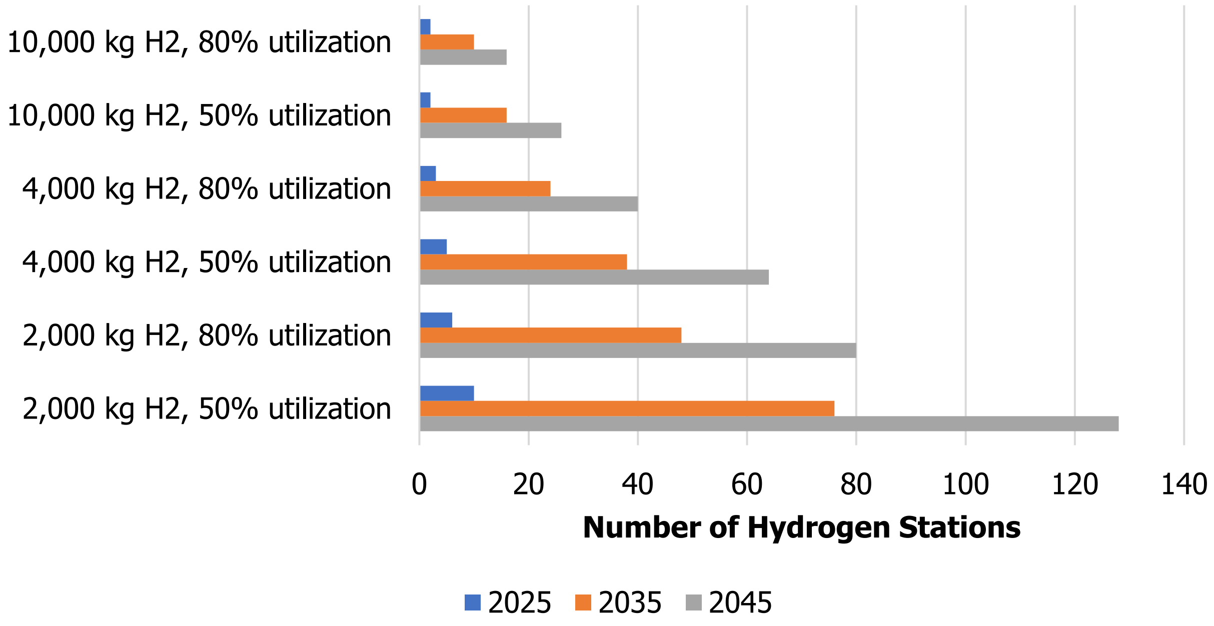


Figure 16: Projected Number of Hydrogen Stations based on Transit Bus Fuel Demand under ICT Scenario



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.

Spatial Allocation of 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 17 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 18 presents the 2035 station siting results. 42 stations were sited, 19 of which are in DACs (about 45 percent of stations). Between 2035 and 2045, the number of required stations increases to 127 stations sited in 2045, see Figure 19. 53 of the stations (42 percent) are in DACs.

Figure 17: SoCAB Drayage and Long Haul Hydrogen Refueling Station Siting for the Year 2025

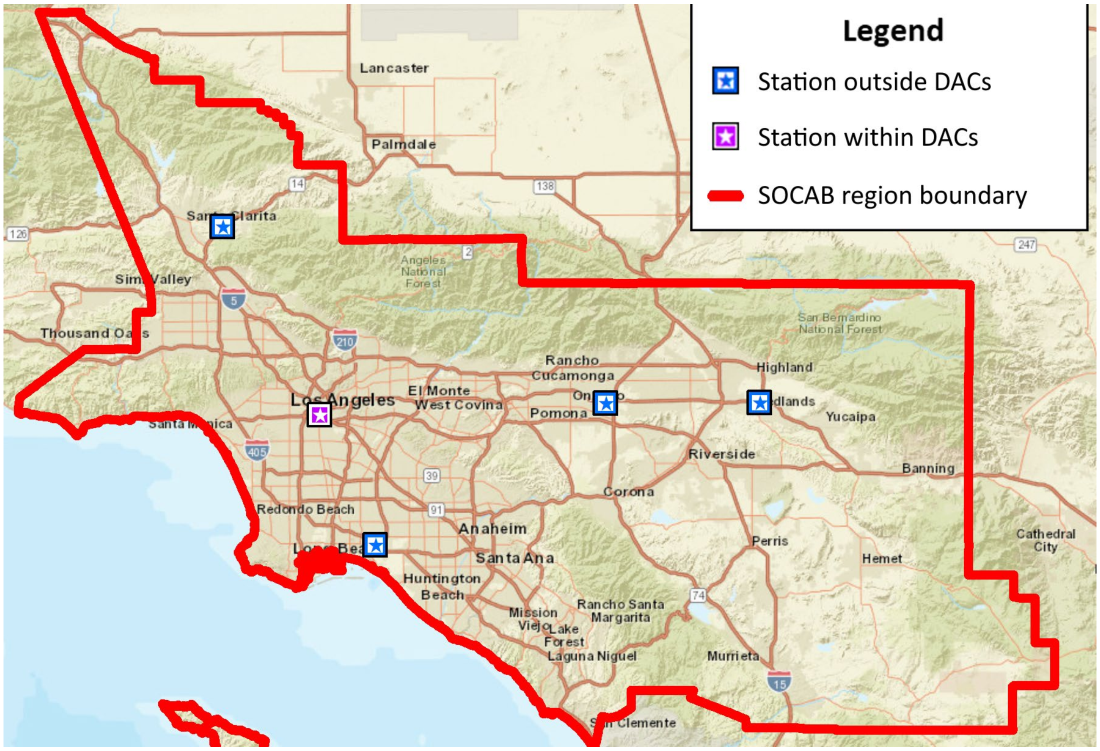


Figure 18: SoCAB Drayage and Long Haul Hydrogen Refueling Station Siting for the Year 2035

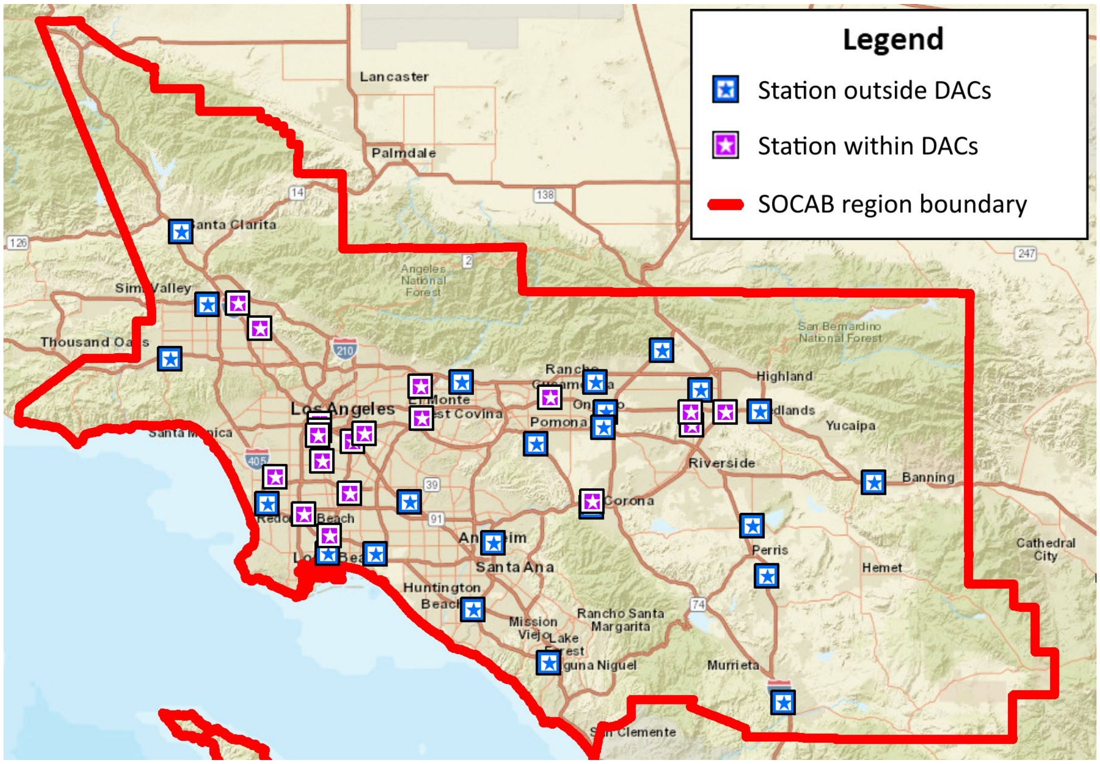
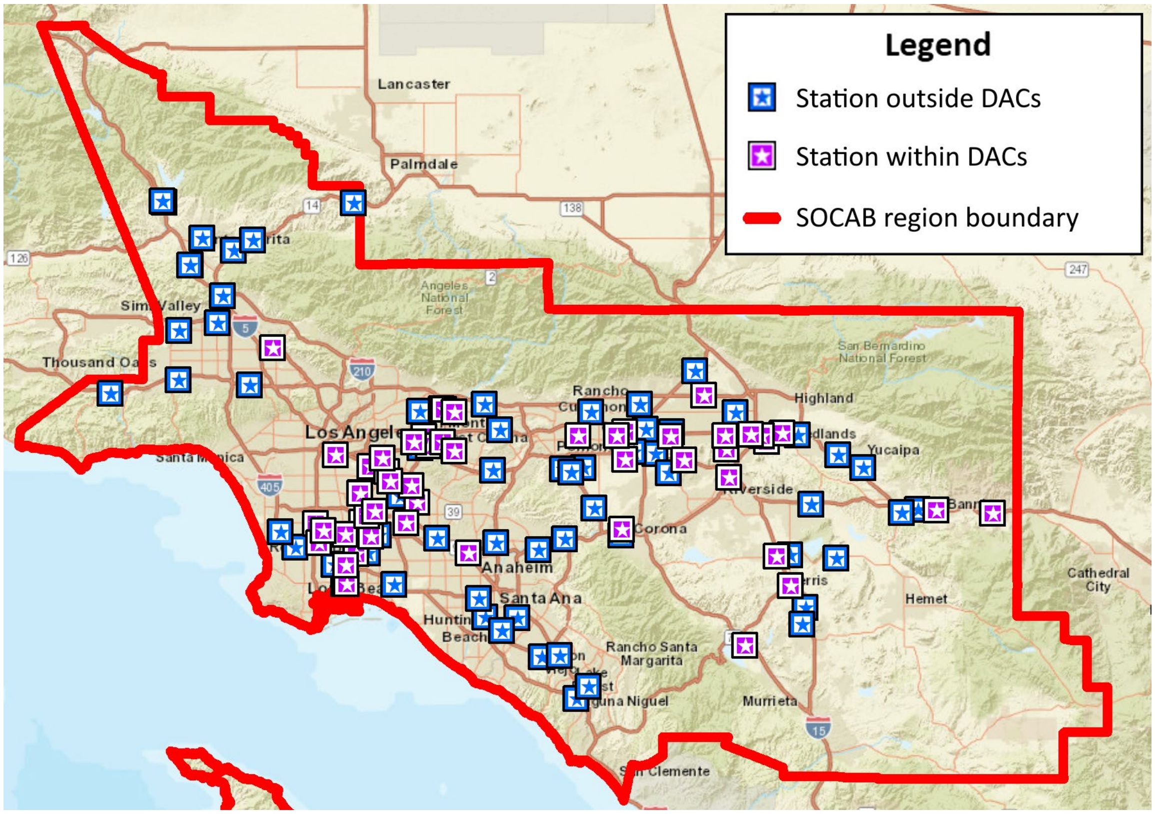


Figure 19: SoCAB Drayage and Long Haul Hydrogen Refueling Station Siting for the Year 2045



While BEV fleets are expected to rely primarily on home-based 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 to 100 miles of range under 20 minutes. For the hydrogen station siting results presented, adding 5 to 7 chargers per station could support 20 percent of the regional drayage and long-haul BEV charging demand projected for 2025, 2035, and 2045.

CHAPTER 3: Outreach, Workforce, and Curriculum Development

The goal of this task was to engage industry stakeholders and community stakeholders and solicit input for inclusion in the development of the Blueprint document. Throughout the project, the team held stakeholder meetings to discuss infrastructure deployment status, opportunities, and challenges; facilitate feedback on model inputs and scenarios; and identify strategies to overcome barriers and accelerate deployment. Table 1 presents stakeholders we engaged during the project to solicit input and feedback.

Table 1: Table of Stakeholder Engagement

Stakeholders
Toyota
FirstElement Fuel, Inc.
Long Beach Clean Cities
Saddleback College
Orange County Transportation Authority
Nuvve
Rhombus Energy Solutions
Air Products

In addition to individual stakeholder outreach, APEP conducted two consultatory meetings over the last year covering MDHD zero-emission vehicle infrastructure standardization.[4] Each meeting included two parts: (1) a session on battery-electric vehicle charging infrastructure standardization; and (2) a session on hydrogen refueling infrastructure standardization. At the meetings, UCI APEP presented findings regarding infrastructure standardization gaps and technology limitations that need to be addressed for widescale deployment of MDHD ZEVs. Additionally, they provided early insights into establishing new standards within the MDHD ZEV market. Table 2 presents consultatory meeting participants.

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[4] Meeting Presentations and supplemental information on MDHD infrastructure standardization is available at: www.apep.uci.edu/mhdv

Table 2: MDHD Infrastructure Standardization Meetings

First Consultatory Meeting October 2021	**Second Consultatory Meeting June 2022**
2050 Partners	AC Transit
AC Transit	Air Liquide
Air Products	Air Products
Argonne National Laboratory	Argonne National Laboratory
BYD	BYD
California Energy Commission	California Energy Commission
California Fuel Cell Partnership	California Fuel Cell Partnership
CARB	California Public Utility Commission
CDFA	CARB
ChargePoint, Inc.	CDFA
CTE	Daimler
Department of Energy	First Element Fuel
EPRI	Flex Power
First Element Fuel	GM
Governor’s Office of Business	Governor’s Office of Business
Hyzon Motors	GTI
Iwatani	Hyzon Motors
National Renewable Energy Laboratory	National Renewable Energy Laboratory
New Flyer	Nikola Motors
Nikola Motors	Nuvve
Nuvve	Proterra
PG&E	Rhombus Energy Solutions
Port of LA	SCAQMD
Port of Long Beach	SFMTA
Proterra	Siemens
Rhombus Energy Solutions	Southern California Edison
SCAQMD	Toyota
SFMTA	U.S. EPA
Shell	Veloce Energy
Siemens	Zen Energy Solutions
Southern California Edison	
Sunline Transit	
Toyota	
U.S. EPA	
Veloce Energy	
WAVE	
XOS	
Zen Energy Solutions	

Source: APEP

Workforce Development

Job growth related to zero-emission vehicles and their associated infrastructure is spurred in part by California’s progressive zero-emission vehicle 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 zero-emission vehicles, in addition to the manufacturing, installation, operation, and maintenance of the related fueling infrastructure [7]. In the U.S., there are roughly 664,000 automotive technicians and mechanics, encompassing both conventional internal combustion engine (ICE) vehicles and clean vehicles [8]. 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 percent of which were in California [9]. 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 [9].

Of particular focus is the availability of automotive technicians and mechanics who can service electric vehicles. California employs roughly 60,500 people in these positions [8]. 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.

At the same time, transitioning to zero-emission vehicles 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 [10]. 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 zero-emission vehicles 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 [11]. Several vehicle OEMs have announced plans to expand investments in U.S. manufacturing facilities [12].

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[5] 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.[6]

Education Credentials and Skill Requirements

Educational credentials and skill requirements for zero-emission vehicle-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 [7]. Relevant certificates include those covering electrical fundamentals, electrical systems, energy systems, hydrogen energy, green hydrogen, hydrogen safety, and electric vehicle powertrains.

Curriculum Development

For this project, UCI APEP collaborated 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

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[5] 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

[6] 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

Most relevant to this work is the Alternative Fuel Vehicle Specialist track. All core classes are listed in Table 3 and at least one elective course is required.

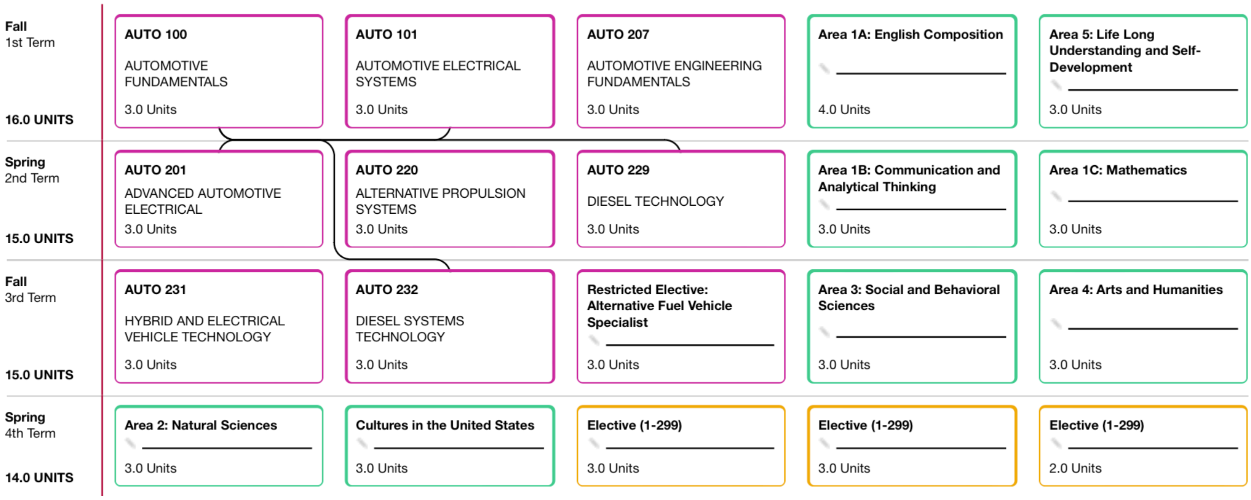
Table 3: Alternative Fuel Vehicle Specialist Course List

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 20.

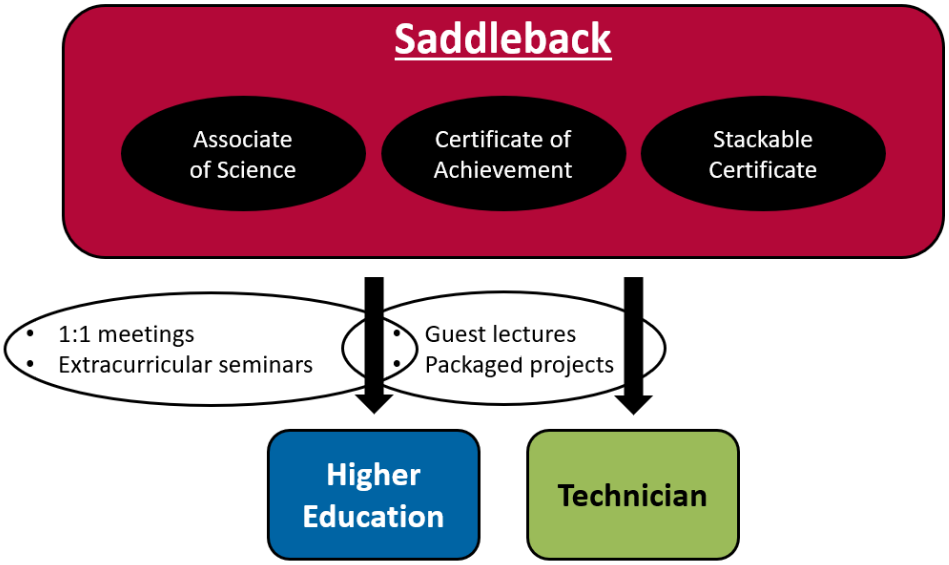
Figure 20: Sample Course Schedule for Automotive Technology A.S. Degree at Saddleback College



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 21. 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 21: 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 at 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.

CHAPTER 4: Conclusions and Recommendations

Zero-emission vehicle adoption can significantly reduce GHG and CAP emissions within the SoCAB region. CAP emissions fall to zero levels with 100 percent zero-emission vehicle adoption except for PM which is emitted due to brake and tire wear. For the scenarios examined, all vocations need both charging and hydrogen fueling infrastructure to support zero-emission vehicle deployment. The following findings stem from this study:

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

- **Developing technologies will play a significant role in enabling the widescale deployment of MDHD ZEVs.**
  Currently, developers are working on megawatt charging and high-flow hydrogen refueling, with standardized commercial product timelines ranging from two to five years. Proprietary solutions may become available sooner.

- **Achieving GHG and CAP emissions reduction goals critically depends on attaining zero-emission MDHD vehicle targets by 2045.**
  MDHD vehicles contribute disproportionately to GHG and CAP emissions in the SoCAB region compared to their population size, making up roughly 15 percent of transportation GHG emissions, over 50 percent of transportation NOx emissions, and over 30 percent of $PM_{2.5}$ emissions. MDHD ZEVs provide an opportunity to significantly reduce these emissions, with 100 percent 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 MDHD ZEV deployment necessitates significant investment in MDHD 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 7,500 to 17,000 chargers, depending on BEV adoption and the ratio of chargers to vehicles. The estimated cost for the chargers, excluding grid upgrade and installation costs, ranges between $1.5 to $3.4 billion.

- **The number of charging and hydrogen stations to support MDHD 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 commercial readiness, and economic and operational variables. It is likely that MDHD 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 infrastructure planning.**

  Charging and hydrogen stations can reduce 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 a year in health benefits, 36 percent 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 MDHD vehicle hydrogen demand.**

  Public stations placed in MDHD 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 facilitate 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 raise safety concerns.

In conclusion, while transitioning to ZEVs offers significant environmental and health benefits, supporting and accelerating the deployment of MDHD ZEVs necessitates careful planning and investment in charging and hydrogen fueling infrastructure.

References

[1] California Air Resources Board, "EMFAC 2021." 2021.

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GLOSSARY

ALTERNATING CURRENT (AC) – Flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

AMBIENT AIR QUALITY STANDARDS (AAQS) – Health- and welfare-based standards for outdoor air which identify the maximum acceptable average concentrations of air pollutants during a specified period of time.

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

CALIFORNIA DEPARTMENT OF TRANSPORTATION (Caltrans) – Responsible for the design, construction, maintenance, and operation of the California State Highway System, as well as the portion of the Interstate Highway System within the state's boundaries.

CALIFORNIA AIR RESOURCES BOARD (ARB) – The "clean air agency" in the government of California, whose main goals include attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution rules and regulations.

CALIFORNIA AMBIENT AIR QUALITY STANDARD (CAAQS) – A legal limit that specifies the maximum level and time of exposure in the outdoor air for a given air pollutant and which is protective of human health and public welfare. CAAQSs are recommended by the OEHHA and adopted into regulation by the ARB. CAAQSs are the standards which must be met per the requirements of the California Clean Air Act (CCAA).

CALIFORNIA ENERGY COMMISSION (CEC) – The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibility are:

1. Forecasting future statewide energy needs
2. Licensing power plants sufficient to meet those needs
3. Promoting energy conservation and efficiency measures
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
5. Planning for and directing state response to energy emergencies.

CARBON DIOXIDE (CO2) – A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green-growing things and by the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent). The major source of CO2 emissions is fossil fuel combustion. CO2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO2 have been increasing at a rate of about 0.5 percent per year and are now about 30 percent above preindustrial levels. (EPA)

CARBON DIOXIDE EQUIVALENT (CDE) – A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as "million metric tons of carbon dioxide equivalents (MMTCDE)" or "million short tons of carbon dioxide equivalents (MSTCDE)." The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP. MMTCDE= (million metric tons of a gas) * (GWP of the gas). For example, the GWP for methane is 24.5. This means that emissions of one million metric tons of methane is equivalent to emissions of 24.5 million metric tons of carbon dioxide. Carbon may also be used as the reference and other greenhouse gases may be converted to carbon equivalents. To convert carbon to carbon dioxide, multiply the carbon by 44/12 (the ratio of the molecular weight of carbon dioxide to carbon). (EPA)

CARBON MONOXIDE (CO) – A colorless, odorless, highly poisonous gas made up of carbon and oxygen molecules formed by the incomplete combustion of carbon or carbonaceous material, including gasoline. It is a major air pollutant based on weight.

CLIMATE CHANGE - Also referred to as "global climate change." The term "climate change" is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, climate change has been used synonymously with the term, "global warming;" scientists, however, tend to use the term in the wider sense to also include natural changes in climate. See also Enhanced Greenhouse Effect. (EPA)

COMPRESSED NATURAL GAS (CNG) – Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

CRITERIA AIR POLLUTANT – An air pollutant for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. Examples include ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, PM10 and PM2.5. The term "criteria air pollutants" derives from the requirement that the U.S. EPA must describe the characteristics and potential health and welfare effects of these pollutants. The U.S. EPA and ARB periodically review new scientific data and may propose revisions to the standards as a result.

DEMAND CHARGE – The sum to be paid by a large electricity consumer for its peak usage level.

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

ELECTRIC VEHICLE CHARGING STATION (EVSE) – Infrastructure designed to supply power to EVs. EVSE can charge a wide variety of EVs including BEVs and PHEVs.

ELECTRIC VEHICLES (EV) – A broad category that includes all vehicles that are fully powered by electricity or an electric motor.

EMISSION FACTOR -- For stationary sources, the relationship between the amount of pollution produced and the amount of raw material processed or burned. For mobile sources, the relationship between the amount of pollution produced and the number of vehicle miles traveled. By using the emission factor of a pollutant and specific data regarding quantities of materials used by a given source, it is possible to compute emissions for the source. This approach is used in preparing an emissions inventory.

EMISSION INVENTORY – An estimate of the amount of pollutants emitted into the atmosphere from major mobile, stationary, area-wide and natural source categories over a specific period of time such as a day or a year.

EMISSION RATE – The weight of a pollutant emitted per unit of time (e.g., tons/year).

EMISSIONS – Released or discharged air contaminants in the ambient air from any source.

ENERGY – The capacity for doing work. Forms of energy include thermal, mechanical, electrical and chemical. Energy may be transformed from one form into another.

ELECTRICITY – A property of the basic particles of matter. A form of energy having magnetic, radiant and chemical effects. Electric current is created by a flow of charged particles (electrons).

EXPOSURE – The concentration of the pollutant in the air multiplied by the population exposed to that concentration over a specified time.

FUEL CELL ELECTRIC VEHICLE (FCEV) – A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell stack that produces electricity to power the vehicle.

GALLON – A unit of volume. A U.S. gallon has 231 cubic inches or 3.785 liters.

GASOLINE – A light petroleum product obtained by refining oil and used as motor vehicle fuel.

GRID – The electric utility companies' transmission and distribution system that links power plants to customers through high power transmission line service (110 kilovolt [kv] to 765 kv); high voltage primary service for industrial applications and street rail and bus systems (23 kv-138 kv); medium voltage primary service for commercial and industrial applications (4 kv to 35); and secondary service for commercial and residential customers (120 v to 480 v). Grid can also refer to the layout of a gas distribution system of a city or town in which pipes are laid in both directions in the streets and connected at intersections.

GROSS VEHICLE WEIGHT (GVW) -- The maximum operating weight/mass of a vehicle as specified by the manufacturer including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo but excluding that of any trailers.

HYBRID AND ZERO-EMISSION TRUCK AND BUS VOUCHER INCENTIVE PROJECT (HVIP) – A project launched in 2009 by the California Air Resources Board in partnership with CALSTART to accelerate the purchase of cleaner, more efficient trucks and buses in California.

HYDROGEN (H2) – A colorless, odorless, highly flammable gas, the chemical element of atomic number 1.

INFRASTRUCTURE – Generally refers to the recharging and refueling network necessary to successful development, production, commercialization and operation of alternative fuel vehicles, including fuel supply, public and private recharging and refueling facilities, standard specifications for refueling outlets, customer service, education and training, and building code regulations.

IOU – An investor owned utility. A company, owned by stockholders for profit, that provides utility services. A designation used to differentiate a utility owned and operated for the benefit of shareholders from municipally owned and operated utilities and rural electric cooperatives.

KILOGRAM (kg) – The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1000 cubic centimeters of water at the temperature of its maximum density.

KILOWATT (kW) -- One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

KILOWATT-HOUR (kWh) -- The most commonly used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumes 534 kWh in an average month.

LIGHT-DUTY VEHICLE (LDV) -- Any motor vehicle with a gross vehicle weight of 6,000 pounds or less.

LOAD – The amount of electric power supplied to meet one or more end users' needs.

LOAD – An end-use device or an end-use customer that consumes power. Load should not be confused with demand, which is the measure of power that a load receives or requires.

LOW CARBON FUEL STANDARD (LCFS) – A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and therefore, reduce greenhouse gas (GHG) emissions. The LCFS standards are expressed in terms of the "carbon intensity" (CI) of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of a comprehensive set of programs in California to cut greenhouse gas emission and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.

MEGAWATT (MW) – One-thousand kilowatts (1,000 kW) or one million (1,000,000) watts. One megawatt is enough electrical capacity to power 1,000 average California homes. (Assuming a loading factor of 0.5 and an average California home having a 2-kilowatt peak capacity.)

MEGAWATT HOUR (MWh) – One-thousand kilowatt-hours, or an amount of electrical energy that would supply 1,370 typical homes in the Western U.S. for one month. (This is a rounding up to 8,760 kWh/year per home based on an average of 8,549 kWh used per household per year [U.S. DOE EIA, 1997 annual per capita electricity consumption figures]).

MICROGRID – A combination of localized electricity generation sources, energy storage devices, and multiple loads that acts as a small electric grid with respect to the main electric grid. The microgrid can operate interconnected or isolated from the main electricity grid.

MILES PER GALLON GASOLINE EQUIVALENT (MPGe) – A measure of the average distance traveled per unit of energy consumed. MPGe is used by the U.S EPA to compare energy consumption of alternative fuel vehicles, plug-in electric vehicles and other advanced technology vehicles with the energy consumption of conventional internal combustion vehicles rated in miles per US gallon.

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS) – Standards established by the U.S. EPA that apply for outdoor air throughout the country. There are two types of NAAQS. Primary standards set limits to protect public health and secondary standards set limits to protect public welfare.

NONATTAINMENT AREA – A geographic area identified by the U.S. EPA and/or ARB as not meeting either NAAQS or CAAQS standards for a given pollutant.

NOx – Oxides of nitrogen that are a chief component of air pollution that can be produced by the burning of fossil fuels.

ORIGINAL EQUIPMENT MANUFACTURER (OEM) – Refers to the manufacturers of complete vehicles or heavy-duty engines, as contrasted with remanufacturers, converters, retrofitters, up-fitters, and re-powering or rebuilding contractors who are overhauling engines, adapting or converting vehicles or engines obtained from the OEMs, or exchanging or rebuilding engines in existing vehicles.

OUTAGE (Electric utility) – An interruption of electric service that is temporary (minutes or hours) and affects a relatively small area (buildings or city blocks).

OZONE – A type of oxygen that has three atoms per molecule instead of the usual two. Ozone is a poisonous gas, but the ozone layer in the upper atmosphere shields life on earth from deadly ultraviolet radiation from space. The molecule contains three oxygen atoms (O3).

PARTICULATE MATTER (PM) – Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines.

PEAK LOAD OR PEAK DEMAND – The electric load that corresponds to a maximum level of electric demand in a specified time period.

PM10 (PARTICULATE MATTER) – A criteria air pollutant consisting of small particles with an aerodynamic diameter less than or equal to a nominal 10 microns (about 1/7 the diameter of a single human hair). Their small size allows them to make their way to the air sacs deep within the lungs where they may be deposited and result in adverse health effects. PM10 also causes visibility reduction.

PM2.5 – Includes tiny particles with an aerodynamic diameter less than or equal to a nominal 2.5 microns. This fraction of particulate matter penetrates most deeply into the lungs.

POWER – Electricity for use as energy.

PPM (PARTS PER MILLION) – The unit commonly used to represent the degree of pollutant concentration where the concentrations are small.

REGULATION – The service provided by generating units equipped and operating with automatic generation controls that enables the units to respond to the ISO's direct digital control signals to match real-time demand and resources, consistent with established operating criteria.

RELIABILITY – Electric system reliability has two components-- adequacy and security. Adequacy is the ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of system facilities. Security is the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system facilities.

SDG&E – The acronym for San Diego Gas & Electric, an electric and natural gas utility serving the San Diego region.

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) – SAE International, formerly the Society of Automotive Engineers, is a U.S.-based, globally active professional association and standards organization for engineering professionals in various industries.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT (SCAQMD) – The air pollution control agency for all of Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties. This area of 10,743 square miles is home to over 16.8 million people–about half the population of the whole state of California. It is the second most populated urban area in the United States and one of the smoggiest. Its mission is to clean the air and protect the health of all residents in the South Coast Air District through practical and innovative strategies.

SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS CLEAN CITIES COALITION (SCAG Clean Cities Coalition) – SCAG Clean Cities Coalition works with vehicle fleets, fuel providers, community leaders, and other stakeholders to save energy and promote the use of domestic fuels and advanced vehicle technologies in transportation.

SOUTHERN CALIFORNIA EDISON (SCE) – One of the nation's largest electric utilities, which delivers power to 15 million people in 50,000 square-miles across central, coastal and Southern California, excluding the city of Los Angeles and some other cities.

TIME-OF-USE (TOU) RATES – The pricing of electricity based on the estimated cost of electricity during a particular time block. Time-of-use rates are usually divided into three or four time blocks per twenty-four hour period (on-peak, mid-peak, off-peak and sometimes super off-peak) and by seasons of the year (summer and winter). Real-time pricing differs from TOU rates in that it is based on actual (as opposed to forecasted) prices which may fluctuate many times a day and are weather-sensitive, rather than varying with a fixed schedule.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) – A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting and enforcement activities.

UNIVERSITY OF CALIFORNIA, IRVINE (UC Irvine/UCI) – A public research university located in Irvine, California. It is one of the 10 campuses in the University of California (UC) system.

VEHICLE MILES TRAVELED (VMT) – The miles traveled by motor vehicles over a specified length of time (e.g., daily, monthly or yearly) or over a specified road or transportation corridor.

ZERO EMISSION (ZE) – An engine, motor, process, or other energy source, that emits no waste products that pollute the environment or disrupt the climate.

ZERO-EMISSION VEHICLE (ZEV) – Vehicles which produce zero emissions from the on-board source of power (e.g., an electric vehicle).