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STAFF REPORT

Senate Bill 643: Clean Hydrogen Fuel Production and Refueling Infrastructure to Support Medium- and Heavy-Duty Fuel Cell Electric Vehicles and Off-Road Applications

An Initial Assessment: Clean Hydrogen Production and Application in Hard-to-Electrify Sectors

September 2023 | CEC-600-2023-053

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ABSTRACT

In 2020, Governor Gavin Newsom issued Executive Order N-79-20, which expanded sales and operation targets for medium- and heavy duty (MDHD) zero-emission vehicles (ZEV) and off-road applications. The California Air Resources Board (CARB) has issued regulations that are accelerating the transition to zero-emission transportation. The California Energy Commission (CEC) and other agencies are investing in MDHD ZEV infrastructure across the state.

Under Senate Bill 643 (Archuleta, Chapter 646, Statutes of 2021), the CEC has prepared the first of three statewide assessments of the MDHD hydrogen fuel cell electric vehicle refueling infrastructure and clean hydrogen fuel production necessary to meet statewide goals and requirements relating to vehicular air pollution. This initial assessment provides an overview of operating and planned MDHD refueling stations and early scenarios of infrastructure needs. These scenarios use data from CARB's *2022 Scoping Plan*, the Alliance for Renewable Clean Hydrogen Energy Systems (ARCH$_2$ES) partnership, the California Transportation Commission's (CTC) staff analysis for SB 671, and a 2022 energy demand planning scenario from the CEC.

The scenarios produced a wide range of results, estimating anywhere from 1 to 602 MDHD stations would be needed by 2030, and by 2035, the range varied from 11 to more than 2,000 MDHD stations. On the supply side, clean hydrogen production is nearly nonexistent in California but is anticipated to grow in the next two years.

At the end of 2022, more than 2,300 MDHD ZEVs are registered in California, and more than 100 of these were fuel cell electric buses. Some transit agencies are using onsite clean hydrogen production to fuel the buses. CARB's incentive program for commercial MDHD ZEVs has funded 2,162 vehicles of which 46 are fuel cell. To date, the CEC has invested more than $100 million for MDHD hydrogen infrastructure deployment. The CEC will continue to evaluate new information and associated infrastructure requirements as the market develops.

Keywords: Fuel cell electric vehicles, transportation electrification, hydrogen fuel infrastructure, network planning, clean hydrogen production, zero emission, off-road, fuel cell electric trucks, fuel cell electric buses.

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EXECUTIVE SUMMARY

California's transportation sector — including passenger vehicles, medium- and heavy-duty (MDHD) vehicles such as trucks and buses, off-road vehicles, and the fuels required to power them – is responsible for roughly half of the state's greenhouse gas (GHG) emissions when including upstream fuel production. Within the transportation sector, MDHD vehicles and off-road sources have a disproportionate effect compared to passenger vehicles on the state's toxic air emissions, which together are responsible for more than 65 percent of nitrogen oxide (NO_x) emissions, more than 90 percent of diesel particulate matter (DPM), and more than 10 percent of GHG emissions statewide. These emissions pose a direct threat to the environment, the economy, and public health, especially to those residing or working in disadvantaged or low-income communities, which are most impacted by these toxic emissions. Therefore, it is a public health imperative that MDHD vehicles rapidly adopt zero-emission technologies and fuels.

In September 2020, the impacts of MDHD vehicles and off-road mobile sources on air pollution were specifically addressed when Governor Gavin Newsom signed Executive Order N-79-20, setting the following targets:

- By 2035, 100 percent zero-emission vehicle (ZEV) sales for new passenger cars and trucks, 100 percent zero-emission vehicle operations for drayage trucks, and 100 percent zero-emission off-road vehicles and equipment, where feasible
- By 2045, 100 percent ZEV operations for MDHD vehicles, where feasible

The goals set forth in Executive Order N-79-20 have influenced policies, requirements, and investments for numerous California agencies and municipalities. The California Air Resources Board (CARB), which is charged with developing programs and regulations to protect the public from the harmful effects of air pollution, recently adopted or amended regulations to reach the goals set forth in Executive Order N-79-20, including:

- Advanced Clean Trucks (ACT) regulation, adopted in 2021, which requires an increasing fraction of truck sales to be ZEVs through 2035, with specific targets for each vehicle class.
- In-Use Off-Road Diesel-Fueled Fleets regulation (Off-Road Regulation), amended in 2022, which requires fleets to phase-out use of the oldest and highest-polluting off-road diesel vehicles and prohibits adding high-emitting vehicles to fleets.
- Advanced Clean Fleets (ACF) regulation, adopted in 2023, which requires fleet operators in certain segments to reach 100 percent ZEVs by 2035 or 2040.

Also, the Innovative Clean Transit (ICT) regulation, adopted in December 2018, requires all public transit agencies to transition gradually to a 100 percent zero-emission bus fleet by 2040.

The ACT and ACF regulations together are expected to result in about 510,000, 1,350,000, and 1,690,000 MDHD ZEVs on California's roads in 2035, 2045 and 2050, respectively. The ACT and ACF regulations provide clear direction to the stakeholders and industries to accelerate commercialization of zero-emission technologies and associated refueling and charging infrastructure. MDHD ZEVs are anticipated to be a mix of battery-electric vehicles

(BEVs) and fuel cell electric vehicles (FCEV). Most of the commercially available MDHD models are BEVs, but more MDHD FCEV options are entering the market. Fleet owners with BEVs are generally expected to charge at their private depot and use public charging stations to make longer trips.

The *2023 Staff Report on Senate Bill 643: Clean Hydrogen Fuel Production and Refueling Infrastructure to Support Medium- and Heavy-Duty Fuel Cell Electric Vehicles and Off-Road Applications* (2023 SB 643 Staff Report) provides an assessment of the state's existing and planned MDHD FCEV refueling infrastructure. Some transit agencies adopted fuel cell electric buses (FCEB) years ago, and because they are used in real-world operations rather than demonstrations, the 2023 SB 643 Staff Report separates the discussion of FCEBs from MDHD FCEVs and provides use cases of transit agencies that have successfully incorporated FCEBs into their operations.

Three MDHD FCEV public refueling stations located in Southern California are open retail and serving heavy-duty FCEVs and FCEBs. A CEC-funded hydrogen refueling station near the Port of Oakland is anticipated to open before the end of 2023. Public funding awards have been made to at least 23 planned public hydrogen refueling stations. There is still uncertainty regarding the technology type and location of infrastructure at this early stage of the transition to MDHD ZEVs. As fleet owners begin to make their decisions on which technology works best for their operations, there will be more data from which to draw assumptions.

By 2035, depending on the assumptions used in four scenarios provided in Chapter 2, MDHD FCEV infrastructure requirement scenarios varied from 11 stations to more than 2,000 stations. One of the scenarios differentiates between depot/private stations and public stations, while the other three do not. The level of uncertainty of what FCEV fleet owners will decide would work best for their operations including cost considerations is still relatively high. For example, a fleet owner could choose to have a "home base" depot station for long-haul trucking that is optimally located within the range where it could refuel at a public refueling station, and possibly another public station if there is a build-out of stations along major freight corridors.

Developments in off-road fuel cell applications are discussed and include early developments in construction, mining, and agriculture, as well as at ports and in the marine, rail and aviation sectors, as directed in Senate Bill 643 (Archuleta, Chapter 646, Statutes of 2021). The 2023 SB 643 Staff Report provides initial infrastructure scenarios, with estimates of clean hydrogen fuel required to support the adoption of MDHD FCEVs and FCEBs at levels to meet specified goals relating to vehicular air pollution. Ports in particular have expressed high interest in fuel cell technology for equipment with demanding duty cycles such as top handlers.

There are competing definitions of clean hydrogen, and pending standardization, the 2023 SB 643 Staff Report recognizes the standard proposed by the U.S. DOE. The U.S. DOE recently proposed a clean hydrogen production standard (CHPS) that established a target of 4.0 kilograms (kg) of CO_2 equivalent produced per kilogram of hydrogen directly produced, for life-cycle (from feedstock through the point of production) GHG emissions of 4.0 kgCO2e/kgH2. This framework allows for several pathways, including nonrenewable but low-carbon pathways, such as hydrogen produced from fossil fuels paired with carbon capture. The CHPS is not a regulatory standard; however, awardees of federal hydrogen hub funding are required to demonstrably aid achievement of the CHPS by lowering emissions across the supply chain to the greatest extent possible. The U.S. DOE will revisit the CHPS by 2028.

Federal assessments of zero-emission infrastructure requirements are ongoing as well, coupled with unprecedented investments in clean hydrogen production. The United States Department of Energy (U.S. DOE) released a draft *DOE National Clean Hydrogen Strategy and Roadmap* in September 2022, providing a snapshot of hydrogen production, transport, storage, and use in the United States.

In recent years, unprecedented investments have been made at the state and federal levels. These investments are from the California state budget and two federal funding packages, the Infrastructure Investment and Jobs Act (IIJA, also referred to as the Bipartisan Infrastructure Law [BIL]), and the Inflation Reduction Act (IRA).

The CEC continues to invest in the research, development, and demonstration of hydrogen applications, as well as in MDHD refueling infrastructure including transit, light-duty refueling infrastructure for passenger vehicles, and clean hydrogen production. The CEC's investments in hydrogen have recently grown due to increased state funding and an increased focus on MDHD refueling infrastructure and to fund research, development, and demonstration in these sectors and market. To date, the CEC has invested about $376 million in hydrogen infrastructure, production, and research and development.

- $176 million for light-duty FCEV refueling infrastructure
- $102.7 for MDHD infrastructure, including enhancements for transit agencies such as on-site fuel production and refueling
- $17 million in fuel standards and equipment certification and light-duty FCEV deployment, MDHD FCEV demonstration, and regional alternative fuel readiness planning
- $22 million for clean hydrogen production projects
- $40 million in hydrogen production, storage, transmission and distribution, and end-use technologies
- $18 million invested for recently closed Energy Research and Development Division (ERDD) solicitations on innovative hydrogen refueling solutions for heavy transport.

The CEC's Fuels and Transportation Division will continue to invest in hydrogen refueling infrastructure and electric vehicle charging infrastructure for MDHD vehicles. Further, there is potential for an additional $40 million toward large-scale centralized hydrogen production and $30 million toward onsite hydrogen production and use from the new Clean Hydrogen Program.

The SB 643 Report Is an Ongoing Effort

The 2023 SB 643 Staff Report provides an initial statewide assessment of MDHD FCEV, FCEB and off-road applications using fuel cell technology, associated refueling infrastructure, clean hydrogen production projects, and scenarios of future demand for clean hydrogen. This assessment is intended to provide an early glimpse into the potential of clean hydrogen to help meet the goals outlined in Executive Order N-79-20, regulations issued in response to the order, and other statewide goals. Unprecedented developments in the MDHD FCEV sector are highlighted, including North America's largest commercial deployment of 30 heavy-duty FCEVs for drayage operations, located adjacent to the Port of Oakland in Northern California. This assessment endeavors to inform policy makers, infrastructure developers, original equipment manufacturers (OEM), and other interested stakeholders while recognizing that all the answers are not known yet, and clean hydrogen production supply and market demand will evolve over time.

2023 Report Analysis and Findings

Statewide regulations including the ACT, ACF, ICT, and the Off Road Regulation are advancing developments in zero-emission MDHD transportation and off-road applications. Complementary state incentive programs include the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), Clean Off Road Equipment Voucher Incentive Project (CORE), and the Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE) Project. These programs, which offset the costs of purchasing or leasing ZEVs and zero-emission equipment, are critical investments as additional research is conducted and demonstrations provide proof of concept, driving applications toward commercialization. An increase in demand from other industries beyond transportation is likely to help drive large-scale clean hydrogen production.

Key Takeaways

Key takeaways from this report include the following:

- Early government regulations and complementary incentive programs to support research, development, and demonstration of hydrogen fuel cell products, and public-private partnerships to invest in infrastructure for FCEVs, FCEBs, off-road applications, and clean hydrogen production, have encouraged market development.
- Continued state and federal funding and private sector investments are needed to increase the scale of production and reduce the cost of clean hydrogen. Transportation applications alone may not be sufficient to reach the demand scale needed to justify large clean hydrogen plants – multiple sectors with high clean hydrogen requirements may help drive production.
- The level of uncertainty for future demand for MDHD FCEVs is demonstrated by the variance between four scenarios presented in this report. Meeting the demand will be contingent on the cost and availability of the clean hydrogen fuel supply, which depends on state and federal policies and investments toward clean hydrogen production and demand from sectors other than transportation.
    - The *2022 Scoping Plan* scenario produced a need for 577 stations in 2030, and 1,797 stations in 2035.
    - The ARCH$_2$ES federal hydrogen hub scenario produced a need for 66 stations in 2030 and 117 stations in 2035. It is important to note that ARCH$_2$ES scenario is project-specific and includes mostly heavy-duty FCEVs and a comparatively small number of medium-duty FCEVs that would mainly refuel at light-duty stations.
    - The SB 671 scenario produced a need for 602 stations in 2030, and 2,157 stations in 2035.

    - The *2022 IEPR Update* AATE3 scenario produced a need for one station in 2030 and 11 stations in 2035. It is important to note that the *2023 IEPR* is considering a scenario with a low hydrogen price, which would result in a higher number of MDHD FCEVs and a subsequent need for many more hydrogen stations. Using this data and CEC staff's infrastructure scenario model would result in a need for many more hydrogen stations. However, this modeling is draft and has not gone through public review as of the publication of the 2023 SB 643 Staff Report, so preliminary results are not included.
- FCEBs are a proven application of heavy-duty fuel cell technology successfully demonstrated beginning 13 years ago and integrated into California's transit agencies' fleets. Some transit agencies are successfully using onsite renewable energy and electrolysis to produce clean hydrogen for their fleets. Transit agencies have different business models, with hydrogen supply contracts based on predictable demand, and onsite maintenance technicians. However, MDHD public refueling stations face greater challenges inherent to unpredictable supply and demand and availability of trained technicians to maintain the stations.
- Although there are challenges, zero- and low-carbon hydrogen in hard-to-electrify transportation and off-road applications can be a key part of a comprehensive portfolio of solutions to meet the clean energy future envisioned for California.

CHAPTER 1: Introduction

California leads the nation in developing and implementing programs to reduce air pollutants from mobile and stationary sources to protect public health and combat the climate crisis. Transportation is a major source of the state's air pollution, contributing nearly 80 percent of nitrogen oxides (NO_x) and 95 percent of toxic diesel particulate matter (DPM) emissions.[1] California's regulations, as well as past and current investments toward reducing greenhouse gas (GHG) emissions continue to be impactful, with GHG and other harmful air pollution emissions from heavy-duty vehicles declining, with the greatest declines in disadvantaged communities. The California Environmental Protection Agency's (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) reported that heavy-duty vehicles and industrial plants subject to California's Cap-and-Trade Program have reduced emissions over the last several years, with heavy-duty vehicles showing a clearer downward trend in emissions reductions in disadvantaged communities.[2] The Cap-and-Trade regulation established a declining limit on major sources of GHG emissions, creating an economic incentive for investment in cleaner, more efficient technologies. The Cap-and-Trade Program has enabled, among other benefits, the advancement of zero-emission trucks to become commercially ready through CARB's demonstration and pilot programs. Overall, DPM concentrations have decreased across California over the last 20 years as a result of this program and other CARB regulations such as the ICT and the Truck and Bus regulation.

While progress continues to be made, a growing urgency to address GHG emissions from transportation is evidenced through new policies, regulations, and unprecedented investments over the last two years under the Biden-Harris Administration, and at the state level through legislation and Executive Orders from Governor Gavin Newsom.

The *2023 Staff Report on Senate Bill 643: Clean Hydrogen Fuel Production and Refueling Infrastructure to Support Medium- and Heavy-Duty Fuel Cell Electric Vehicles and Off-Road Applications* (2023 SB 643 Staff Report) follows Senate Bill (SB) 643 (Archuleta, Chapter 646, Statutes of 2021). This law requires the California Energy Commission (CEC) to provide a statewide assessment of clean hydrogen fuel production and infrastructure needed to support the adoption of medium- and heavy-duty (MDHD) fuel cell electric vehicles (FCEV), fuel cell electric buses (FCEB), and off-road applications and equipment to meet specified goals and

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1 CARB. "Advanced Clean Trucks Fact Sheet," https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet. *Diesel particulate matter (DPM)* is tiny solid particles in the exhaust from trucks, buses, trains, ships, and other equipment with diesel engines. *DPM* includes hundreds of different chemicals, many of which are harmful to health.

2 California Office of Environmental Health Hazard Assessment (OEHHA) 2022. *Impacts of Greenhouse Gas Emission Limits Within Disadvantaged Communities: Progress Toward Reducing Inequities,* https://oehha.ca.gov/environmental-justice/report/ab32-benefits.

requirements related to vehicular air pollution.[3] The CEC is required to complete the first assessment by December 31, 2023, and update the assessment at least once every three years until January 1, 2030.

A separate CEC report published on August 24, 2023, *Staff Report on Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment: Assessing Charging Needs to Support Zero-Emission Vehicles in 2030 and 2035*,[4] assesses the infrastructure requirements for battery-electric vehicles (BEV), including light-duty (LD) electric vehicles and MDHD electric vehicles. The California Air Resources Board's (CARB) *2022 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development* assesses LD FCEV deployment and refueling infrastructure. A joint report by the CEC and CARB, *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*,[5] assesses LD FCEV refueling infrastructure.

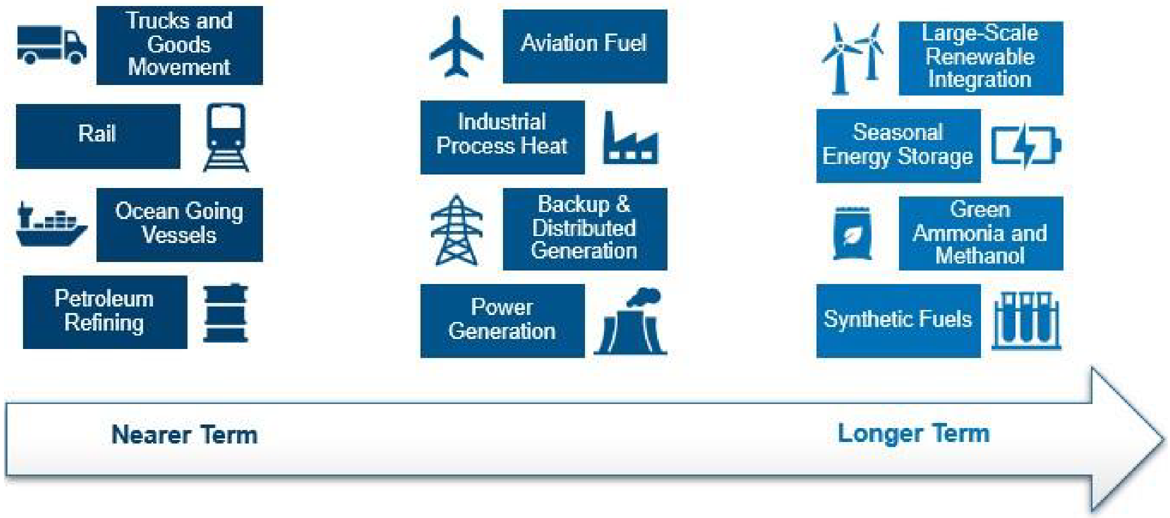
Grid reliability and hard-to-electrify sectors such as MDHD on-road transportation, off-road applications including non-road sectors such aviation, rail, maritime, and industrial processes are areas with a high potential for increased use of low-carbon or clean hydrogen.

3 Executive Order No. N-79-20 and any state board regulatory action that requires or allows zero-emission vehicles or applications in the MDHD transportation and off-road sectors.

4 Davis, Adam, Tiffany Hoang, Thanh Lopez, Jeffrey Lu, Taylor Nguyen, Bob Nolty, Larry Rillera, Dustin Schell, and Micah Wofford. 2023. *Staff Report on Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment: Assessing Charging Needs to Support Zero-Emission Vehicles in 2030 and 2035*. California Energy Commission. Publication Number: CEC-600-2023-048. https://www.energy.ca.gov/publications/2023/second-assembly-bill-ab-2127-electric-vehicle-charging-infrastructure-assessment.

5 Berner, Jane, Miki Crowell, and Andrew Martinez. 2022. *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. California Energy Commission and California Air Resources Board. Publication Number: CEC-600-2022-064, https://www.energy.ca.gov/sites/default/files/2022-12/CEC-600-2022-064.pdf.

Figure 1:Simplified Version of Nearer- and Longer-Term Opportunities for Hydrogen Decarbonization



Source: CEC staff[6]

Many of the opportunities highlighted in Figure 1 are discussed in the 2023 SB 643 Staff Report.

Health Impacts of MDHD Transportation and Off-Road Applications on Disadvantaged and Low-Income Communities

Replacing or retrofitting fossil-fuel powered MDHD vehicles with zero-emission technology will reduce GHG emissions and DPM emissions in disadvantaged and low-income communities near ports, distribution centers, and highways. Most major sources of diesel emissions, such as ships, trains, and trucks, operate in and around ports, rail yards, and heavily traveled roadways. These areas are often near highly populated areas, making elevated DPM levels an urban problem, with large numbers of people exposed to higher DPM concentrations. Off-road applications such as fossil fuel-powered agricultural equipment make elevated DPM and other pollutants in regions such as San Joaquin County a rural problem, as well.

The OEHHA report referenced earlier in this chapter evaluated the environmental and health equity of California's climate policies, finding that the communities that have benefited most from DPM reductions during the period of 2000–2019 were in high-scoring CalEnviroScreen (CES)[7] tracts. The report also found that zero-emission statewide goals for heavy-duty vehicles

6 Bailey, Stephanie, Jane Berner, David Erne, Noemí Gallardo, Quentin Gee, Akruti Gupta, Heidi Javanbakht, Hilary Poore, John Reid, and Kristen Widdifield. 2023. *Final 2022 Integrated Energy Policy Report Update.* California Energy Commission. Publication Number: CEC-100-2022-001-CMF, https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2022-integrated-energy-policy-report-update.

7 CalEnviroScreen (CES), or California Communities Environmental Health Screening tool, is a screening method that can be used to help identify California communities that are disproportionately burdened by sources of pollution.

could result in PM2.5[8] concentrations from those vehicles to be 58 percent lower in a scenario of complete transition to zero-emission heavy-duty vehicles by 2045, compared to the business-as-usual scenario.[9]

Policy Context

There are several policies at the federal, state, and local levels that target GHG and criteria air pollutants and present goals for zero-emission vehicles (ZEV). The California Legislature has been instrumental in providing direction and funding toward the effort to reduce harmful emissions and protecting its residents, with a particular focus on disadvantaged communities. To help address state climate change and air quality objectives, the California Legislature passed Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007), which created the Clean Transportation Program (CTP), which invests approximately $100 million annually, leveraging public and private investments to support innovations in a broad portfolio or transportation and fuel technologies that help California meet its energy, clean air, and climate change goals. Assembly Bill 126 (Perea, Chapter 401, Statutes of 2013) reauthorized the CTP until January 1, 2024. The California state legislature has the opportunity to extend the CEC's Clean Transportation Program to benefit California's residents and businesses through greater access to ZEV infrastructure.

On September 23, 2020, Governor Gavin Newsom's Executive Order N-79-20 set unprecedented, world-leading goals:

- By 2035, 100 percent ZEV sales for new passenger cars and trucks, 100 percent ZEV operations for drayage trucks, and 100 percent zero-emission off-road vehicles and equipment where feasible.
- By 2045, 100 percent ZEV operations for MDHD vehicles, where feasible.[10]

California leads the nation in developing a market for ZEV technologies to help meet its goals related to air quality and the environment and is home to many zero-emission OEMs due to its strong investment in the industry, education, and workforce.[11] Currently, BEVs, battery-electric buses (BEB), FCEVs, and FCEBs are the commercially available ZEV technology choices for MDHD transportation. To date, a wide range of regulations have been adopted to meet emission reduction goals for passenger vehicles, transit buses, airport shuttles, trucks, ferries, locomotives, and off-road equipment. Incentive programs administered by local, state, and federal government agencies provide funding to help businesses comply with these regulations and accelerate commercialization of these technologies.

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8 *Particulate matter (PM)*, also referred to as particle pollution, is tiny particles or droplets in the air. *PM2.5* is particulate matter that is 2½ microns or less wide.

9 OEHHA. 2022. Impacts of Greenhouse Gas Emission Limits Within Disadvantaged Communities. *Impacts of Greenhouse Gas Emission Limits Within Disadvantaged Communities: Progress Toward Reducing Inequities (ca.gov).*

10 Office of Governor Gavin Newsom. Executive Order N-79-20, https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf.

11 CARB. "Zero-Emission Vehicle Manufacturing and Technologies for Medium- and Heavy-Duty Vehicles in California," https://ww2.arb.ca.gov/sites/default/files/2021-08/MapofZeroEmissionOEMs.pdf.

At the federal level, President Joseph R. Biden's Executive Order 14057 directs the United States to reduce its Scope 1 and 2 GHG emissions[12] by 65 percent below 2008 levels by 2030 and achieve 100 percent ZEV acquisitions by 2035, with the goal of a net-zero emissions economy by 2050.[13] Under Executive Order 14008, President Biden established the Justice40 Initiative, which directs federal agencies to ensure that at least 40 percent of benefits achieved through the climate and clean energy investments are realized within disadvantaged communities.[14] In April 2023, the Biden-Harris administration announced new proposed vehicle pollution standards to make all vehicles cleaner and more efficient, including a new rule that built on the final standards that the United States Environmental Protection Agency (U.S. EPA) released in December 2022 for criteria pollutant emissions from heavy-duty vehicles to help accelerate the clean vehicle transition in a technology-neutral way.[15]

Unprecedented Federal Investments in Hydrogen

More than 50 years ago, the federal government's "moonshot initiative" helped the United States put the first people on the moon by using hydrogen as fuel for rocket propulsion and fuel cell onboard the spacecraft. Since then, U.S. DOE funding has resulted in more than 1,100 hydrogen and fuel cell patents, 30 commercial technologies, and more than 65 technologies that could be commercial within the next several years.[16]

Federal investments in clean hydrogen[17] production have accelerated in recent years.[18] The U.S. DOE built off the moonshot concept to develop the Energy Earthshots initiative, intended to accelerate development of clean energy solutions within the decade. The initiative began with the launch of the Hydrogen Shot on June 7, 2021, which endeavors to reduce the cost of clean hydrogen by 80 percent by 2030. In 2022, the United States Congress further

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12 Scope 1 emissions are direct GHG emissions that occur from sources that are controlled or owned by an organization. Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling.

13 President Joseph R. Biden Jr. December 8, 2021. Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/. (Accessed May 14, 2023).

14 President Joseph R. Biden, Jr. January 27, 2021. Executive Order on Tackling the Climate Crisis at Home and Abroad, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/. (Accessed May 14, 2023).

15 President Joseph R. Biden, Jr. April 12, 2023. Fact Sheet: Biden-Harris Administration Proposes New Standards to Protect Public Health that Will Save Consumers Money and Increase Energy Security, https://www.whitehouse.gov/briefing-room/statements-releases/2023/04/12/fact-sheet-biden-harris-administration-proposes-new-standards-to-protect-public-health-that-will-save-consumers-money-and-increase-energy-security/.

16 3 L. Steele, Pacific Northwest National Laboratory. "2019 Patent Analysis for the U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office," U.S. Department of Energy, Washington, DC, September 2020.

17 U.S. DOE's proposed clean hydrogen production standard is an initial target for life-cycle GHG emissions of 4.0 $kgCO_2e/kgH_2$.

18 U.S. DOE. "U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Draft Guidance," https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard.pdf?_gl=1*1278no4*_ga*NDczNzk0ODM4LjE2NTE2MTI0NTg.*_ga_VEJ5DJ7LND*MTY4NDYxMzcwMC4yOS4xLjE2ODQ2MTM3NjguMC4wLjA.

acknowledged the importance of hydrogen as a clean energy carrier by passing legislation with provisions that provide $8 billion toward the establishment of Regional Clean Hydrogen Hubs[19] through the Infrastructure Investment and Jobs Act (IIJA), also referred to as the Bipartisan Infrastructure Law (BIL).[20] In addition, the Inflation Reduction Act (IRA) provides a tax credit of up to $3.00 per kilogram (kg) of clean hydrogen produced. The hydrogen hubs will be one of the largest investments in U.S. DOE history. The historic funding through the BIL is complemented by new incentives in the IRA for qualified clean hydrogen produced with prevailing wages and apprenticeship requirements. Additional investments in clean hydrogen production through the BIL include $1 billion for electrolysis and $500 million for manufacturing and recycling.

Federal investments in MDHD ZEV infrastructure through the BIL include $2.5 billion in the Discretionary Grant Program for Charging and Fueling Infrastructure. In February 2023, the U.S. DOE announced $7.4 million in funding awards to seven projects that will develop MDHD charging and refueling corridor infrastructure plans. One of the awarded projects is focused on MDHD FCEV fueling network along the Interstate 10 corridor between Southern California and Texas. The "Houston to Los Angeles (H2LA)- I-10 Hydrogen Corridor Project" will result in a flexible and scalable blueprint for hydrogen fueling and heavy-duty freight truck network from Houston to Los Angeles.[21]

CEC Investments in Hydrogen Technologies and Infrastructure

Within the United States, California leads in hydrogen technology development, manufacturing, and infrastructure investments. California has 65 open retail hydrogen stations, with 65 additional stations planned through state and private investments. The only other state with an open retail station is Hawaii. Since 2008 and through July 2023, the CEC has invested nearly $376 million to support hydrogen research, development, and deployment projects. These investments include:

- $176 million in hydrogen refueling stations for light-duty FCEVs. Of these, 15 are planned to be multiuse[22] and include HD dispensers.
- $56 million in MDHD hydrogen refueling infrastructure.
- $46.7 million in MDHD hydrogen refueling infrastructure through the EnergIIZE program.
- $17 million in fuel standards and equipment certification, light-duty FCEV deployment, MDHD fuel cell vehicle demonstration, and regional alternative fuel readiness planning.
- $22 million in clean hydrogen production.

19 U.S. DOE. Office of Clean Energy Demonstrations. "https://www.energy.gov/oced/regional-clean-hydrogen-hubs," https://www.energy.gov/oced/regional-clean-hydrogen-hubs.

20 This report will reference BIL rather than IIJA, which are interchangeable, for consistency.

21 U.S. DOE. February 15, 2023. "Biden-Harris Administration Announces Funding for Zero-Emission Medium- and Heavy-Duty Vehicle Corridors, Expansion of EV Charging in Underserved Communities," https://www.energy.gov/articles/biden-harris-administration-announces-funding-zero-emission-medium-and-heavy-duty-vehicle.

22 A multi-use hydrogen refueling station includes light-duty and heavy-duty fueling dispensers.

- $40 million in hydrogen research and demonstration projects on emerging hydrogen production, storage, transmission and distribution, and end-use technologies.
- $18 million for recently closed Energy Research and Development Division (ERDD) solicitations on innovative hydrogen refueling solutions for heavy transport, hydrogen blending and lower NO_x emissions in gas-fired generation, and assessing hydrogen's role in California's decarbonizing electric system.

The CEC's Clean Hydrogen Program, administered by ERDD, is a $100 million program to provide financial incentives to eligible in-state projects for the demonstration or scale-up of production, processing, delivery, storage, or end use of clean hydrogen. Through competitive solicitations, these funds will become available to support projects in California over the next year. Furthermore, the CEC is developing a recurring funding opportunity for MDHD ZEV charging and refueling infrastructure along transportation corridors.

Developments in the MDHD Market

In California's transportation sector, light-duty (LD) fuel cell vehicles were introduced in California in larger numbers starting in 2016, and cumulative sales as of June 2023 total over 16,000. Both vehicle manufacturers and fleets are showing more interest in MDHD FCEVs. FCEBs are a demonstrated heavy-duty ZEV technology, and more than 100 FCEBs are part of California transit agencies' fleets, with additional FCEBs on order and included in the agencies' plans to reach the ICT regulation's zero-emission requirement. Moreover, new applications of hydrogen as a replacement to fossil fuels are being demonstrated in rail, marine, aviation, and other off-road sectors.

In the United States, most MDHD FCEV applications have been prototype development and demonstrations of the technologies, but over the last year, some have become commercially available and eligible for HVIP. The CEC anticipates having additional data to inform scenarios included in future iterations of the SB 643 report. Examples of demonstrations, pilots, and lessons learned through them include the Shore-to-Store demonstration at the Port of Los Angeles, funded through the Zero- and Near Zero-Emission Freight Facilities (ZANZEFF) program.[23] Additionally, the Northern California Zero-Emission Regional Truck Operations (NorCal ZERO) project, which is near completion, will be the largest commercial deployment of Class 8[24] FCEVs in North America.[25]

Incentive programs are offsetting the costs of new infrastructure and equipment for zero-emission applications. Incentives are offered to qualifying entities through public agencies including CARB, CEC, the California Public Utilities Commission (CPUC)7, the California State

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23 Port of Los Angeles. "Zero- and Near Zero-Emission Freight Facilities (ZANZEFF) Shore to Store Project." https://kentico.portoflosangeles.org/getmedia/db7c41ac-59b3-4491-8bb4-8a02d63b495d/zanzeff-fact-sheet.

24 A Class 8 vehicle weighs at least 33,001 pounds; examples of Class 8 vehicles include large buses, drayage tractors, and refuse/recycling trucks. Appendix A includes a graphic of different vehicle classes.

25 Center for Transportation & the Environment (CTE). "NorCal ZERO: Zero-Emission Regional Truck Operations With Fuel Cell Electric Trucks," https://cte.tv/project/norcal-zero-zero-emission-regional-truck-operations-with-fuel-cell-electric-trucks/.

Transportation Agency (CalSTA), the California Transportation Commission (CTC), regional air quality management districts, among others. The importance of collaboration across agencies to ensure that public funds are invested in a manner that serves the state's economy, residents, and policy goals is becoming more apparent, particularly with the passage of the ACF regulation in April 2023. Recognizing the need for a cohesive interagency approach to funding ZEV infrastructure, a joint statement of intent to collaborate on zero-emission vehicle infrastructure development in California was signed by the CEC, CARB, CPUC, Caltrans, Department of General Services (DGS), Governor's Office of Business Development (GO-Biz) and the CTC.[26]

Beyond the CEC's past and current investments in hydrogen research, demonstrations, workforce development and infrastructure deployment, many incentive programs for zero-emission projects are funded through the California Climate Investments (CCI) program. The CCI program is a statewide initiative that puts billions of cap-and-trade dollars into the Greenhouse Gas Reduction Fund (GGRF) to help reduce GHG emissions, strengthen the economy, and improve public health and the environment, especially in the most disadvantaged and low-income communities. Across California, there are 75 CCI programs administered by 23 state agencies, with the Legislature appropriating funds from the GGRF to those agencies. In Fiscal Year 2022–23, the Legislature appropriated $3 billion from the GGRF, bringing the total of appropriations to $22.6 billion. CARB administers many CCI programs, including those that provide incentives to hydrogen MDHD transportation and off-road applications, such as ZANZEFF, Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), Clean Off Road Equipment Voucher Incentive Project (CORE), and Advanced Technology Demonstration and Pilot Projects.[27]

26 CEC, CARB, CPUC, Caltrans, DGS, GO-Biz, CTC. April 20, 2023. *Zero-Emission Vehicle Infrastructure Joint Statement of Intent*, https://ww2.arb.ca.gov/sites/default/files/2023-04/ZEV%20Infrastructure%20Joint%20Statement%20of%20Intent%204-20-23%20final.pdf.

27 CARB. "California Climate Investments Funded Programs," https://ww2.arb.ca.gov/our-work/programs/california-climate-investments/california-climate-investments-funded-programs.

Defining Clean Hydrogen and Scaling Production to Meet Demand

Standardization of definitions for hydrogen are under development. Senate Bill 1075 (Skinner, Chapter 363, Statutes of 2022) requires CARB, in consultation with the CEC and CPUC, to prepare an evaluation on the development, deployment, and use of hydrogen, including policy recommendations and strategies for decarbonization, including definitions for different categories of hydrogen by June 1, 2024. Internationally, the definition varies, and the carbon intensity[28](CI) of different production methods can be difficult to calculate. Hydrogen produced through electrolysis using electricity from renewable energy sources is generally considered zero-emission production. However, there could be emissions generated during other phases of the fuel's full lifecycle. For example, there may be distribution-related emissions if a diesel-fueled truck transports the hydrogen from the production site to the demand location.

Pending standardized definitions of hydrogen in California through the SB 1075 effort, the *2023 SB 643 Staff Report* recognizes the definition of clean hydrogen production proposed by the U.S. DOE. In response to a requirement in the BIL, the U.S. DOE proposed a clean hydrogen production standard (CHPS) that established a target of 4.0 kg of CO_2 equivalent produced per kilogram of hydrogen that is directly produced, for life-cycle (from feedstock through the point of production) GHG emissions of 4.0 kg CO2e/kgH2.[29] This framework allows several pathways, including nonrenewable but low-carbon pathways, such as hydrogen produced from fossil fuels paired with carbon capture. The CHPS is not a regulatory standard; however, awardees of federal hydrogen hub funding are required to demonstrably aid achievement of the CHPS by lowering emissions across the supply chain to the greatest extent possible. The U.S. DOE will revisit the CHPS by 2028.

Clean hydrogen is a key element of a portfolio of solutions to reach California's emission reduction goals, as it is a zero- or low-carbon fuel that can replace carbon-intensive, fossil-derived hydrogen. Currently, clean hydrogen is produced in relatively small volumes in comparison to fossil-derived hydrogen because of costs and other challenges not uncommon to other nascent sectors, such as supply chain issues and equipment availability and permitting by local jurisdictions. New programs and investments are necessary to increase the scale of production and reduce costs and contribute to widespread decarbonization of California's economy. There are already many ways to produce hydrogen, but most are not nearly as clean as they need to be to achieve the decarbonization required to meet climate targets.

As shown in Figure 2, U.S. DOE's H2@Scale, low- or zero-carbon hydrogen can be produced through steam methane reformation (SMR)[30] with carbon capture utilization and storage (CCUS), gasification of waste, or at nuclear power plants, using high temperature electrolyzers

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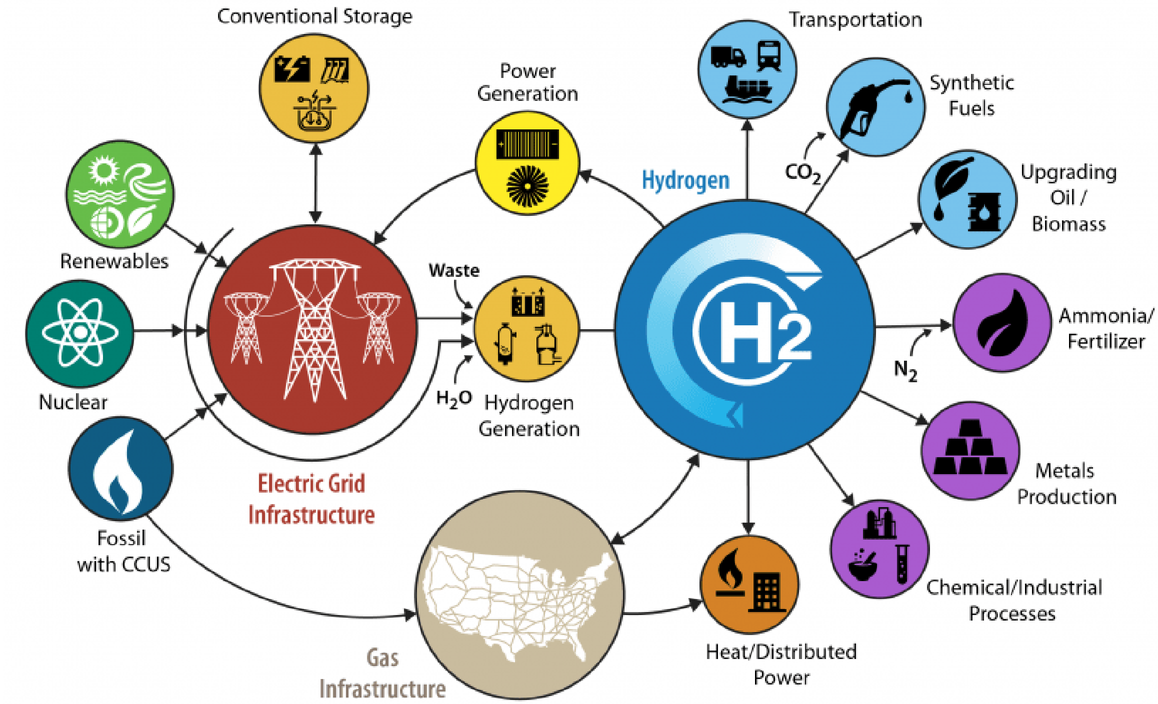
28 Carbon intensity (CI) is a measure of carbon dioxide and other greenhouse gases per unit of activity. For example, it may refer to how many grams of carbon dioxide are released to produce a kilowatt hour of electricity.

29 U.S. DOE. "U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Guidance," https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard-guidance.pdf.

30 Steam methane reformation (SMR) is a process in which methane molecules are split to extract hydrogen with carbon dioxide (CO2) as a by-product. Methane and CO2 are GHGs.

to produce hydrogen.[31] Electrolysis using renewable energy sources such as solar or wind near the demand source can produce zero-emission hydrogen.

Figure 2: Hydrogen Is a Versatile Technology for a Clean Energy Future



Source: U.S. DOE Hydrogen and Fuel Cell Technologies Office.[32]

More than 95 percent of hydrogen produced in California is from fossil fuels. Stations funded under recent CTP hydrogen refueling infrastructure solicitations or stations that are receiving LCFS HRI credits are required to comply with the renewable hydrogen requirements specified in CARB's LCFS regulation. The current LCFS requirement for renewable hydrogen is 40 percent. The manner in which this requirement is met requires additional explanation. Book-and-claim accounting refers to the chain-of-custody model in which decoupled environmental attributes are used to represent the ownership and transfer of transportation fuel under the Low Carbon Fuel Standard (LCFS) program, without regard to physical traceability. For reporting transactions, the LCFS program recognizes the use of book-and-claim accounting for pipeline-injected biomethane in North America that is either claimed as a transportation fuel or claimed as a feedstock to produce hydrogen for transportation purposes. This allows a hydrogen producer to purchase biomethane from the natural gas pipeline even though what is withdrawn from the pipeline is fossil natural gas.

Most LD refueling stations rely on excess gaseous hydrogen from existing industrial applications. Hydrogen fuel costs for gaseous hydrogen have risen sharply at the LD stations in 2023. In July 2021, the average retail price at hydrogen refueling stations was about

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31 DOE. November 9, 2022. "4 Nuclear Power Plants Gearing Up for Clean Hydrogen Production," https://www.energy.gov/ne/articles/4-nuclear-power-plants-gearing-clean-hydrogen-production.

32 U.S. DOE Hydrogen and Fuel Cell Technologies Office. "H2@Scale," https://www.energy.gov/eere/fuelcells/h2scale.

$16/kg. In July 2023, the retail price at LD stations was about $25/kg. Hydrogen station operators have attributed the price increase to several factors, including rising natural gas prices that in turn raise the production cost of hydrogen, inflation, higher energy costs spurred by the war in Ukraine, and decreased market value of LCFS credits that many station operators rely on to subsidize the pump price of hydrogen.

Many MDHD commercial fleet owners are likely to enter into long-term fuel purchase agreements with station owners that will be at a reduced cost that is less than what a LD station would charge at the pump. These agreements are comparable to the transit agencies' fuel supply contracts, in which the demand can be quantified and matched with the supply, and cost savings can be realized.

CEC staff estimates that the fuel cell system used in a heavy-duty FCEV is about 1.9 times more efficient than an average internal combustion engine. A heavy-duty FCEV can travel the same distance with 0.5898 kg of gaseous hydrogen as a regular heavy-duty truck can travel on a gallon of diesel. With that estimate, a $25.00 kg of gaseous hydrogen would be adjusted to $14.75, still making diesel a cheaper fuel than hydrogen. The price of hydrogen will likely need to reach or come close to price parity with diesel to encourage widespread adoption of MDHD FCEVs.

Table 1: Retail Price Comparison of Hydrogen, Gasoline and Diesel

Fuel Type/Measure	Retail Price (July 2023)	Adjusted for Efficiency
Gasoline/gallon	$4.90	n/a*
Diesel/gallon	$5.10	$5.10
Gaseous hydrogen/kg	$25.00	$14.75

***Heavy-duty trucks typically run on diesel fuel rather than gasoline.**

Source: CEC Staff

Liquid hydrogen, which is used by some transit agencies at the reported delivered cost of between $7 and $9 per kg, is less expensive to store and transport and likely to dominate production, onsite storage, and dispensing in the future. The storage costs and densities of liquid hydrogen far exceed those of gaseous hydrogen. However, it is important to note that stations that use liquid storage and cryo-pump refueling technologies typically face higher station costs. While many factors weigh into station operating costs, according to OEM Hyzon motors, liquid hydrogen has been estimated to be up to $5 per kg less expensive all-in to dispense than high-pressure gaseous for MDHD FCEVs. OEMs are currently exploring the use of liquid hydrogen for MDHD FCEVs, citing increased range and no added weight in comparison to gaseous hydrogen.[33]

33 Hyzon Motors. August 30, 2023. "Hyzon Motors Successfully Completes First Customer Demo of Liquid Hydrogen Fuel Cell Electric Truck." https://www.hyzonmotors.com/in-the-news/hyzon-motors-successfully-completes-first-customer-demo-of-liquid-hydrogen-fuel-cell-electric-truck.

Current demand for hydrogen in California's transportation sectors is primarily for FCEBs and for LD FCEVs. Emerging demand from other sources include MDHD FCEVs, cargo-handling equipment, yard tractors, and nonroad applications including rail, maritime, and aviation. These sectors alone are unlikely to create large-scale production of clean hydrogen without demand from other sectors, such as industrial uses and electricity generation.

The CEC Fuels and Transportation Division program staff collaborates with many experts on developing hydrogen refueling infrastructure and deployment of FCEVs, including:

- CARB, the CPUC, the Governor's Office of Business and Economic Development (GO-Biz) and the California Department of Food and Agriculture, Division of Measurement Standards (CDFA/DMS).
- The South Coast Air Quality Management District (SCAQMD), Bay Area Air Quality Management District (BAAQMD), and other air districts.
- The U.S. DOE and national laboratories, including the National Renewable Energy Laboratory (NREL) and the Lawrence Berkeley National Laboratory (LBNL).
- Industry stakeholders, including the National Hydrogen Fuel Cell Partnership and the California Hydrogen Business Council.

Staff also considers input from public comments received in workshops and submitted to the docket to develop grant solicitations and analyses. The public is encouraged to visit the following web pages to become involved in CEC activities:

- Subscriptions: https://www.energy.ca.gov/subscriptions
- Events: https://www.energy.ca.gov/events
- Solicitations: https://www.energy.ca.gov/funding-opportunities/solicitations

CHAPTER 2:
Medium- and Heavy-Duty Fuel Cell Electric Vehicles and Infrastructure

Background

This chapter discusses California's existing and planned MDHD FCEV refueling infrastructure and provides scenarios of how MDHD FCEVs could help reach statewide emission-reduction goals. Over the last two years, the pace of innovation, investment, and awareness of hydrogen as a truck fuel has increased. Most developments are with heavy-duty truck classes[34] used for freight movement. While freight vehicles provide many benefits to California's economy, including domestic goods movement, international trade, and other essential services, they also come with serious environmental costs. Although freight vehicles represent less than 2 percent of California registered vehicle stock, they are responsible for about 23 percent of on-road GHG emissions in the state because of comparatively low fuel efficiency and high number of miles traveled per year.[35] The biggest trucks, Classes 7 and 8 tractors, have the highest NO_x emissions within California's transportation sector, amounting to about 118.7 tons per day (tpd).[36]

MDHD ZEVs offer compliance with established GHG reduction targets and an opportunity to address degraded air quality, particularly in some of the most impacted, under resourced regions. There are two MDHD ZEV options — FCEVs and BEVs. Most commercially available options for MDHD ZEVs are BEVs, although unprecedented developments with MDHD FCEVs have occurred over the last two years. Both technologies have the potential to contribute to meeting statewide emissions goals. LD FCEVs began demonstrating on California's roads more than 20 years ago.[37] OEMs developing MDHD FCEVs and developers of MDHD refueling stations can leverage the knowledge and technologies developed for LD FCEVs and FCEBs and their refueling equipment and infrastructure.

Fleet owners likely consider multiple factors, including vehicle availability, refueling times, range, and cost-benefit analyses that consider fuel and electricity costs and vehicle maintenance in deciding which MDHD ZEVs best suit their requirements. The availability of refueling or charging infrastructure is an important factor as well. Figure 9, MDHD Hydrogen Refueling Network – Existing and Planned, provides a statewide view of developed and

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34 Appendix A defines and provides graphics of vehicle classes.

35 Based on analysis from California Energy Commission Energy Assessments Division, with data from the California Department of Motor Vehicles. California Air Resources Board. June 22, 2018. "California Greenhouse Gas Inventory for 2000–2018," https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/data/tables/ghg_inventory_scopingplan_sum_2000-18.pdf.

36 CARB 2022 CEPAM v1.01.

37 Electric Vehicle Transportation Center. September 2014. *Analysis of Fuel Cell Vehicle Developments,* http://fsec.ucf.edu/en/publications/pdf/fsec-cr-1987-14.pdf.

planned MDHD FCEV refueling infrastructure in California. Commercial availability of MDHD FCEVs is discussed in Table 3 in the context of vehicles currently eligible for HVIP incentives.

World-Leading Regulations

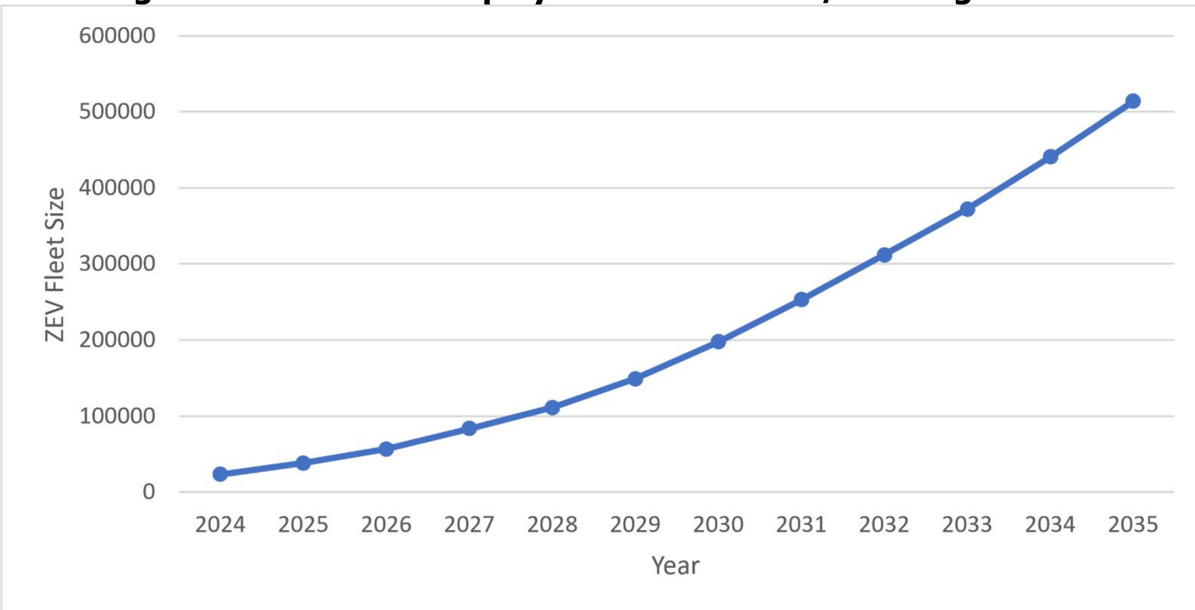
The Advanced Clean Trucks (ACT) and Advanced Clean Fleets (ACF) regulations are designed to work in tandem to cut air pollution and will be particularly effective to those who reside and work in low-income and disadvantaged communities. The ACT regulation requires manufacturers to accelerate sales of new zero-emission heavy-duty vehicles from 2023 to 2035, helping ensure that MDHD ZEVs are brought to the market. The ACF regulation works in conjunction with the ACT regulation by allowing manufacturers to sell only zero-emission MDHD ZEVs starting in 2036. When the ACF regulation was approved by CARB in April 2023, California became the first jurisdiction in the world to end the sales of traditional combustion trucks by 2036, which is instrumental in creating a path toward the state's goal of 100 percent zero-emission MDHD trucks in operation by 2045.[38] The regulation affects MDHD on-road vehicles with a gross vehicle weight rating greater than 8,500 pounds, off-road yard tractors, and light-duty mail and package deliveries. Furthermore, the ACF regulation provides different requirements for fleets to begin transitioning to zero-emission, including the following:

- Drayage trucks, local delivery and government fleets must transition by 2035.
- Garbage trucks must be zero-emission by 2039.
- All other vehicles covered by the regulation must be zero-emission by 2042.

For ACF to be successful, investments in public and private MDHD infrastructure are needed.

38 Office of Governor Gavin Newsom. April 28, 2023. "California Approves World's First Regulation to Phase Out Dirty Combustion Trucks and Protect Public Health," https://www.gov.ca.gov/2023/04/28/california-approves-worlds-first-regulation-to-phase-out-dirty-combustion-trucks-and-protect-public-health/.

Figure 3: MDHD ZEV Deployment Due to ACT/ACF Regulations



Source: CARB, Proposed Advanced Clean Fleets Regulation, Appendix F, Figure 5. (Online). Available at https://ww2.arb.ca.gov/rulemaking/2022/acf2022.

Local air quality management districts have developed rules to address the impacts of truck pollution as well. One of many examples include SCAQMD's Rule 2305, which established the Warehouse Actions and Investments to Reduce Emissions (WAIRE) program to cut truck pollution, increase electrification, and reduce health impacts in disadvantaged and low-income communities that are often most impacted by diesel exhaust.[39] The rule applies to about 3,000 warehouses across the region. WAIRE is a points-based program – warehouses subject to the Rule must earn points by, for example, acquiring zero-emission trucks, receiving visits from zero-emission trucks, or installing an onsite solar panel system, among other options.[40]

CEC Investments in MDHD FCEV Infrastructure

To date, the CEC has invested nearly $103 million in MDHD FCEV and FCEB infrastructure through several solicitations, which includes funding invested through GFO-20-603, "Block Grant for Medium-Duty and Heavy-Duty Zero-Emission Vehicle Refueling Infrastructure Incentive Projects," through the Clean Transportation Program. The solicitation intended to seek a block grant recipient to design and implement various MDHD ZEV refueling infrastructure incentive projects throughout California that would address critical barriers to infrastructure deployment. Clean transportation nonprofit CALSTART, Inc. (CALSTART) was awarded the agreement of up to $50 million in March 2021, which was increased to up to $276 million in December 2021.

39 South Coast Air Quality Management District. Facility-Based Mobile Source Measure. http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/facility-based-mobile-source-measures/warehs-distr-wkng-grp. (Accessed May 2, 2022.)

40 South Coast Air Quality Management District. Rule 2305 – Warehouse Indirect Source Rule. (Table 3, WAIRE Menu.) http://www.aqmd.gov/docs/default-source/rule-book/reg-xxiii/r2305.pdf?sfvrsn=9.

In early 2022, CALSTART launched Energy Infrastructure Incentives for Commercial Vehicles (EnergIIZE), California's first-ever block grant program designed to provide streamlined incentives infrastructure incentives for public and private fleets, owners, operators, school bus fleets, and transit agencies that plan to deploy battery-electric or hydrogen fuel cell electric vehicle technology. The 2022 EnergIIZE hydrogen funding lane allocated $17 million for five MDHD hydrogen refueling stations, one of which is for private fleet use only. Demand exceeded available funds, indicating a strong interest from station developers. The four publicly available hydrogen projects awarded funding are included in Table 5. The 2023 EnergIIZE hydrogen funding lane made available $29.7 million to potential developers, and project awards are anticipated to be announced this year.

These CEC investments in MDHD hydrogen infrastructure are in addition to significant other investments by the CEC in hydrogen infrastructure and production, including for light-duty hydrogen fuel cell electric vehicles. The CEC will continue to make investments in MDHD infrastructure to support MDHD hydrogen and electric trucks and buses.

MDHD FCEV Drayage, Long-Haul, and "Last-Mile" Delivery Trucks

The following sections discuss three applications of commercial trucks — drayage, long-haul and "last-mile"[41] delivery trucks. The ACF regulation prioritizes transitioning drayage and last mile delivery trucks to zero-emission first because of the relatively short travel distances and impact on disadvantaged communities. Federal efforts such as the CFI program acknowledge the importance of building infrastructure along major corridors to support the transition of long-haul trucks to zero-emission.

Freight movement is complex, and the diverse requirements of drayage, long-haul, and regional last-mile delivery trucks pose unique challenges for new powertrain technologies. MDHD BEVs and FCEVs are the zero-emission option for these applications, and the discussion of which technology is the best fit for different uses is ongoing, with demonstrations of both technologies informing OEMs, investors, and fleet owners in the transition to zero-emission MDHD transportation.

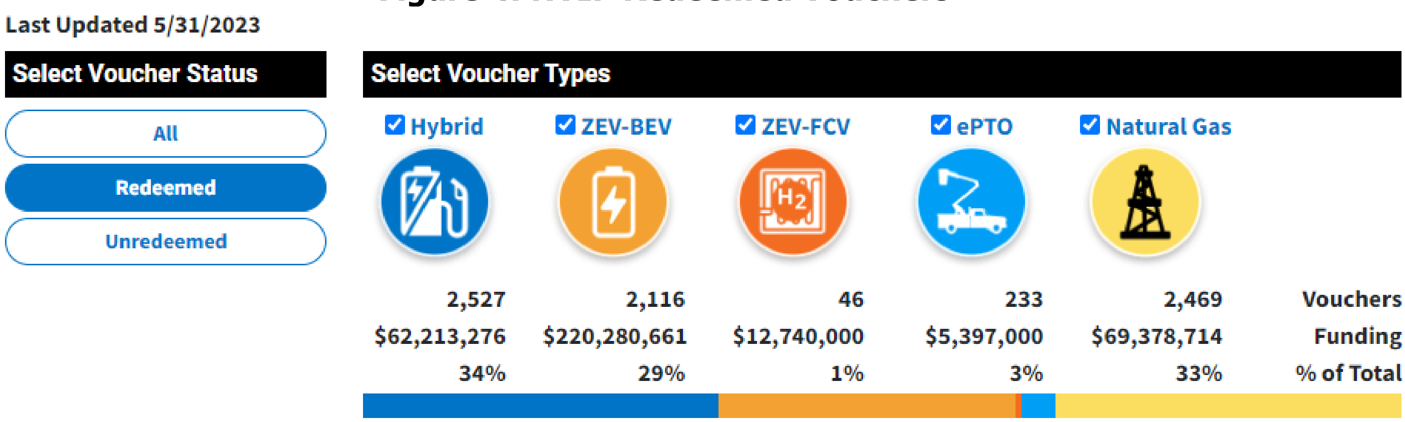
There are more offerings across the range of MDHD vehicle classes available in electric charging vehicle options relative to hydrogen fuel cell electric vehicle options. In May 2023, CARB's HVIP program lists 152 vehicles within three categories — battery-electric, hydrogen fuel cell electric, and electric power take-off (ePTO)[42]. Of the 152, there are 138 electric charging options and seven hydrogen fuel cell electric options. The seven hydrogen fuel cell electric options consist of transit buses and Class 8 trucks. Hydrogen fuel cell electric options are not available across all vehicle classes. For example, there are no hydrogen-powered school buses or medium-duty trucks that are commercially available, but demonstrations are underway.

41 "Last-mile" delivery trucks are used to bring items from a local warehouse or fulfillment center for final delivery to customers.

42 An electric power take-off (ePTO) vehicle takes power from an on-vehicle source (like a battery or hydrogen fuel cell) that produces no emissions. Work vehicles with ePTO are deemed HVIP-eligible by CARB based on a demonstration that the vehicle engine does not idle to recharge the battery or to power the truck.

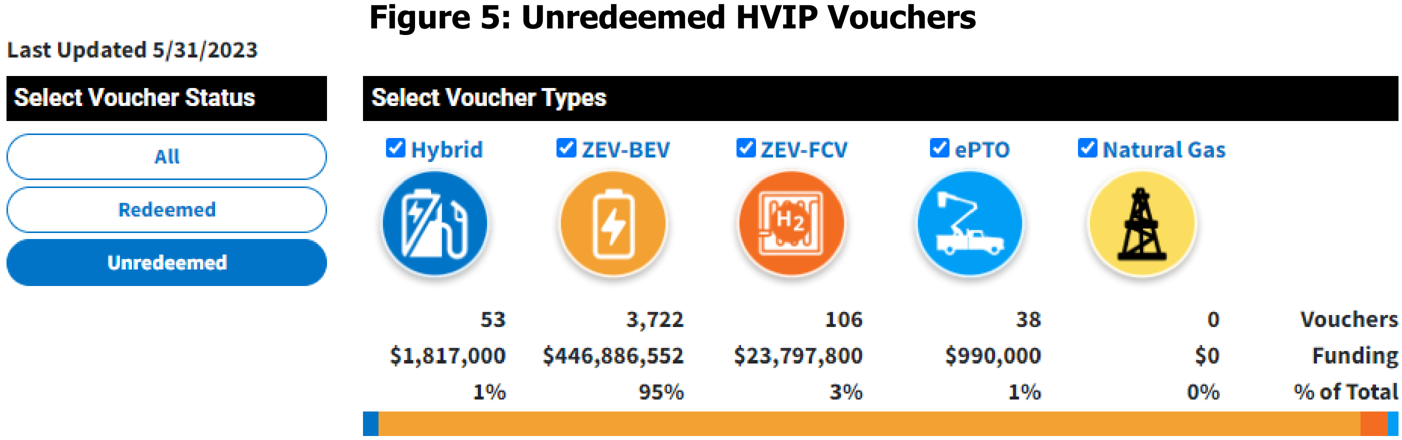
HVIP data provided in Figures 4 and 5 below show that as of May 31, 2023, of redeemed vouchers, there were 2,116 BEVs and 46 FCEVs. For upcoming vehicle deployments, as indicated as unredeemed, there are anticipated to be 3,722 BEVs and BEBs and 106 FCEVs and FCEBs. This is not the full range of zero-emission vehicles that will be deployed in California in the coming years. Drawing a linear parallel to the potential magnitude between the two technology types at this time is possible but may be premature. Important ongoing activities such as the possibility that California will receive a federal hydrogen hub funding award could spur infrastructure buildout at scale. Uncertainty about the availability of clean hydrogen, lack of operating MDHD stations, few available models, and fuel price are likely factors in decisions about purchasing or leasing MDHD FCEVs. However, investments by the state and federal governments are intended to address these uncertainties over the next three years and beyond.

Figure 4: HVIP Redeemed Vouchers



Source: CARB. [California HVIP Voucher Map and Data](https://californiahvip.org/impact/#deployed-vehicle-mapping-tool). https://californiahvip.org/impact/#deployed-vehicle-mapping-tool.

Figure 5: Unredeemed HVIP Vouchers



Source: CARB. [California HVIP Voucher Map and Data](https://californiahvip.org/impact/#deployed-vehicle-mapping-tool). https://californiahvip.org/impact/#deployed-vehicle-mapping-tool.

Drayage Trucks

Traditional drayage trucks are on-road, diesel-fueled, Classes 7 and 8 heavy-duty trucks that transport containers and bulk items to and from ports, intermodal rail yards, distribution centers, and other locations. They are ideal early targets for ZEV adoption due to the relatively short travel distances and impact on disadvantaged communities surrounding ports and intermodal rail yards. As of December 2022, there are more than 140,500 trucks in CARB's Drayage Truck Registry with 2010 or newer model year engines. Of those, about 51,500 are based in California, and 189,000 are out of state. About 33,500 drayage trucks service California's ports and intermodal rail yards annually.[43] The Ports of Los Angeles/Long Beach, referred to in Table 2 below as POLA, and the Port of Oakland (POAK) provided the information included in the table. Staff estimated the inventory for other seaports based on past survey data, and the inventory for trucks serving intermodal railyards was estimated based on aggregated data.

Table 2: Drayage Truck Inventory in Calendar Year 2019

Vehicle Category	POAK	POLA	Other Seaports	Intermodal Railyards	Total
In-State Class 8 Active Trucks	4,200	14,000	1,500	9,000	28,700
In-State Class 8 Inactive Trucks	n/a	2,800	n/a	n/a	2,800
In-State POAK Class 8 Already in POLA*	140	n/a	n/a	n/a	140
Classes 4-7	20	180	n/a	n/a	200
Out-of-State	820	850	n/a	n/a	1,670
Total	**5,180**	**17,830**	**1,500**	**9,000**	**33,510**

*** The 140 vehicles were registered at two ports – the POAK and POLA. The not applicable (n/a) for POLA is to prevent double counting the vehicles.**

Source: CARB[44]

The ports and intermodal railyards that are required to comply with the ACF regulation are located within 1 mile of a disadvantaged community, as categorized by the California Environmental Protection Agency (CalEPA), which uses CalEnviroScreen (CES), a mapping tool that helps identify communities that are most affected by pollution and where people are

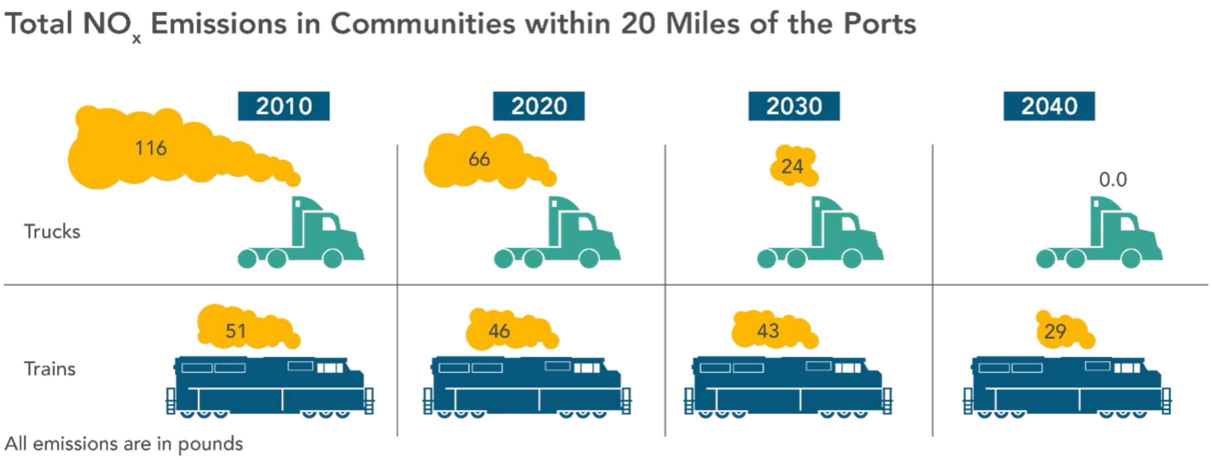
43 CARB. November 2022. "CARB Fact Sheet: 2022 Advanced Clean Fleets Regulation — Proposed Drayage Truck Requirements," https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-2022-advanced-clean-fleets-regulation-proposed-drayage-truck#:~:text=Approximately%2033%2C500%20drayage%20trucks%20service,or%20112%20times%20per%20year.

44 CARB. August 30, 2022. "Emissions Inventory and Results: Advanced Clean Fleets Regulation," https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/appf.pdf.

particularly vulnerable to pollution effects. CES uses environmental, health, and socioeconomic information to calculate scores for every census tract, and these scores are mapped, which provides a visual, comparative representation of different communities.[45]

Figure 6 provides an analysis of NO_x emissions within 20 miles of ports from drayage trucks versus trains moving the same amount of freight. The analysis shows that under CARB's regulations, trucks will produce fewer emissions compared to trains by 2030, partly because of efforts including the Cap-and-Trade Program, and the ACT and ACF regulations.

Figure 6: Truck vs. Train NOx Projected Emissions Under CARB Regulations



Source: CARB[46]

Drayage companies have a relatively straightforward compliance pathway under the ACF regulation. Any combustion-powered trucks must register in the CARB online system by December 31, 2023, or it will not be able to access any port, railroad, or other regulated area. These "legacy" drayage trucks can continue to operate through their minimum useful life. Beginning January 1, 2024, all new Classes 7 and 8 registrants to the CARB online system must be zero-emission or they will not be allowed to register or enter the regulated area. All drayage trucks entering regulated areas are required to be zero-emission by 2035.

The adjacent Ports of Long Beach and Los Angeles in San Pedro Bay are the largest fixed sources of air pollution in California, and the South Coast Air Basin (SoCAB) is one of the most polluted air basins in the United States, largely because the trucks and equipment used at the ports burn diesel fuel. Other contributing and related factors include the emissions from warehouses located in SoCAB, as they are a key destination for trucks and have other sources of emissions, including cargo-handling equipment. The governing boards of both ports unanimously agreed to the *2017 Clean Air Action Plan (CAAP) Update*, which targets NO_x and PM emission reductions and set the goal of 100 percent zero-emission operations. Since 2005, the strategies identified in the first adopted *Clean Air Action Plan* have resulted in reported

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45 California Office of Environmental Health Hazard Assessment (OEHHA). "About CalEnviroScreen," https://oehha.ca.gov/calenviroscreen/about-calenviroscreen. (Retrieved April 2023.)

46 CARB. https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-2023-advanced-clean-fleets-regulation-drayage-truck. https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-2023-advanced-clean-fleets-regulation-drayage-truck.

emission reductions of more than 85 percent for PM, 50 percent for NO_x, and 95 percent for sulfur oxides (SO_x).[47]

Using the ports as demonstration sites of MDHD ZEV infrastructure, equipment, and vehicles is a strategic way to create broad reach to the supply chain providers that use domestic ports. One of the first demonstration projects, the ZANZEFF program Shore-to-Store project, has concluded, and others are underway to evaluate and gain insights on MDHD FCEVs. To demonstrate the capability of MDHD FCEVs in real-world operations, the Shore-to-Store project was conducted at the Port of Los Angeles, the Los Angeles Basin, and the Inland Empire.[48] Toyota North America and Kenworth Truck Company HD jointly designed and built 10 Class 8 FCEVs for the demonstration. Equilon Enterprises LLC, doing business as Shell Oil Products U.S., built three MDHD hydrogen stations — two that received grant funding from CARB and SCAQMD for the Shore-to-Store demonstration and one additional station in the same operating region.[49] The project exhibited supply chain transport from the port to warehouses and was funded with a $41,122,260 grant from CARB and an equal match from project partners including SCAQMD.[50]

The CEC and CARB jointly issued GFO-20-606, "Zero-Emission Drayage Truck and Infrastructure Pilot Project," under the CEC's Clean Transportation Program and CARB's FY 2019–20 Funding Plan for Clean Transportation Incentives. The Center for Transportation and the Environment (CTE) was awarded $9,185,045 from the CEC and $11,979,914 from CARB for the NorCal ZERO project, which, when completed, will be the largest commercial deployment of Class 8 FCEVs in North America. The project will deploy 30 Hyundai XCIENT Class 8 FCEVs that will be refueled at a new hydrogen refueling station in Oakland to provide drayage services at the Port of Oakland and possibly longer-haul services in Northern California. As of September 2023, all the Hyundai XCIENTs had arrived from South Korea, and a mobile refueler was brought onsite to refuel them, pending completion of the refueling station. A project update will be included in the *2023 Final Report on Senate Bill 643: Clean Hydrogen Fuel Production and Refueling Infrastructure to Support Medium- and Heavy-Duty Fuel Cell Electric Vehicles and Off-Road Applications*.

47 Ports of Long Beach and Los Angeles. " Clean Air Action Plan Strategies," https://cleanairactionplan.org/strategies/. (Accessed May 15, 2023).

48 Port of Los Angeles. "Zero- and Near-Zero-Emission Freight Facilities (ZANZEFF) Shore to Store Project," https://kentico.portoflosangeles.org/getmedia/db7c41ac-59b3-4491-8bb4-8a02d63b495d/zanzeff-fact-sheet.

49 Table 5, Existing and Planned Infrastructure.

50 Ibid.

Long-Haul Trucks

Long-haul trucking is generally defined as long-distance transportation of cargo of 250 miles or more. Long-haul trucks can be either in-state or out-of-state vehicles, and the distinction is important in the context of California's zero-emission truck regulations. Although long-haul truck drivers are required to adhere to federal and state laws, ensuring out-of-state vehicles meet California regulations requires greater and more coordinated outreach and enforcement effort than in-state operators. It is potentially less likely that out-of-state vehicles will be able to fuel at fleet "home-base" stations and may be more likely to rely on public charging or hydrogen refueling stations.

New federal and state investment funding opportunities that may affect long-haul trucking because of the need for well-planned publicly available stations include the U.S. Department of Transportation's (U.S. DOT) Charging and Fueling Infrastructure (CFI) discretionary grant program. Established through the BIL, the CFI program provides up to $2.5 billion to eligible applicants to create community plans for infrastructure, or strategically deploy publicly accessible EV, hydrogen, propane, and natural gas fueling infrastructure along designated alternative fuel corridors. Strategic corridor infrastructure buildout within states and interstate is critical to the success of applications of ZEVs to prevent issues such as revenue loss by freight owners, range anxiety, and other undesirable outcomes that could result from insufficient publicly available charging and refueling infrastructure.

In April 2023, the North American Council for Freight Efficiency (NACFE) issued a report that provided its findings on zero-emission applications for freight, including hydrogen-based powertrains for Class 8 long haul freight routes pulling van trailers.[51] The NACFE found that a mix of HD FCEVs and BEVs will be needed for a zero-emission freight future, with HD BEVs as the most economical and efficient choice for shorter-distance duty cycles, and HD FCEVs as a viable solution for heavier, longer-distance duty cycles. NACFE's conclusions included the following:

- Growth in the HD FCEV industry is more dependent on production and distribution of hydrogen fuel, rather than the availability of vehicles or refueling stations.
- Hydrogen costs should decrease as production scales up, and large-scale production requires multiple industries, such as steel and cement manufacturing industries would need to migrate to hydrogen, not just transportation alone.[52]

"Last-Mile" Delivery Trucks

CEC staff is not aware of any commercially available MD FCEVs in California; however, there is an ongoing demonstration using retrofitted delivery vans. CTE is working with the United Parcel Service (UPS) and other project partners to develop an MD FCEV delivery van that aims to address concerns for zero-emission MD FCEVs. The "Fuel Cell Hybrid Electric Delivery Van Deployment Project" began in July 2014 and has since completed Phase 1, which consisted of

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51 NACFE. "Hydrogen Trucks: Long Haul's Future?" https://nacfe.org/research/electric-trucks/hydrogen/#. (Accessed May 13, 2023).

52 Ibid.

a prototype fuel cell delivery van that operated for more than one year in West Sacramento and Gardena. Phase 2 included the manufacturing and engineering of 15 MD FCEV delivery vans using 30 kW fuel cell engines developed and built by Cummins. The vehicles were assembled, validated, and began UPS package delivery service in Ontario in August 2023 and will be demonstrated through the end of 2024. The project, which serves a high concentration of disadvantaged communities in the Inland Empire, received U.S. DOE's Hydrogen Program 2023 Systems Development & Integration award in recognition of its achievements in the development and demonstration of a fleet of MD FCEVs operating in disadvantaged communities.[53]

Figure 7: Fuel Cell Hybrid Electric Van Deployment Project

Source: CTE

Current MDHD FCEV Market

In California and throughout the United States, there are only a few examples of MDHD FCEV refueling stations built and operating, adding to the challenges faced by infrastructure developers that are trying to navigate the processes of planning, constructing, and operating refueling stations. Without a high level of confidence, including transparency of infrastructure requirements, fueling standards, equipment availability and function, and uncertainty regarding the cost and reliability of infrastructure, potential developers have been cautious to invest. In parallel, OEMs have been slow to develop MDHD FCEVs in the United States.

The ACT and ACF regulations are driving commercial availability of MDHD FCEV models and hydrogen fuel cell powertrain retrofits. While the industry is still developing, the landscape is

53 CTE. August 2023. "CTE Collaborates with Partners on Innovative Fuel Cell Delivery Van Project." https://cte.tv/cte-collaborates-with-partners-on-innovative-fuel-cell-delivery-van-project/.

changing, as evidenced by Table 3, which provides the MDHD FCEV models eligible for HVIP.[54] Prior to 2023, only one Class 8 HD FCEV model was eligible for HVIP, and four have been added since then, as well as a zero-emission powertrain. In May 2023, a fleet carrier for the United States Postal Service and a drayage carrier operating in the Ports of Los Angeles and Long Beach announced the execution of a purchase order for 50 Nikola Tre Class 8 FCEVs. The trucks are scheduled to be delivered between the end of 2023 and beginning of 2024.[55]

The timeline for commercialization of MDHD FCEVs and hydrogen engine technologies designed to meet different fleet applications and procurement models to purchase or lease MDH FCEVs are key, as is scaling production from pilot projects to widespread use. Other important market drivers include making total cost of ownership competitive through fuel savings and maintenance reductions. As discussed in Chapter 1, and presented in Table 1, the retail price of gaseous hydrogen fuel is much higher than diesel fuel, and a scale up in hydrogen production is considered to be an important factor to help drive hydrogen fuel costs down. In 2023, five new Class 8 HD FCEV models were added as HVIP-eligible, and one OEM received CARB's executive order certifying that it had developed a zero-emission powertrain.

Table 3: HVIP Eligible MDHD FCEV Models*

Make	Model	Class	Tank Capacity (kg)	Tank Rated Pressure (Bar)	Typical Range (Miles)
Hyundai	XCIENT	8	50	700	500
Hyzon Motors	FCET8	8	50	350	300-350
Hyzon Motors	FCEV8-100	8	50	350	300-350
Hyzon Motors	FCEV8-200	8	50	350	300-350
Nikola	TRE[56]	8	70	700	500

CARB HVIP[57]

*HVIP-Eligible FCEBs provided in Chapter 3, Table 17

OEMs using a CARB-certified powertrain may also be eligible for federal incentives, and if the MDHD FCEV is for drayage applications, it may be eligible for the Ports of Long Angeles and Long Beach Clean Truck Fund incentives. For MDHD FCEVs Classes 4 and up, a zero-emission powertrain certification will be an additional requirement for all new HVIP vehicle-eligible applications submitted to CARB on or after January 1, 2023.

54 Tom's Truck Center. "Inventory: New Nikola TRE FCEV," https://www.ttruck.com/inventory/new-2022-nikola-trebev-commercial-truck-1n9apb1axn2393178/. (Accessed May 3, 2023.)

55 AJR Trucking. May 1, 2023. Accessed May 13, 2023. "AJR Trucking Announces Order for 50 Nikola Tre FCEVs," https://www.ajrtrucking.com/blog/ajr-trucking-announces-order-for-50-nikola-tre-fcevs/.

56 Nikola Motors. March 6, 2023. "Specifications for Nikola TRE FCEV," http://www.nikolamotor.com/wp-content/uploads/2023/04/FCE009_FCEV-US-Spec-Sheet-03.06.23.pdf.

57 CARB. "All Vehicles," https://californiahvip.org/vehicles/?t_type=379. (Accessed April 30, 2023).

Announcements of New MDHD FCEVs

With growing public and private investments in MDHD FCEVs, OEMs are responding with announcements of new fleet applications of zero-emission technologies. The Advanced Clean Transportation Expo held in Long Beach in May 2023 is an annual event that, among other objectives, allows OEMs to present prototypes and models that are in development or demonstration.[58]

Table 4: HD Models Announced at the 2023 ACT Exposition

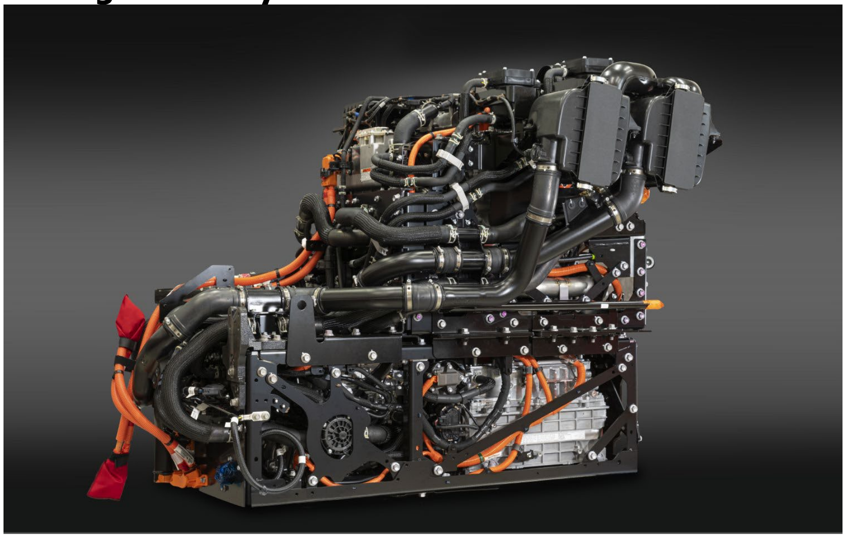
Make	Model	Class	Tank Capacity (kg)	Tank Rated Pressure (Bar)	Typical Range (Miles)
Kalamar Ottawa	CT195-70 Terminal Tractor	8	16	700	n/a
Hyundai	XCIENT Fuel Cell Tractor	8	68.6	700	450
Capacity	H2 Terminal Truck	8	15.1	350	n/a
Kenworth	T680 FCEV Daycab	8	58.8	700	450

Source: CEC staff. May not include all announced models.

The Shore-to-Store demonstration project proved that hydrogen fuel cells can power heavy long-haul tractor-trailers that require long-range travel. The project also demonstrated that hydrogen can be used as a fuel to power a fuel cell powertrain that performs much like a diesel powertrain in terms of torque and reliability, with added benefits including zero tailpipe emissions and a quieter, smoother drive. Demonstration projects can result in proof-of-concept technologies that become commercially available. Toyota deployed 10 Kenworth T680 Class 8 trucks that served real-world customers via drayage routes for the Shore-to-Store project.

58 U.S. DOE. "Advanced Clean Transportation Expo," https://cleancities.energy.gov/events/28474. (Accessed May 14, 2023).

Figure 8: Toyota's Zero-Emission Powertrain



Credit: Toyota

In April 2023, CARB issued an executive order certifying Toyota's HD fuel cell electric powertrain kit as a zero-emission powertrain (ZEP), which is shown in Figure 8. The ZEP is a hydrogen-fueled kit that includes fuel cell stacks, batteries, electric motors, and transmission.[59] This powertrain kit and others that may be in development by other companies provide an alternative to traditional diesel powertrains currently used in commercial goods transportation for companies seeking to transition the vehicles they use in their fleets to zero-emission trucks.

Existing and Planned MDHD Infrastructure

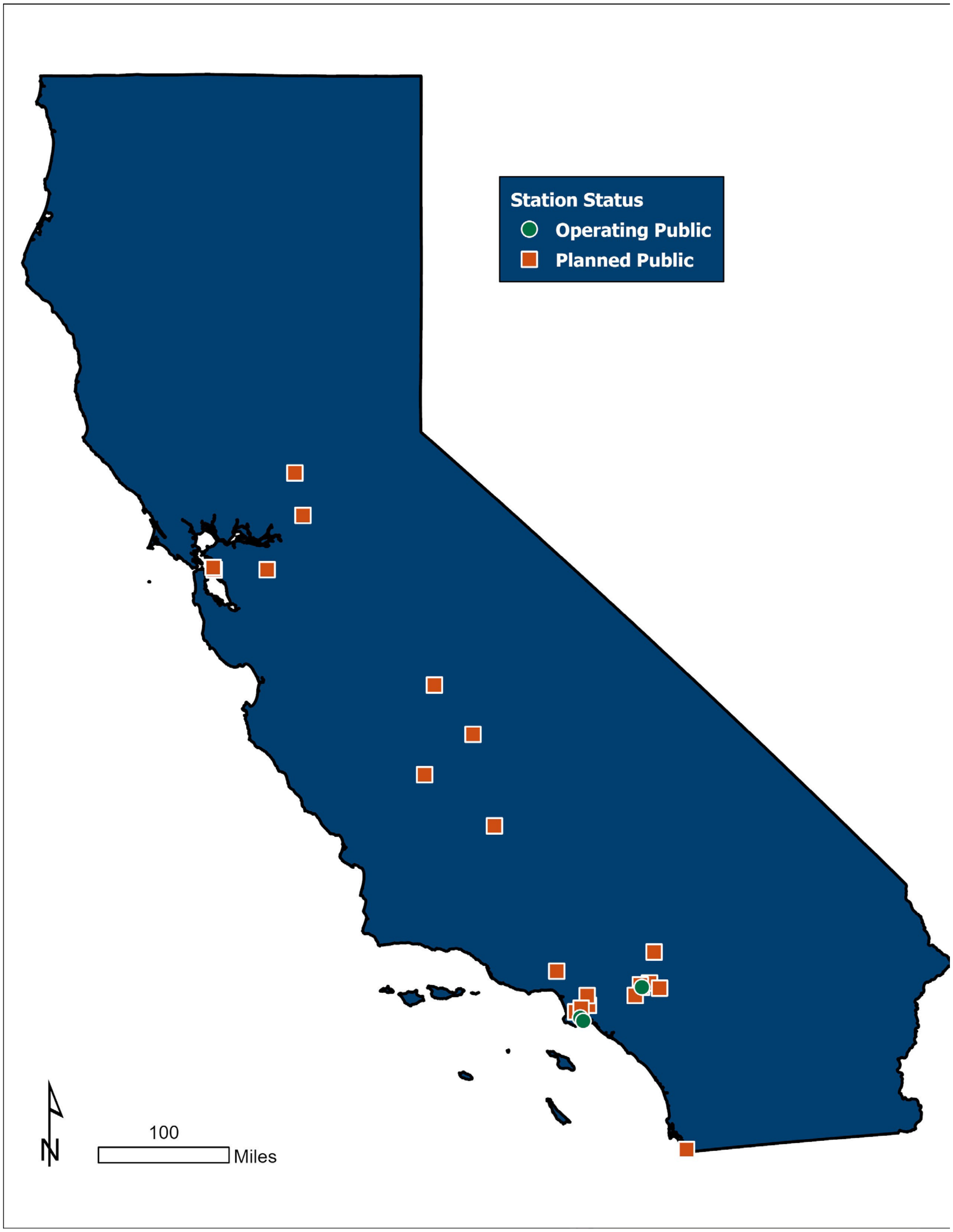
Based on information available to the CEC, three MDHD FCEV public retail refueling stations are operating in California, and 22 have been awarded funding and are in varying stages of development, including some that are multiuse that will have dispensing platforms for both HD and LD fueling. Additional infrastructure that is planned or has been developed by private industry is not reflected in Figure 9 and Table 5.

There are four general categories of FCEV refueling stations:

1. Private station that provides fuel to a single fleet
2. Private station that provides fuel to multiple fleets under a shared-use agreement
3. Public station that is restricted to a specific class of vehicles (LD vs. HD)
4. Public station that provides fuel for all on-road vehicle types

59 Toyota. April 24, 2023. "Toyota Receives Zero Emission CARB Executive Order for HD Fuel Cell Electric Powertrain Kit," https://pressroom.toyota.com/toyota-receives-zero-emission-carb-executive-order-for-hd-fuel-cell-electric-powertrain-kit/.

Figure 9: Operating and Planned MDHD Public Hydrogen Refueling Stations in California*



Credit: CEC staff

*Chapter 3, Figure 14, provides FCEB refueling infrastructure, current and planned.

Table 5: Operating and Planned MDHD Public Hydrogen Refueling Stations in California

Station Developer/Operator	Operating/ Planned	City	County	Capacity (kg)	Fuel Pressure (bar)	HD Fueling Positions
Shell	Operating	Wilmington	Los Angeles	1,140	350/700	2
Shell	Operating	Long Beach (POLB)	Los Angeles	1,140	350/700	2
Shell	Operating	Ontario	San Bernardino	1,140	350/700	2
FirstElement Fuel*	Planned	McClellan Park	Sacramento	18,000	700	2
FirstElement Fuel*	Planned	Fresno	Fresno	8,000	700	2
FirstElement Fuel*	Planned	Livermore	Alameda	8,000	700	2
FirstElement Fuel*	Planned	Kettleman City	Kings	18,000	700	2
FirstElement Fuel*	Planned	Oakland	Alameda	18,000	700	2
Air Products and Chemicals*	Planned	Galt	Sacramento	tba**	350/700	tba
Nikola	Planned	Ontario	San Bernardino	4,000	700	2
Nikola	Planned	Rialto	San Bernardino	tba	tba	tba
Nikola	Planned	Colton	San Bernardino	tba	tba	tba
Nikola	Planned	Hesperia	San Bernardino	tba	tba	tba
Nikola	Planned	Carson	Los Angeles	tba	tba	tba
Nikola	Planned	Otay Mesa	San Diego	tba	tba	tba
Nikola	Planned	West Sacramento	Yolo	tba	tba	tba
Air Products and Chemicals	Planned	Paramount	Los Angeles	3,000	350/700	tba

Station Developer/Operator	Operating/ Planned	City	County	Capacity (kg)	Fuel Pressure (bar)	HD Fueling Positions
Equilon	Planned	Carson	Los Angeles	tba	tba	tba
Pilot Travel Centers	Planned	Bakersfield	Kern	tba	tba	tba
Air Products and Chemicals	Planned	Visalia	Tulare	tba	tba	5
Prologis	Planned	Van Nuys	Los Angeles	tba	700	5
Prologis	Planned	Rancho Cucamonga	San Bernardino	tba	700	5
Prologis	Planned	Ontario	San Bernardino	tba	700	5
Prologis	Planned	Commerce	Los Angeles	tba	700	2
Prologis	Planned	Compton	Los Angeles	tba	700	2

Credit: CEC, CTC, CALSTART, CalSTA

***Planned for multiuse (light, medium, and heavy duty FCEV refueling)**

****To be announced (tba)**

*****Planned as capable of dispensing 250 kg hydrogen per hour**

Two of the three operating Shell MDHD refueling stations were partially funded as part of the Shore-to-Store demonstration. Six of the stations were funded through CEC grant funding solicitations and are planned to be multiuse stations, providing opportunities for HD and LD FCEVs to refuel at separate areas of the station. Table 5 includes four of the five MDHD refueling projects by developers that in total were awarded $17 million through the 2022 EnergIIZE hydrogen funding lane solicitation. Four of the five awarded stations will be publicly available, and the fifth is for a private fleet. CALSTART opened its 2023 EnergIIZE Hydrogen Funding Lane in April 2023, with a total of $29.7 million available. Nine projects were awarded funding; however, their locations had not been released at the time of publication of the 2023 SB 643 Staff Report and are not included in in Figure 9 or Table 5.

Estimating Demand for MDHD FCEV Stations

Given the present uncertainty regarding the number and classes of MDHD FCEVs that will become commercially available, the timing of infrastructure development and decisions by fleet owners to opt for either BEVs or FCEVs, and the high cost of hydrogen as a transportation fuel, the future demand for MDHD FCEV infrastructure and clean hydrogen supply required is challenging to predict. Demonstrations such as Shore-to-Store and pilot projects such as the NorCal ZERO drayage project have proven or are demonstrating that

MDHD FCEVs can be successful in drayage operations. The UPS project is demonstrating the viability of using MD FCEVs for last-mile deliveries.

The planning aspects for a hydrogen system are complicated and depend on several factors, including permitting, supply chain availability, and hydrogen supply availability. Modeling potential future systems across supply and demand sectors and ways that they could scale up over time is a complex undertaking.[60] The transportation sector would contribute to the development of a hydrogen ecosystem if there is strong demand growth for LD and MDHD FCEVs, with some research indicating that demand on a scale of 300–500 tons[61] per day by 2030 may be sufficient to reduce the costs associated with clean hydrogen.[62] However, infrastructure alone will not result in the proliferation of MDHD FCEVs. There are various factors that will have an effect, and, as such, public investments should be done in a pragmatic manner based on robust data.

The following section provides potential scenarios of MDHD infrastructure deployment from 2025 through 2035. Current and future estimated hydrogen demand scenarios for FCEBs are provided in Appendix B. Methodologies, sources and assumptions used to produce the following four scenarios are provided in Appendix C of the 2023 SB 643 Staff Report.

2022 Scoping Plan Infrastructure Scenario

In 2006, the Legislature passed Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006),[63] which created a multiyear program to reduce GHG emissions in California. AB 32 required CARB to develop a Scoping Plan to indicate how California can reduce emissions to 1990 levels by 2020.[64] CARB approved the inaugural Scoping Plan was in 2008 and three subsequent updates, the most recent version being the *2022 Scoping Plan*, released in November 2022.[65]

The *2022 Scoping Plan* explores the role low-carbon hydrogen can have in decarbonizing the transportation, industrial, and other sectors and highlights the importance of growth in the production and distribution of clean hydrogen, to help drive the scale of demand from those and other sectors. The *2022 Scoping Plan* provides scenarios that explore technology and fuel options to reduce dependence on fossil fuels. These scenarios are not forecasts but rather projections of GHG emission reductions that may be achieved through combinations of actions between the present and 2045. The modeling outputs and results are contingent on key

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60 Fulton, L.; Jenn, A.; Yang, C.; Burke, A.; Acharya, T.; Li, X., et al. 2023. *California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California: Final Synthesis Modeling Report*. *UC Davis: Hydrogen Pathways Program*. Retrieved from https://escholarship.org/uc/item/27m7g841.

61 One ton is equivalent to 917 kg.

62 Fulton, L.; Jenn, A.; Yang, C.; Burke, A.; Acharya, T.; Li, X., et al. 2023. *California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California: Final Synthesis Modeling Report. UC Davis: Hydrogen Pathways Program.* Retrieved from https://escholarship.org/uc/item/27m7g841.

63 Also known as the California Global Warming Solutions Act.

64 CARB. "About AB 32 Climate Change Scoping Plan," https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/about. (Accessed April 29, 2023).

65 CARB. November 2022. *2022 Scoping Plan for Achieving Carbon Neutrality,* https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf.

assumptions, limitations of data sets, and model capacity to reflect the complexities of California's energy system.

The *2022 Scoping Plan Appendix H: AB 32 GHG Inventory Sector Modeling* provides technical support for the modeling analysis of the AB 32 GHG Inventory sectors. References for assumptions related to the transportation sector modeling are included in Table H-4 of Appendix H. CARB's Emission Factors Model (EMFAC) 2021 was used to develop baseline on-road energy consumption, providing vehicle miles traveled, vehicle stock shares by fuel type, and vehicle populations.[66] Infrastructure scenarios were not part of the assessment, and the CEC staff scenario does not differentiate between depot/private stations and public stations. FCEV fleet owners will decide what will work best for their operations including cost considerations. For example, a fleet owner could choose to have a "home base" depot station for long-haul trucking that is optimally located within the range where it could refuel at a public refueling station, and possibly another public station if there is a build-out of stations along major trucking corridors.

CEC staff used the medium-duty and heavy-duty hydrogen fuel cell vehicle stock provided in *2022 Scoping Plan: GHG Inventory Sectors Modeling Data Spreadsheet* and the set of assumptions provided in Appendix C of the 2023 SB 643 Staff Report to produce the scenario provided in Table 6 and corresponding estimated hydrogen demand in Table 7. CEC staff is not aware of any MD FCEV vehicles that are commercially available at this time; as such, the likelihood of needing 17 medium-duty stations by 2025 is low. Moreover, there is an expectation that MD FCEVs may be able to refuel at light-duty stations. However, the light-duty station footprint may not allow for larger vehicles and the LD FCEV customer experience is also an important consideration.

Table 6: 2022 Scoping Plan Infrastructure Scenario

Stations	**2025**	**2030**	**2035**
Medium Duty	17	395	1,129
Heavy Duty	30	182	668
Total Stations	**47**	**577**	**1,797**

Source: CEC staff [67]

66 CARB. *2022 Scoping Plan: Appendix H – AB 32 GHG Inventory Sector Modeling.* https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf.

67 CEC staff estimate based on MDHD vehicle stocks provided in *2022 Scoping Plan*. Staff assumptions: For MD FCEVs, 10 kg/day; MD station capacity of 1,000 kg/day at 80 percent capacity. For HD FCEVs, 30 kg/day, HD station capacity of 3,000 kg/day at 80 percent capacity. FCEBs are not included.

Table 7: 2022 Scoping Plan Scenario: Estimated Hydrogen Demand from MDHD FCEVs (kg)

Vehicle Class	2025	2030	2035
Medium Duty	3,173,310	72,136,410	206,017,680
Heavy Duty	19,583,856	119,655,468	438,949,584
Total Annual Demand (kg)	**22,757,166**	**191,791,878**	**644,967,264**

Source: CEC staff

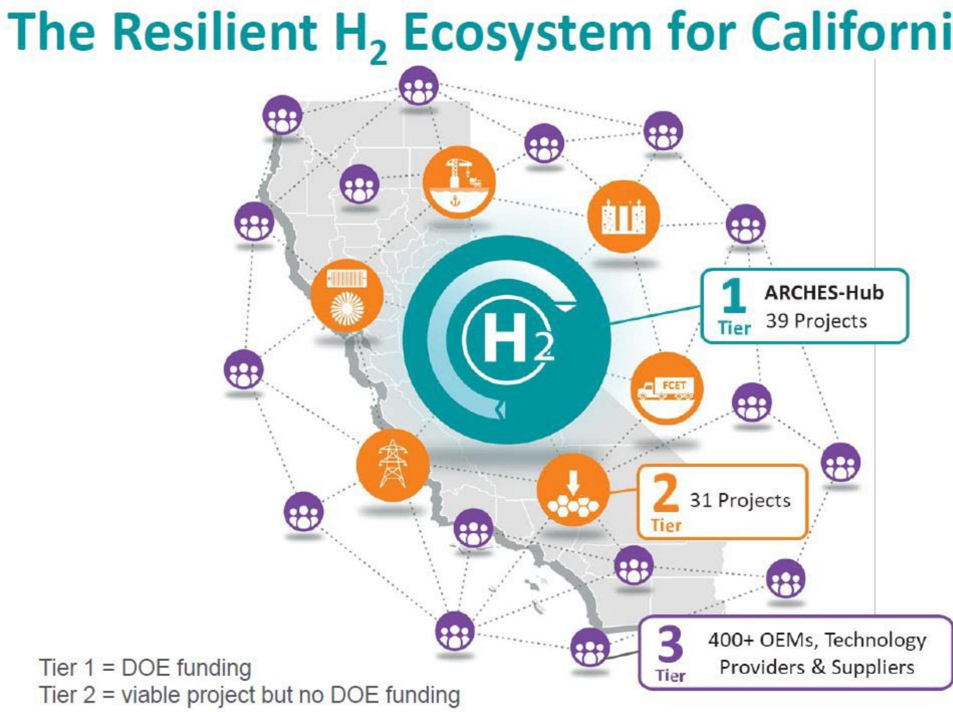
Alliance for Renewable Clean Hydrogen Energy Systems ($ARCH_2ES$) Federal Hub: Background and Infrastructure Scenario

In September 2022, the U.S. DOE opened a $7 billion funding opportunity for the regional clean hydrogen hubs. The law defines the term "regional clean hydrogen hub" as "a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity." In response to this opportunity, GO-Biz, the University of California system, the State Building and Construction Trades Council of California, and the Renewables 100 Policy Institute formed $ARCH_2ES$.

$ARCH_2ES$ is a public-private partnership created to promote and oversee the design, development, and deployment of hydrogen infrastructure projects in California across at least three sectors, including power, heavy-duty transportation, and marine and inland ports. $ARCH_2ES$ priorities include the following:

- Create an economically sustainable, expanding, clean hydrogen market
- Focus efforts on communities with the largest pollution burden
- Prioritize the hardest to abate sectors with the biggest emissions profiles, focusing on creating economically sustainable markets

Figure 10: ARCH₂ES Resilient Clean Hydrogen Ecosystem Vision



Source: GO-Biz. September 8, 2023. Panel 1, Presentation 1E, Tyson Eckerle. "California's Clean Hydrogen Market Development." https://www.energy.ca.gov/event/workshop/2023-09/iepr-commissioner-workshop-potential-growth-hydrogen.

ARCH$_2$ES submitted a concept paper in December 2022 that requested $1.25 billion from the U.S DOE with a cost share of $4.75 billion, and a project duration of eight years to build the hydrogen hub. The full ARCH$_2$ES project proposal totaled $11.3 billion. Encouraged by the U.S. DOE to submit a full application, ARCH$_2$ES submitted its proposal to become a national hydrogen hub on April 7, 2023.[68] An announcement of awards by the U.S. DOE is anticipated to occur in fall 2023.

Pending the U.S. DOE's announcement of awards, information about the projects and other details that comprise the ARCH$_2$ES proposal is confidential. Table 8 provides a heavy-duty station scenario developed by the University of California, Davis, an ARCH$_2$ES partner, in collaboration with CEC staff. Medium-duty stations are not included in this scenario – an assumption of the ARCH$_2$ES scenario is that most MD FCEVs will be able refuel at light-duty and/or heavy-duty stations. Another assumption is that the stations will scale-up in size over time; with earlier stations having a capacity of about 3,500-5,000 kg/day, and stations in 2035 having a capacity of around 7,000-8,000 kg/day. A few private/depot stations that may be part of the ARCH$_2$ES proposal are not reflected in Table 8. Additional details about the assumptions used to produce this scenario are included in Appendix C.

68 ARCHE$_2$S. April 7, 2023. "California Submits Application to U.S. Department of Energy for Federal Funding to Become a National Hydrogen (H2) Hub," https://archesh2.org/california-submits-application-to-u-s-department-of-energy-for-federal-funding-to-become-a-national-hydrogen-h2-hub/.

Table 8: ARCH$_2$ES Federal Hub Infrastructure Scenario

Stations	2025	2030	2035
Heavy Duty Stations (Public)	**12**	**66**	**117**

Source: UC Davis, ARCH$_2$ES partnership

Table 9: ARCH$_2$ES Federal Hub Scenario Estimated Hydrogen Demand

	2025	2030	2035
Total Annual Demand (kg)	**8,940,325**	**74,502,705**	**120,859,530**

Source: UC Davis, ARCH$_2$ES partnership

Senate Bill 671 Draft MDHD Infrastructure Scenario

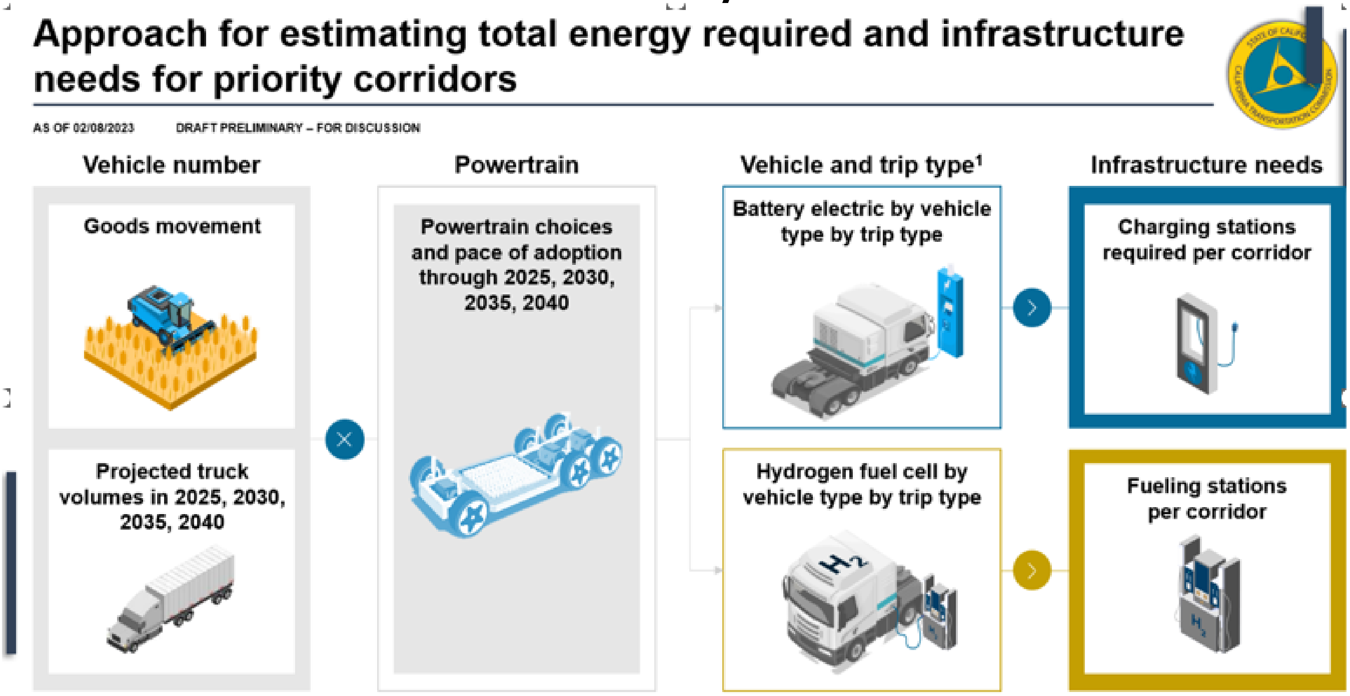
Senate Bill 671 (Goncalves, Chapter 671, Statutes of 2021)[69] requires the CTC to prepare a Clean Freight Corridor Efficiency Assessment that identifies freight corridors, or segments of corridors, and the infrastructure needed to support the deployment of zero-emission MDHD vehicles by December 1, 2023. CTC staff developed the draft assessment in collaboration with a SB 671 workgroup and several other state agencies, including CARB, the CEC, GO-Biz, Caltrans, CalSTA, and the CPUC. The workgroup was public, and CTC staff reached out to advocates and experts from the freight industry when establishing the workgroup.

CTC staff found that estimates of zero-emission freight infrastructure needs depend on several variables, and there is uncertainty when predicting what will occur over the next 20 years. Hence, three potential scenarios of infrastructure needs were prepared. The methodology used to develop three possible scenarios of zero-emission infrastructure is described in the Senate Bill 671 Infrastructure Needs Assessment prepared by CTC staff.[70]

69 Senate Bill 671 (Gonzalez, Chapter 769, Statutes of 2022). Clean Freight Corridor Efficiency Assessment, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB671.

70 CTC. "Senate Bill 671 Infrastructure Needs Assessment." https://catc.ca.gov/-/media/ctc-media/documents/programs/sb671/092023-infrastructure-needs-assessment-a11y.pdf.

Figure 11: CTC Approach for Estimating Energy Requirements and Infrastructure Needs for Priority Corridors



[1] Vehicle types include Classes 4-8. Trip types include urban, regional, long-haul.

Source: CTC staff

The assessment provided a high BEV scenario, a balanced scenario, and a high FCEV scenario. The information provided in Table 10 reflects the SB 671 balanced scenario infrastructure needs for FCEVs from 2025 through 2035, which assumes 19 percent of vehicle Class 4-8 zero-emission trucks will be FCEVs by 2025 and 73 percent will be FCEVs by 2035. This assumption is based on the likely total cost of ownership parity with internal combustion engines, with cost parity assumptions based on industry insights and a McKinsey Center for Future Mobility study.[71] The scenarios include Classes 4–8 trucks and exclude Class 2b–3 vehicles because the vehicle class categories used are based on CARB's class definitions as outlined in EMFAC 2021, which defines Class 4 as the first medium-duty public fleet truck vehicle. In contrast, the 2022 Scoping Plan scenario includes Classes 2b–8 vehicles.

71 McKinsey & Company. January 30, 2023. "Why the Economics of Electrification Make This Decarbonization Transition Different." https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/why-the-economics-of-electrification-make-this-decarbonization-transition-different?stcr=F2E91F7E3B364985951002C7AEE3335D&cid=other-eml-alt-mip-mck&hlkid=5029d8f5ce4c43abb7c63ff53e942ad0&hctky=1234124&hdpid=4eb1e872-7192-48d7-b6cb-0642d205d4c5.

Table 10: SB 671 Balanced Scenario MDHD FCEV Infrastructure

Stations	2025	2030	2035
MDHD Private	7	150	539
MDHD Public	21	451	1,618
Total Stations	**28**	**602**	**2,157**

Source: CTC staff

CTC staff provided the estimated hydrogen fuel demand shown in Table 11 under the balanced scenario.

Table 11: SB 671 Balanced Scenario Estimated Annual Hydrogen Demand (kg)

Vehicle Class	2025	2030	2035
Medium-Duty	199,473	4,137,056	18,881,023
Heavy-Duty	7,943,377	171,585,233	611,006,435
Total Annual Demand (kg)	**8,142,850**	**175,722,289**	**629,887,458**

Source: CTC staff

Additional Achievable Transportation Electrification 3 MDHD FCEV Energy Demand Scenario

The CEC prepares an Integrated Energy Policy Report (IEPR) every two years that provides updates on a variety of energy issues facing California. As part of the IEPR process, the CEC develops and adopts forecasts of end-use electricity demand. In the *2022 Integrated Energy Policy Report Update (2022 IEPR Update)*, the transportation energy demand forecast was modified in consideration of the world-leading state goals for ZEVs and strong supporting regulatory and programmatic initiatives. The Additional Achievable Transportation Electrification (AATE) framework begins with a baseline forecast that uses economic and demographic inputs, coupled with vehicle choice and vehicle travel models, which determine total vehicle stock and transportation energy demand for the LD and MDHD sectors. The *2022 IEPR Update* includes an AATE Scenario 3, which considers an increased amount of electric vehicle adoption and associated electricity demand, which informs resource procurement and grid planning.

The *2022 IEPR Update* AATE Scenario 3 shows a low uptake in MDHD hydrogen vehicles due to a range of modeling inputs, including a relatively high hydrogen fuel price received from NREL, which made hydrogen trucks less viable in the truck choice model. As more data for MDHD hydrogen vehicles become available, the inputs for the MDHD models will be refined.

The AATE-3 Scenario was produced by CEC staff using assumptions and inputs provided in Appendix C of the 2023 Staff Report on SB 643. As with the 2022 Scoping Plan Scenario, this scenario does not differentiate between depot/private stations and public stations. FCEV fleet owners will decide what will work best for their operations which will include cost, location, fleet size, and other considerations.

Table 12: AATE3 MDHD FCEV Infrastructure Scenario

Stations Requirements	2025	2030	2035
Medium-Duty FCEV	0	1	10
Heavy-Duty FCEV	0	0	1
Total Stations	**0**	**1**	**11**

Source: CEC staff[72]

Table 13: AATE3 Scenario Estimated Annual Hydrogen Demand (kg)

Vehicle Class	2025	2030	2035
Medium-Duty	0	43,483	685,862
Heavy-Duty	0	0	6,215
Total Annual Demand (kg)	**0**	**43,483**	**692,077**

Source: AATE3 scenario prepared by CEC staff

72 CEC staff estimate based on MDHD vehicle stocks provided in AATE-3. Staff assumptions: For MD FCEVs, 10 kg/day, 365 days; MD station capacity of 1,000 kg/day at 80 percent capacity. For HD FCEVs, 30 kg/day, 365 days, HD station capacity of 3,000 kg/day at 80 percent capacity. FCEBs are not included.

Estimating a Range for Future MDHD FCEV Hydrogen Demand

The variance among the four scenarios indicates a level of uncertainty at this early stage of the transition to MDHD ZEVs in California. Estimating MDHD FCEV station requirements and hydrogen demand in future iterations of this assessment will have a higher level of certainty:

- More fleet owners will have decided on the best ZEV technology fit for their operations, which will depend on several factors, including the commercial availability of MDHD ZEVs.
- Future assessments under SB 643 will include scenarios prepared in collaboration with Lawrence Berkeley National Lab using its Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operations, and Deployment (HEVI-LOAD) model. HEVI-LOAD will assess the hydrogen refueling infrastructure needs of on-road MDHD FCEVs, mapping different percentages of vehicle stock breakdowns onto the AATE3 BEV populations to assess adoption scenarios. This information creates a foundation on which the model will build vehicle simulation functionality to determine the optimal refueling infrastructure needed to support them, including identifying ideal locations and associated energy demand quantification based on the vehicle simulation.

Challenges in Deployment of MDHD FCEV Refueling Infrastructure

An overarching challenge in MDHD FCEV refueling infrastructure deployment is that commercially available vehicles and public refueling infrastructure are necessary to the other, and investments need to be made in both. The CEC and other state agencies are already making significant investments in hydrogen station infrastructure. State, federal, and private investments toward researching, developing, and testing MDHD FCEV refueling infrastructure have generally concluded that common challenges in building the refueling stations include land acquisition, site readiness, permitting processes, and high capital and operational costs, even with government incentives. To date, these challenges, along with others, have affected the development of MDHD FCEV refueling infrastructure. Additional challenges associated with MDHD FCEVs include lack of consumer choice in commercially available models, high purchase price or lease cost, and high price of hydrogen at the pump. Further, most hydrogen produced today is through the use of fossil fuels.

The CEC is committed to addressing the barriers within its control and has invested $26 million toward building more in-state hydrogen production facilities to help address several of the issues listed above and detailed below. Potential future investments in production through ERDD's Clean Hydrogen Program include $40 million toward large-scale centralized hydrogen production and $30 million toward onsite hydrogen production and use. These are in addition to significant nation-leading investments by the CEC in hydrogen refueling infrastructure to serve light-duty hydrogen fuel cell passenger vehicles and MDHD hydrogen trucks and buses. Further, to better understand consumer experience at refueling stations, the CEC is contracting with University of California, Davis (UC Davis), to conduct an LD FCEV customer survey, as well as interviews with MDHD FCEV fleets, fuel suppliers, and equipment providers.

Investment Costs of Hydrogen Refueling Stations

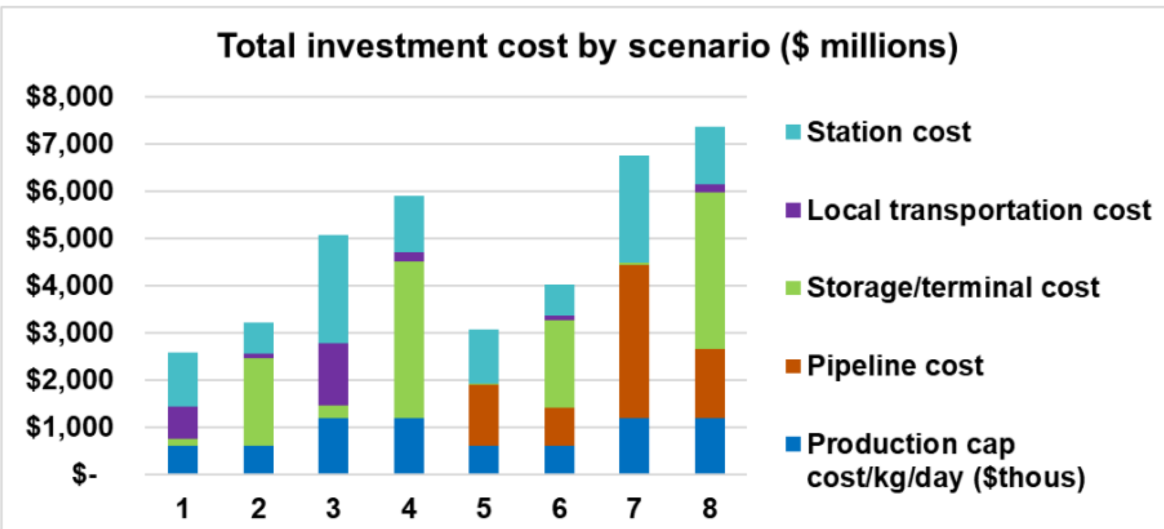
There are many variables that determine the capital cost for constructing and operating MDHD stations. Figure 12, Hydrogen Refueling Station Investment Scenarios, and Figure 13, Hydrogen Refueling Station Investment Cost by Scenario, provide eight scenarios that offer a sense of the scale and costs for hydrogen stations that could be built by 2030 and serve the transportation sector in California.[73]

Figure 12: Hydrogen Refueling Station Investment Scenarios

	1	2	3	4	5	6	7	8
System size (tonnes/day)	500	500	1000	1000	500	500	1000	1000
Liquid or gaseous dominated	G	L	G	L	G	L	G	L
Nearby or distant production	N	N	N	N	DP	DPT	DP	DPT
Number of stations	300	200	600	300	300	200	600	300
Average station size (tonnes/day)	1.67	2.50	1.67	3.33	1.67	2.50	1.67	3.33
Average distance (km)	50	50	50	50	1000	500	1500	500
Electricity price	$0.06	$0.06	$0.06	$0.06	$0.03	$0.03	$0.03	$0.03
Electrolyzer cap factor	67%	67%	67%	67%	33%	33%	33%	33%

Source: UC Davis Institute of Transportation[74]

Figure 13: Hydrogen Refueling Station Investment Cost by Scenario



Source: UC Davis Institute of Transportation[75]

Variables including the number of stations in the state network, station size, fuel delivery method, type of hydrogen (liquid vs. gaseous), cost of electricity and others, as listed in the vertical column in the table at the top of Figure 12. Scenario 1 is the lowest investment with the capital cost of the station providing most of the investment, with nearby production and gaseous hydrogen delivered. Scenarios 2, 4, 6 and 8 show the high cost of storage when the station receives liquid hydrogen, as the stations must have storage and equipment to compress the hydrogen to gaseous for use by the MDHD FCEVs. In the future, if OEMS make

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73 Fulton, L.; Jenn, A.; Yang, C.; Burke, A.; Acharya, T.; Li, X., et al. 2023. *California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California: Final Synthesis Modeling Report.* UC Davis: Hydrogen Pathways Program. Retrieved from https://escholarship.org/uc/item/27m7g841.

74 Ibid.

75 Ibid.

MDHD FCEVs commercially available that use liquid hydrogen, these investment scenarios would include a lower storage cost.

Lead Time for Vehicles and Stations

Table 14, Light-Duty Station Development Phases, from the CEC's *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*, provides insight into lead times for the development of refueling stations.[76]

Table 14: Light-Duty Station Development Phases

Phases	Description	Responsible Entity(ies)
Phase One: From start of CEC grant-funded project to initial permit application filing	Begins when the grant-funded project agreement is executed and includes site selection and site control, station planning, participation in pre-permitting meetings for confirmation of station design consistency with local zoning and building codes and filing the initial permit application with the authority having jurisdiction (AHJ). Equipment ordering could occur during this phase.	Grant recipient and AHJ
Phase Two: From initial permit application filing to receipt of approval to build	Consists of AHJ review of the application and potential site reengineering/redesign based on AHJ feedback. Minor construction work sometimes begins.	Grant recipient and AHJ
Phase Three: From approval to build to station becoming operational	Includes station construction and meeting operational requirements: fuel supply, hydrogen quality testing, dispensing per standard, successful refueling of one FCEV, and receipt of an occupancy permit from the AHJ.	Grant recipient and AHJ
Phase Four: From station becoming operational to becoming open retail	The station undergoes accuracy testing with the California Department of Food and Agriculture/Division of Measurement Standards (DMS) and protocol testing with auto manufacturers and the Hydrogen Station Equipment Performance (HyStEP) device. Once the station has been confirmed to meet the refueling protocol, the station is categorized as open retail.	Grant recipient, DMS, CARB (HyStEP), and auto manufacturers

Source: CEC

76 Berner, Jane, Miki Crowell, and Andrew Martinez. 2022. *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. California Energy Commission and California Air Resources Board. Publication Number: CEC-600-2022-064, https://www.energy.ca.gov/sites/default/files/2022-12/CEC-600-2022-064.pdf.

Permitting

Hydrogen refueling stations that serve passenger and commercial vehicles require the approval of local building, planning and fire officials. Many of California's permitting entities may not have seen a drawing set of hydrogen refueling infrastructure yet. The project location, size, and other factors determine the specific permits and approvals needed. These approvals typically involve factors such as local governments' land-use and zoning restrictions, state and local ordinances such as setback requirements, and possible grid interconnection agreements if the clean hydrogen is generated at the refueling infrastructure site. Ensuring consistent interpretation of fire and safety codes among authorities having jurisdiction (AHJ) would help alleviate uncertainty with permitting processes.

While state and federal agencies are providing education on hydrogen refueling stations, there continues to be a low level of public awareness of factors including potential risks, most of which can be addressed. Senate Bill (SB) 1291 (Archuleta, Chapter 373, Statutes of 2021) streamlines the permitting and approval process by requiring local government agencies to review applications administratively for the installation of hydrogen fueling stations and allows for denials based only on health and safety impacts. The legislative intent of SB 1291 was, in part, to encourage the installation of hydrogen fueling stations by removing the obstacles to and minimizing the costs of permitting the stations.

Fuel Supply

Clean hydrogen fuel production in California is nearly nonexistent, although in recent years, through public-private partnerships and private investments, production projects are moving forward. If California is awarded a U.S. DOE hydrogen hub, the supply and demand landscape for clean hydrogen would change over the next eight years and beyond, depending on the amount of the award, private investments, and project completion rates. Most of the hydrogen dispensed in California's LD FCEV refueling network, and by transit agencies that are not using onsite clean hydrogen production, is produced using fossil fuel-powered SMR. The entity then purchases and retires biogas credits to receive credits through CARB's LCFS program. Additional discussion of hydrogen fuel supply is included in Chapter 5: Hydrogen Supply — Production, Storage, and Distribution, of the 2023 SB 643 Staff Report.

Fueling Standards for MDHD FCEVs

Light-duty hydrogen fueling stations in California typically follow[77] the Society of Automobile Engineers' (SAE) J2601 fueling protocol, which provides the allowable ramp rates of pressure during hydrogen fueling. Ideally, MDHD FCEVs would have faster fueling to account for larger tank sizes. The U.S. DOE provides 700 bar[78] fueling standards and specifications and a fueling rate of 8 kg per minute by 2030 as its current goal, with an ultimate goal of 10 kg per minute. Past station developers have used their own protocols; however, an updated fueling protocol for gaseous hydrogen-powered HD vehicles is needed to provide guidance for performance-

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77 This is voluntary unless, for example, it is a grant requirement. For stations that have received funding from the CEC, it is a grant requirement.

78 Dispensed hydrogen gas is compressed by the compression subsystem to either 350 bar (35 MPa) or 700 bar (70 MPA). Hydrogen station dispensing pressure was increased to 700 bar from 350 bar for LD FCEVs around 2009.

oriented dispenser standards for safe refueling of hydrogen-powered transit buses and MDHD vehicles. SAE J2601-2, the current fueling protocol for MDHD FCEVs, allows for refueling at 7.2 kg per minute, but that is not a standard; it is a maximum advised fueling rate.

In 2014, SAE International released a short guidance document for MDHD fueling, the *SAE J2601-2 Fueling Protocol for Gaseous Hydrogen Powered Heavy Vehicles*,[79] which provides an overview of operational limits for dispensing pressures of 350 bar but is not a comprehensive fueling protocol. The guidance document allowed for faster refueling, but some of the equipment, including a higher-flow nozzle, was not available at that time. The SAE J2601 fueling protocol has a Category D, which allows for dispensing pressures of 700 bar[80] fills above 10 kg. Developers of planned MDHD stations have indicated that they intend to deploy high-flow dispensers that use the SAE J2601-5 protocol, which is under development and will address high-flow 700 bar fills for MDHD FCEVs. A subgroup for J2601-5, within SAE's Fuel Cell Interface Task Force, is working on developing these standards.

The California Department of Food and Agriculture (CDFA) Division of Measurement Standards (DMS) is responsible for enforcement of the state's weights and measures laws and regulations and must certify any device used for metering the sale of commercial items within California. CDFA-DMS regulations ensure the accurate metering of hydrogen mass dispensed in each sale. In April 2021, CDFA-DMS announced a regulation for many device types used for commercial purposes, including low- and zero-emission motor vehicle-fueling devices. This regulation established the first inspection frequencies for the oversight of hydrogen fueling devices.

With funding provided by the U.S. DOE Fuel Cell Technology Office under the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) program, Sandia National Laboratories and NREL contracted with Powertech Labs to develop and build the Hydrogen Station Equipment Performance (HyStEP) device.[81] The HyStEP device is a mobile, self-contained hydrogen refueling station testing unit that uses CSA Group's Hydrogen Gaseous Vehicle 4.3 test methods for hydrogen fueling parameter evaluation to determine compliance with *SAE J2601-1 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*. The device confirms that stations meet industry performance and safety standards before a station opens for public refueling. In April 2023, CARB, in consultation with the CEC and NREL, released 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 MDHD hydrogen refueling stations. CARB is reassessing the budget and application process for the RFP and anticipates re-releasing a new RFP prior to the end 2023.

The International Organization for Standardization (ISO) is an independent, nongovernmental organization that develops and publishes international standards, including for hydrogen

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79 SAE International. *Fueling Protocol for Gaseous Powered Heavy-Duty Vehicles SAE J2601,* https://www.sae.org/standards/content/j2601/2_201409/#:~:text=SAE%20J2601%2D2%20is%20a,powered%20vehicle%20fleet(s). (Retrieved March 2023.)

80 One megapascal (MPa) is equal to 10 bar. Conversely, 1 bar is equal to 0.1 MPa.

81 Hydrogen Tools. "HYSTEP Device," https://h2tools.org/hystep-hydrogen-station-equipment-performance-device.

refueling and dispensing. ISO has acknowledged that cross-collaboration and coordination among different countries that may have standards in place that are working well could be improved. ISO includes standards for gaseous hydrogen refueling stations, including *ISO 19880-1:2020*, which is targeted for the fueling of LD FCEVs, but also provide guidance for fueling MDHD FCEVs.[82] New fueling protocols are being developed for integration into the *ISO 19885-3 Standard*. Other countries, including Japan and the European Union, have developed standards for HD fueling, but in the United States, industry lacks the fueling protocol standards for developing MDHD refueling stations.

An example of California's interim solution while MDHD fueling protocols are developed is the EnergIIZE hydrogen funding implementation manual, which requires applicants to conform to the most recent version of one or more of the following fueling protocols or an equivalently accepted industry standard.

Table 15: Eligible Hydrogen Fueling Protocols

Fueling Protocol	Description
SAE J2601-1 Category D	>10 kilogram tank sizes
SAE J2601-2	HD fueling
SAE J2601-4	Ambient temperature fueling
SAE J2601-5	MC Formula-based[83]
JPEC-S 0003	Japanese bus fueling protocol
SAE J2600	Defines geometries of receptacles for different pressure levels

Source: 2022 EnergIIZE Implementation Manual

Equipment and Supply Chain Considerations

National codes and standards specify requirements for equipment and installation at hydrogen fueling stations to ensure that hydrogen is produced, stored, and dispensed safely. The CEC, GO-Biz, and the SCAQMD participate in the cooperative research and development agreement projects with H2@Scale national laboratories consortium for the advancement of hydrogen fueling infrastructure for HD vehicles. This research partnership will provide design considerations and risk analysis for HD hydrogen refueling stations, design concepts for a heavy-duty fueling performance test device, and design a model to evaluate the dispensing capacity of HD hydrogen refueling stations.

NREL's Innovating Hydrogen Stations project is a research and industry partnership for an experimentally validated, high-flow rate fueling model and near-term hydrogen station innovations. This DOE-funded multiyear project is a first-of-a-kind experimental research

82 International Organization for Standardization (ISO). *ISO 19880-1:2020 Gaseous Hydrogen – Fueling Stations – Part 1: General Requirement,* https://www.iso.org/standard/71940.html (Accessed May 26, 2023).

83 Under development but not yet published.

capability of fueling 60+ kg of hydrogen at a rate of 10 kg per minute, the DOE's ultimate fill rate target by 2030 for Class 8 long-haul trucks.

There are few examples of MDHD refueling stations in the United States; however, based on the CEC's experience with LD refueling stations, equipment failure can result in stations being offline for extended periods due to a shortage of available equipment and supply chain issues.

CHAPTER 3: Fuel Cell Electric Buses and Refueling Infrastructure

This chapter discusses FCEBs and refueling infrastructure used by California's transit agencies, the current demand, a future demand scenario for hydrogen fuel, use cases of transit agencies that are operating FCEBs, and opportunities and challenges in this sector. Policy drivers, regulations, and incentive programs have contributed to the success of the commercial availability of FCEBs in California and the fuel production and refueling infrastructure required to support them. FCEBs are a proven heavy-duty transportation application for fuel cell technology.

California transit agencies have used different operational models in deploying FCEBs. Alameda County Transit's (AC Transit) cryogenic pumps enable large-scale back-to-back fueling. Orange County Transit Authority and Foothill Transit have adopted liquid hydrogen truck deliveries for minimum on-site support. Moreover, SunLine Transit Agency has the largest on-site electrolytic hydrogen production system in California. These models could provide other transit agencies — including those outside California — options and an understanding about how they could deploy their FCEBs based on their respective unique situations.

The other available option for zero-emission buses (ZEBs) is a battery-electric bus (BEB). Both technologies are being used by transit agencies. ZEBs are acting as a technology foothold in the heavy-duty zero-emission vehicle sectors. As more transit agencies deploy ZEBs or scale up their deployment, the technologies will further improve, and some aspects are transferrable to MDHD ZEVs. Drayage, yard, and delivery trucks have similar weight considerations, durability requirements, drivetrains, and components. The knowledge and experience gained from installing infrastructure, developing training programs, and operating ZEB technologies are enabling market expansion into other HD vehicle applications.

Innovative Clean Transit Regulation (ICT)

CARB's Innovative Clean Transit (ICT) regulation was adopted in December 2018 to replace the Fleet Rule for Transit Agencies, and it is the first regulation in the United States to require a vocational HD vehicle application to completely transition to a zero-emission technology. The ICT regulation requires a percentage of new bus purchases to be ZEBs, and this percentage increases gradually with time, as demonstrated in Table 16. The ICT regulation also requires transit agencies to submit a complete Zero-Emission Bus Rollout Plan (Rollout Plan) to CARB that provides detailed information on how the agency will incorporate ZEBs into their fleets, to meet the ICT regulation requirement of a 100 percent ZEB fleet by 2040. Large transit agencies are those that either operate more than 65 buses in annual maximum service in either the South Coast Air Basin or in the San Joaquin Valley Air Basin. A large transit agency is also defined as one that operates in an urbanized area with a population of at least 200,000 with at least 100 buses in annual maximum service.

The Rollout Plans provide the planning map to ensure that the ZEB procurement, infrastructure build out, and fuel cost management are synchronized. The rollout plans that are considered complete by CARB are posted online to provide awareness to communities and other interested parties and can also be used as models for other transit agencies to follow.[84] The Rollout Plans indicate that transit agencies are receptive to both ZEB technologies, and most have plans to adopt a mix.[85]

Table 26: ICT Regulation — Annual ZEB Purchase Requirements

Date	Large Transit Agency	Small Transit Agency
2023–2025 (standard 40-ft buses only)	25%	n/a
2026–2028 (all types, if passed federal testing)	50%	25%
January 1, 2029, and thereafter	100%	100%

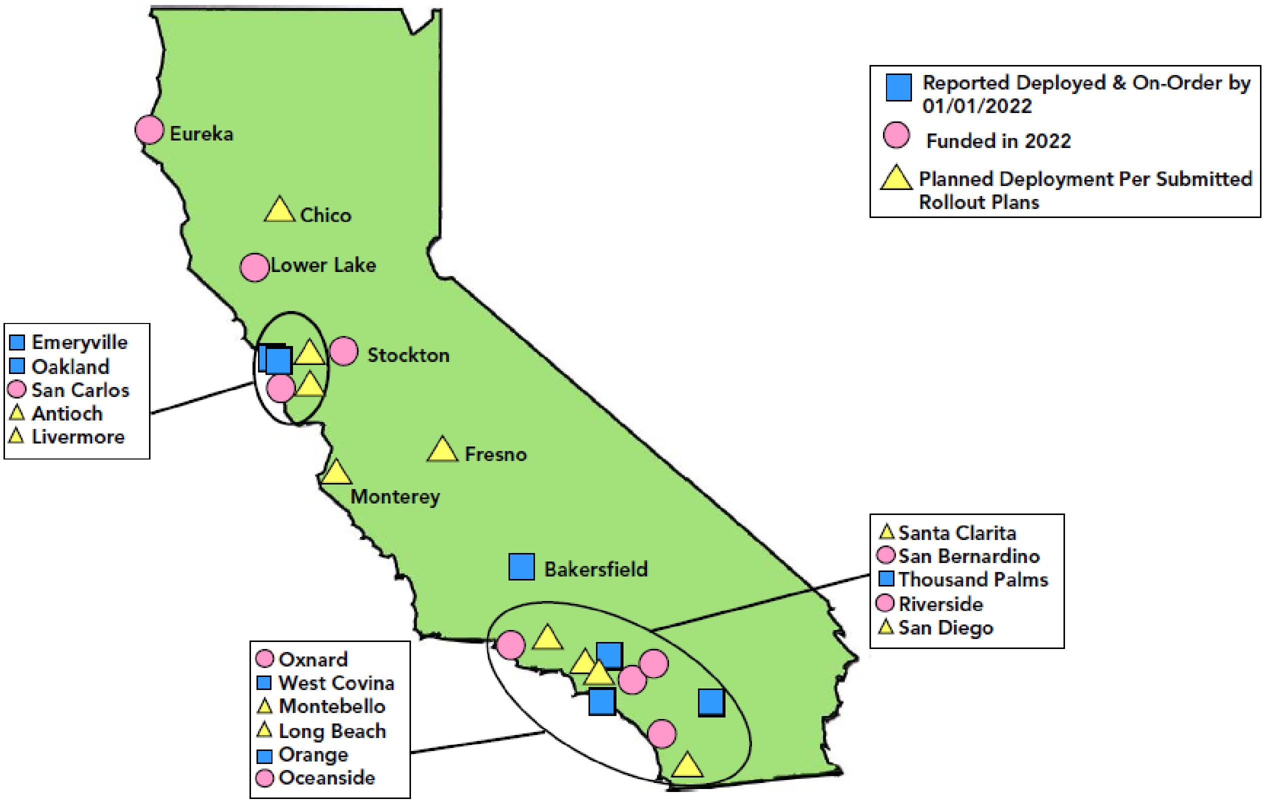
Source: NREL

The ICT regulation was an important first step in transitioning California's HD vehicles to zero emission, bringing awareness to zero-emission technologies and reducing NO_x and GHG emissions statewide — particularly in disadvantaged and low-income communities, which are often in densely populated areas served by transit. About 11,500 transit buses in California are required to abide by the ICT requirement to transition to zero-emission by 2040.

84 CARB. Updated May 31, 2023. "ICT — Rollout Plans," https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans. (Accessed June 1, 2023).

85 NREL. "Comprehensive Review of California's Innovative Clean Transit Regulation: Phase I Summary Report." https://ww2.arb.ca.gov/sites/default/files/2022-08/ICT-ComprehensiveReview-Phase1_0.pdf.

Figure 14: Zero-Emission Bus Deployment in California



Source: CARB, 2022 Innovative Clean Transit reporting data, federal discretionary funding programs, various state incentive programs, and transit agency rollout plans. Map last updated 10/20/22. An updated map may be available in the 2023 SB 643 Final Report.

AC Transit, Foothill Transit, Golden Empire Transit, SunLine Transit and Orange County Transit, together, have more than 100 FCEBs in operation. FCEBs typically carry up to 40 kg of hydrogen and consume about 25–30 kg of hydrogen per day. A station that needs to fuel five buses will require a capacity of about 150 kg per day. Refueling a full tank of hydrogen for an FCEB takes about 10 minutes.

Appendix B includes transit agency reported data in the ICT reporting tool, awarded funds, and submitted rollout plans, as well as current and future hydrogen demand scenarios.

Table 17 provides the HVIP-eligible FCEBs as of May 2023, which is analogous to Table 3 in Chapter 2 of the 2023 SB 643 Staff Report, which provides the HVIP-eligible MDHD FCEVs.

Table 17: HVIP-Eligible FCEBs

Make	Model	Class	Tank Capacity (kg)	Tank-Rated Pressure (Bar)	Typical Range (Miles)
New Flyer	Xcelsior Charge FC™ 40′	Class 8	37.5	350	370+
New Flyer	Xcelsior Charge FC™ 60′	Class 8	56	350	370+

Source: CARB HVIP[86]

CEC Investments in Transit Fleet Hydrogen Infrastructure

CEC investments in transit fleet hydrogen infrastructure for FCEBs include GFO-20-602, "Zero-Emission Transit Fleet Infrastructure Deployment." Through the solicitation, the CEC approved $36 million in funding for two hydrogen refueling infrastructure projects to support the large-scale conversion of transit bus fleets to FCEBs. North County Transit District was awarded $6 million for refueling infrastructure to support a future deployment of 50 FCEBs; SunLine Transit was awarded nearly $5 million to establish new hydrogen refueling infrastructure at the existing bus refueling and charging transit stations; and AC Transit was awarded more than $4.5 million to upgrade an existing FCEB refueling station. Refueling infrastructure for transit is eligible for funding from the CEC's EnergIIZE program.

Alameda-Contra Costa Transit (AC Transit) – Early Adopter of FCEBs

AC Transit is one of the largest transit operators in California, with a fleet of more than 630 buses. Since 1999, AC Transit has advocated for fuel cell technology, organizing a public-private partnership to develop zero-emission solutions for HD transportation applications. AC Transit's fuel cell bus program began in 2000 and included three buses that used fuel cell powertrains,[87] two hydrogen stations, and installation of an early generation electrolyzer, which operated from 2002 to 2008. AC Transit organized the Zero Emission Bay Area (ZEBA) bus project in 2008 as a partnership with four transit partners in the region, including Golden Gate Transit, San Mateo County Transit District (SamTrans), Santa Clara Valley Transportation Authority, and San Francisco Muni.[88] The ZEBA demonstration included 12 FCEBs, which began revenue service in May 2010, and two hydrogen fueling stations. The hydrogen fueling stations, both designed and built by Linde, LLC at two locations adjacent to AC Transit's bus

86 CARB. "California HVIP Catalogue," https://californiahvip.org/vehicles/?t_type=379 (Accessed June 14, 2023).

87 Before 2010, a fuel cell powertrain was dominant in AC Transit's demonstrations of fuel cell buses, AC Transit used a different technology than what is currently used, which is fuel cell electric.

88 Andrichak, Chris. (Alameda-Contra Costa Transit District). 2021 *Oakland Hydrogen Refueling Station*. California Energy Commission. Publication Number: CEC-600-2021-041, https://www.energy.ca.gov/publications/2021/oakland-hydrogen-refueling-station.

routes, provided hydrogen through a combination of delivered liquid hydrogen and hydrogen produced through electrolysis.[89]

With the $4.5 million awarded through GFO-20-602, AC Transit is upgrading the existing hydrogen refueling station at the Oakland Seminary Avenue site in East Oakland. The existing infrastructure serves about 13 FCEBs, but funding for this project will enable operation of a larger fleet of up to 60 FCEBs that will be placed in service by 2024. AC Transit is upgrading the station to enable increased storage, more frequent deliveries of fuel, and additional dispensers. The new station will allow fueling of two buses at any time and will be capable of back-to-back fueling of the entire fleet in six to eight hours. The FCEBs serviced at the station serve 55 percent of the disadvantaged communities in the Oakland area. AC Transit's bus lines also provide connections to major job centers in San Francisco and Oakland. As detailed in its June 2022 *AC Transit Zero Emission Bus Transition Plan*, AC Transit will have fully transitioned to a ZEB fleet of 178 BEBs and 458 FCEBs by 2035.[90]

SunLine Transit Agency

SunLine Transit Agency (SunLine Transit) provides public transit services to Southern California's Coachella Valley. The community served is low-income and disadvantaged.[91] SunLine Transit's first hydrogen refueling station opened in 2006, using a hydrogen source of natural gas autothermal reforming. SunLine Transit completed a new station in late 2019 with the capability to produce 900 kg/day of clean hydrogen on-site through electrolysis, and the station can fuel about 32 FCEBs.[92] This station replaced SunLine Transit's older natural gas reformer that was not capable of producing enough hydrogen for the agency's growing FCEB fleet. Through GFO-20-602, SunLine Transit was awarded nearly $5 million to establish new hydrogen refueling infrastructure at the existing bus refueling and charging transit station.[93] The project will support the conversion of 17 compressed natural gas (CNG) buses to FCEBs, resulting in an estimated reduction of 512,000 kg of CO_2 annually. SunLine anticipates these net GHG reductions to increase up until 2033, when the station is expected to reach capacity, fueling 45 FCEBs each year.[94]

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89 Eudy, Leslie, Matthew Post, and Matthew Jeffers (NREL). September 2017. TP-5400-68413. *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Sixth Report,* https://www.nrel.gov/docs/fy17osti/68413.pdf.

90 AC Transit. June 2022. *AC Transit Zero Emission Bus Transition Plan,* https://www.actransit.org/sites/default/files/2022-06/0162-22%20ZEB%20Transition%20Plan_052022_FNL.pdf

91 U.S. Environmental Protection Agency. "EJ and Supplemental Indexes in EJScreen | US EPA," https://www.epa.gov/ejscreen/ej-and-supplemental-indexes-ejscreen.

92 Collins, Elizabeth and Matthew Post (NREL). July 2022. *Sunline Transit Agency Fuel Cell Electric Bus Progress Report Data Period Focus: January 2020 Through December 2021,* https://www.nrel.gov/docs/fy22osti/83559.pdf.

93 SunLine Transit Agency. October 7, 2021. "SunLine Celebrates National Hydrogen Day Tomorrow With Five New Hydrogen Fuel Cell Buses and Advancing Hydrogen Projects," https://www.sunline.org/news/sunline-celebrates-national-hydrogen-day-tomorrow-with-five-new-hydrogen-fuel-cell-buses-and.

94 Comiter, Michael. 2021. *Localized Health Impacts Report Under Solicitation GFO-20-602 Zero Emission Transit Fleet Infrastructure Deployment*. California Energy Commission. Publication Number: CEC-600-2021-004, https://www.energy.ca.gov/sites/default/files/2021-04/CEC-600-2021-004.pdf.

Challenges and Opportunities for Transit Agencies

Capital costs for FCEBs and BEBs are still higher than those of conventional combustion engine buses. However, federal and state incentive programs such as awards from FTA, incentives through the HVIP program, and credits from the LCFS program can help offset those costs. In addition, the fuel cost is a barrier, and FCEBs require financing that may be outside many of these agencies' budgets. Transit agencies operating FCEBs cite a reliable fuel supply, the cost of electricity and hydrogen fuel, and uncertainties regarding future fuel pricing as challenges to operate a fleet of FCEBs cost-effectively. Another challenge is the limited availability of needed bus types, such as cutaways and motor coaches. Demonstration projects are under development to address this barrier.

While it may be more expensive to adopt an FCEB fleet due to the capital costs of a hydrogen fueling station and the bus purchase price, costs decrease as the fleet size increases, making large transit agencies prime candidates for FCEB fleets. Small, rural transit agencies with hilly terrain and long distances between stops, and temperature constraints, are showing interest in adopting FCEBs to meet ICT targets.

Opportunities for transit agencies that have not yet incorporated FCEBs into their fleets include the prospect of using existing business models by transit agencies that are operating FCEBs. Benefits of incorporating FCEBs into transit agency fleets include fast refueling time (<10 minutes), a similar refueling infrastructure footprint as CNG refueling stations, and FCEBs being well-suited for long routes and colder weather.

CHAPTER 4: Developments in Off-Road Fuel Cell Electric Applications and Infrastructure

This chapter discusses off-road applications and demonstrations using hydrogen fuel technologies. Hydrogen fuel-powered applications in these sectors are limited to mostly prototypes and demonstrations and a few real-world applications, such as forklifts, which have been commercially available for a number of years.[95] Off-road vehicles and equipment, such as other cargo handling equipment (CHE), excavators, and agricultural and construction applications are major sources of harmful air pollutants.[96] Other off-road applications, also referred to as non-road sectors,[97] such as marine, rail, and aviation, are major contributors, as well.

Hydrogen fuel technologies may help decarbonize some off-road applications that are challenging to electrify directly due to high energy requirements and continuous or multiple shift operations that require fast refueling times. Major challenges in off-road applications include the ability to store enough hydrogen onboard the vehicles to meet the operating requirements, commercial availability of mobile refueling options, and the need for additional research, development, and demonstration to understand the technology gaps. There are also growing opportunities, such as relocatable microgrids to support temporary worksites, supported by grant funding awards from the CEC, CORE vouchers, and other sources.

Regulations and Incentive Programs for Off-Road Applications

Executive Order N-79-20 directs CARB to develop and propose strategies to achieve 100 percent zero emissions from off-road vehicles and equipment operations in California by 2035, where feasible. In response, CARB has amended existing and developed new regulations and incentive programs to help the state reduce emissions and drive market development in off-road sectors.

- The In-Use Diesel-Fueled Transport Refrigeration Units[98] (TRU) and the TRU Generation Sets and Facilities Where TRUs Operate (TRU ATCM) regulations were amended to

95 U.S. DOE. "Early Markets: Fuel Cells for Material Handling Equipment."
https://www.energy.gov/sites/prod/files/2014/03/f9/early_markets_mhe_fact_sheet.pdf.

96 Pang, Kaili, Kaishan Zhang, and Shuai Ma. "Tailpipe Emission Characterizations of Diesel-Fueled Forklifts Under Real-World Operations Using a Portable Emission Measurement System." *Journal of Environmental Sciences,* Volume 100, 2021, pages 34–42, ISSN 1001-0742, https://doi.org/10.1016/j.jes.2020.07.011.(https://www.sciencedirect.com/science/article/pii/S1001074220303144).

97 Marine, rail, and aviation off-road applications may also be referred to as non-road applications in the 2023 SB 643 Staff Report.

98 A "transport refrigeration unit (TRU)" is a refrigeration system powered by diesel internal combustion engines designed to refrigerate or heat perishable products transported in various containers including truck vans, semitruck trailers, shipping containers, and railcars.

include more stringent standards, and zero-emission requirements, including that all truck TRUs operating in California must be zero-emission by December 31, 2029.[99]

- The Vessels At Berth regulation requires the control of exhaust emissions from vessels while at berth using shore power, zero-emission technologies, or other CARB-approved strategies.
- Amendments to the existing Commercial Harbor Craft regulation became effective January 1, 2023, and include zero-emission requirements and opportunities.
- Possible amendments to the Cargo Handling Equipment (CHE) regulation (CHE regulation) may include a transition to 100 percent zero-emission operations beginning in 2026.
- Recent amendments to the Off-Road Regulation, which applies to construction and mining, operations, and other industries, require fleets to phase out the oldest off-road diesel vehicles in California and prohibit adding high-emitting vehicles to a fleet.
- A potential new regulation for forklifts would drive greater deployment of zero-emission forklifts within fleets.[100]

The off-road sector's zero-emission transition to suitable applications with hydrogen fuel cells or propulsion is emerging. Some challenges for hydrogen infrastructure for off-road applications include the need for vehicle standards including onboard storage pressure and fueling interface; the cost of hydrogen fueling systems, along with the costs associated with the use of grid or off-grid power; and a power connection.[101] As with MDHD FCEVs, without sufficient refueling infrastructure or commercially available mobile refuelers, OEMs may be hesitant to invest in off-road technologies, develop and demonstrate them, and make them commercially available. Regulations coupled with incentive programs are driving development. Proton exchange membrane (PEM) fuel cells are being used in forklifts, but they are not suitable for all off-road applications.

CEC Investments in Off-Road Hydrogen Applications

The CEC has invested in emerging off-road and non-road fuel cell applications and innovative hydrogen refueling solutions. A recent example includes GFO-22-502, "Innovative Hydrogen Refueling Solutions for Heavy Transport*,*" a jointly funded grant funding opportunity led by ERDD with funding from the Gas R&D Program and the CTP, with goals including advancement of innovative hydrogen refueling solutions to support fuel cell technologies in emerging HD and on-road and off-road sectors. These goals may be accomplished by reducing hydrogen delivery and refueling costs, improving reliability, enabling higher fill rates, and minimizing energy losses.

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99 CARB. October 2022. *2022 Amendments to the TRU ATCM*, https://ww2.arb.ca.gov/sites/default/files/2022-09/advisory_22_30_0.pdf.

100 Forklifts are most prevalent in manufacturing and at freight facilities, such as warehouses, distribution centers, and ports.

101 Argonne National Laboratory. January 2022. *Mission Innovation Hydrogen Fuel Cells Off-Road Equipment and Vehicles Workshop Summary Report*, https://www.anl.gov/sites/www/files/2022-07/H2%40Offroad-%20Workshop%20Report-07-11-2022.pdf.

Table 18: Emerging Off-Road Applications NOPA

Project Applicant	Title	CEC Funds Recommended	Match Funds
ZeroAvia Federal, Inc.	Liquid Hydrogen Refueler for Hydrogen-Electric Aircraft Applications	$3,250,000	$1,625,000
Zero Emission Industries Inc.	Cryogenic Hydrogen Infrastructure Replacement Product ("CHIRP") (formerly Portable, Zero Boil-off Liquid Hydrogen Bunkering System)	$5,250,000	$1,675,000
	Total Funding Recommended	**$8,500,000**	**$3,300,000**

Source: CEC GFO-22-502 NOPA

In 2023, the CEC is partnering with CARB to support Advanced Technology Demonstration and Pilot projects. Specifically, the CEC will provide emerging opportunities for infrastructure to support vehicle demonstrations in zero-emission aviation, locomotive and marine sectors, as well as funding for construction, agriculture, and other off-road sectors.

Off-Road Incentive Programs

The Clean Off-Road Equipment Voucher Incentive Project (CORE) was launched in February 2020 with a funding allocation of $41 million. CORE provides a streamlined voucher process by which purchasers can receive funding to help offset the higher cost of cleaner zero-emission off-road equipment. It is analogous to HVIP for zero-emission trucks and buses. While the goal of CORE is to help purchasers overcome the incremental cost barrier of zero-emission off-road equipment, the methods developed for determining voucher amount also consider other factors, such as current market penetration and the projected need for incentives. Moreover, increased funding is being made available to encourage equipment deployments in disadvantaged and low-income communities, as well as infrastructure expansion. Increased funding is also available for projects that are purchased and deployed by small businesses.

The FY 2022–23 Funding Plan for Clean Transportation Incentives allocated $182 million to CORE,[102] and on July 18, 2023, CALSTART, which administers CORE, will open the funding for eligible zero-emission off-road equipment vouchers. Incentive programs for infrastructure are offered through EnergIIZE, and the CEC provides grant funding opportunities in off-road hydrogen refueling demonstrations, such as GFO-22-502.

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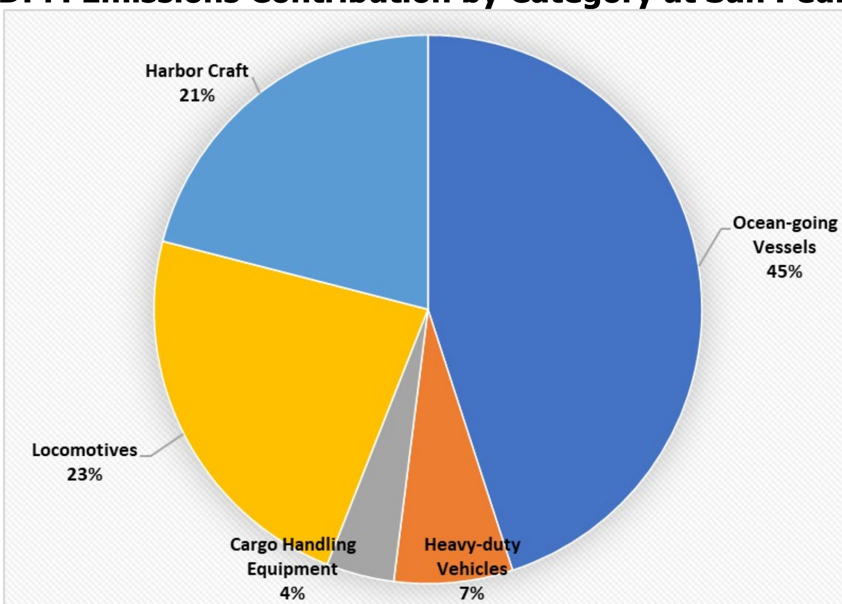
102 CARB. "Low Carbon Transportation Investments and AQIP Funding Plans | California Air Resources Board," https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low-1.

Emissions From Off-Road Applications at Ports

In addition to toxic air pollutants emitted by drayage trucks and trains, as discussed in Chapter 2, off-road applications at ports are major contributors of harmful emissions. The adjacent Ports of Long Beach and Los Angeles in San Pedro Bay are the largest fixed sources of air pollution in California. Yard trucks are the largest source of emissions in all classifications of CHE but can be difficult to convert to zero-emissions due to the unique duty cycle and operating environment.

Commercial harbor craft are in the top three emitting categories at seaports, contributing more diesel particulate matter emissions than trucks in 2023 at the San Pedro Ports, as shown in Figure 15. CARB staff compared current emissions and future projected emissions from moving cargo by trucks and trains, using an example scenario from San Pedro Ports.[103]

Figure 15: DPM Emissions Contribution by Category at San Pedro Bay Ports

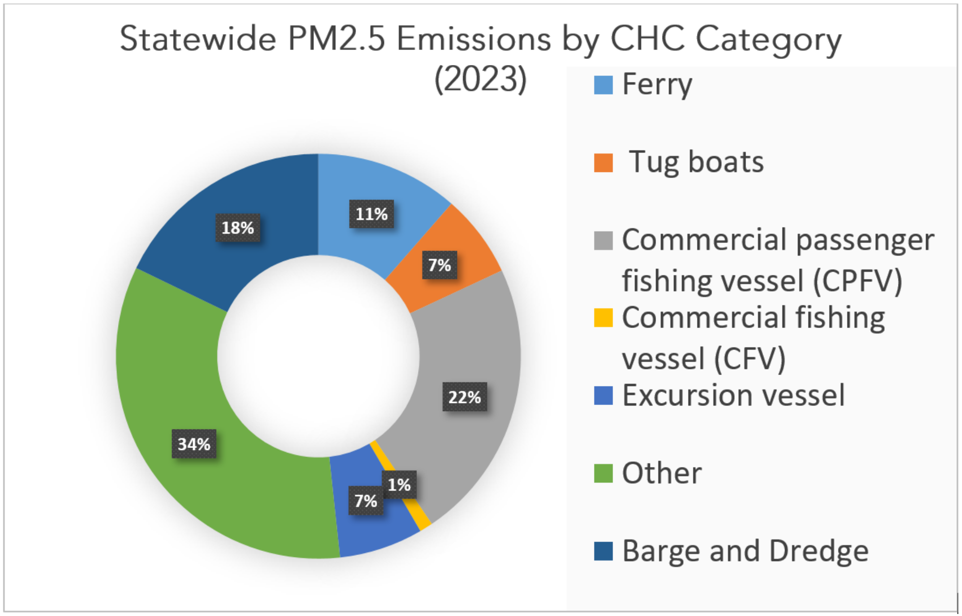


Source: CARB[104]

103 CARB. https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-2023-advanced-clean-fleets-regulation-drayage-truck. https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-2023-advanced-clean-fleets-regulation-drayage-truck.

104 CARB. "Proposed Amendments to the Commercial Harbor Craft Regulation," https://ww2.arb.ca.gov/resources/fact-sheets/proposed-amendments-commercial-harbor-craft-regulation/printable/print. (Accessed April 25, 2023).

Figure 16: Statewide $PM_{2.5}$ Emissions by Commercial Harbor Craft (CHC) Category



Source: CARB[105]

Tugboats or towing vessels are one of the largest emitting types of commercial harbor craft. In 2023, tugboats will emit 19 percent of total commercial harbor craft PM 2.5 emissions[106] and 23 percent of total commercial harbor craft oxides of NO_x emissions.[107] Many communities surrounding the ports are disadvantaged communities, and addressing emissions from harbor craft is critical for the state to achieve its air quality and environmental justice goals.

Due to the high level of commercial activity and traditional reliance on combustion engines for motive power, ports have become relative hot spots for air pollutant emissions. These air pollutants include emissions of fine particulate matter, oxides of nitrogen, and greenhouse gases, largely related to diesel fuel combustion. Since ports tend to be adjacent to and essentially embedded in the local communities, these emissions are of great concern to these communities, particularly for the associated acute and chronic health impacts.

Marine ports use a wide variety of mechanical equipment for their various operations. The equipment includes top and side loaders for moving shipping containers, rubber tire gantry cranes for related operations, day trucks that operate in and near the port vicinity, large forklifts, as well as the drayage trucks that move cargo from ports to rail lines and other destinations. A demonstration of a hydrogen-powered yard truck at the Port of Los Angeles concluded in 2023. The project was partially funded by the California Climate Investments (CCI) program and administered by CARB through its Advanced Technology Demonstration and Pilot projects, Zero Emissions for California Ports (ZECAP) program. The project system included hydrogen ground storage, and refueling did not rely on compression or cooling, but

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105 CARB. "CHC Fact Sheets: Ferries," https://ww2.arb.ca.gov/resources/fact-sheets/chc-fact-sheet-ferries/printable/print. Accessed May 5, 2021.

106 PM2.5 is fine, inhalable particles with diameter 2.5 micrometers and smaller.

107 CARB. November 2021. "CHC Fact Sheet," https://ww2.arb.ca.gov/resources/fact-sheets/chc-fact-sheet-tugboats-towing-vessels.

rather a cascade fill where the hydrogen flows from high pressure to low pressure. The only electricity required was to power the safety system of the project. The hydrogen was delivered through tube trailer, the fueling time was up to 15 minutes, and fill ups were required every two days to perform regular service for 8 hours a day.[108] Additional efforts to decarbonize the equipment at ports through demonstrations are discussed in the Off-Road Hydrogen Demonstrations in Rail, Aviation, and Marine section of this chapter.

Cargo Handling Equipment

Cargo handling equipment (CHE) includes motorized vehicles used to handle cargo or perform maintenance activities at California's ports and intermodal rail yards. The type of equipment includes, but is not limited to, yard trucks, rubber-tired gantry cranes, container handlers and forklifts.[109] CARB adopted the mobile cargo handling equipment regulation (CHE regulation) in 2005 to reduce toxic and criteria emissions from the equipment. The CHE regulation was fully implemented by the end of 2017. CARB plans to amend the regulation to transition to zero emissions and will assess the availability and performance of zero-emission technology that could replace combustion-powered cargo equipment and consider other solutions such as efficiency improvements.[110]

Lighter-duty industrial applications of CHE can be found at warehouses and similar distribution operations. According to the U.S. DOE, there are more than 50,000 hydrogen fueled forklifts operating across the United States.

108 ZECAP Webinar, December 12, 2022. "Piloting Zero-Emission Transportation at the Port of Los Angeles," https://hydrogenyardtruck.com/.

109 CARB. "Cargo Handling Equipment," https://ww2.arb.ca.gov/our-work/programs/cargo-handling-equipment#:~:text=Mobile%20cargo%20handling%20equipment%20is,container%20handlers%2C%20forklifts%2C%20etc. (Accessed March 1, 2023).

110 CARB. Retrieved March 1, 2023. https://ww2.arb.ca.gov/resources/documents/cargo-handling-equipment-regulation-transition-zero-emissions (Accessed March 1, 2023).

Figure 17: Fuel Cell Cargo Handling Equipment in Warehouse Operations

Credit: Plug Power

Since 2016, Plug Power has assisted Amazon with the deployment of more than 15,000 fuel cells to replace batteries in forklifts across 70 distribution centers.[111] In 2022, the companies signed a new supply contract for 10,590 tons of green hydrogen per year, which will provide enough annual power for 30,000 forklifts or 800 HD FCEVs. Across Amazon's operations, the company is testing HD FCEVs and fuel cell power generation stations.[112]

Off-Road Hydrogen Demonstrations in Rail, Aviation and Marine

Off-road, as defined in the 2023 SB 643 Staff Report, includes nonroad sectors such as rail, aviation, and marine. This section briefly describes these applications in the context of how they may be used in hydrogen technology applications, and regulations that are in development or have been implemented to reduce emissions.

Rail Demonstrations

In addition to the transport of goods by trucks, another traditional mode of cargo movement in California and throughout the nation is trains. Diesel-powered locomotives emit fine particulate matter, $PM_{2.5}$, NO_x, and GHG. As of 2022, locomotives are projected to produce more than 640 tons per year of $PM_{2.5}$ and more than 29,800 tons per year of NO_x.[113]

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111 Amazon. August 25, 2022. "Amazon Adopts Green Hydrogen to Help Decarbonize Its Operations," https://www.aboutamazon.com/news/sustainability/amazon-adopts-green-hydrogen-to-help-decarbonize-its-operations.

112 Ibid.

113 CARB. "CARB Fact Sheet: Locomotives," https://ww2.arb.ca.gov/resources/fact-sheets/carb-fact-sheet-locomotives.

One category of diesel-powered locomotives is a switcher locomotive. There are 260 switcher locomotives operating in California within rail yards that are used to assemble and disassemble trains within short distances, comparable to a tugboat in maritime operations. Sierra Northern Railway is building and testing a zero-emission hydrogen fuel cell switcher locomotive at the Port of West Sacramento, which is a proof-of-concept project that could be commercialized.[114]

Regulatory actions related to the emissions from diesel locomotives have been implemented and continue to be revisited and refined. In April 2023, CARB approved updates to its In-Use Locomotive Regulation, which is expected to result in the following outcomes:

- Construction and operation of new or expanded manufacturing plants for zero-emission locomotive technologies, including fuel cells
- Construction of supporting infrastructure, including hydrogen fueling stations
- Displacement of fossil fuel extraction, refinement, manufacture, distribution, and combustion
- Increased demand for the extraction of raw minerals used in the production of fuel cells from source countries and states.[115]

Incentive programs are available to help offset the costs of zero-emission transportation and associated refueling or charging infrastructure, including the Transit and Intercity Rail Capital Program (TIRCP), Carl Moyer Memorial Air Quality Standards Attainment Program (administered through air districts), and the AB 617 Community Air Protection Grants, among others. Awarded $3 million from the TIRCP in 2018, the San Bernardino County Transportation Authority (SBCTA) will be piloting zero-emission rail technology for passenger rail service between San Bernadino and Redlands, with plans to debut North America's first battery- and hydrogen powered train in 2024.[116] The Zero-Emission Multiple Unit (ZEMU) rail vehicle will replace one diesel multiple unit and provide service along a nine-mile rail corridor.[117]

114 Valley Vision. "Zero Emission Hydrogen Locomotive Pilot – West Sacramento," https://www.valleyvision.org/projects/zero-emission-hydrogen-locomotive-pilot-west-sacramento/.

115 CARB. April 27, 2023. Board Item # 23-4-1 Summary, https://ww2.arb.ca.gov/sites/default/files/barcu/board/books/2023/042723/23-4-1bis.pdf.

116 San Bernardino County Transportation Authority (SBCTA). "Zero-Emission Multiple Unit (ZEMU)," https://www.gosbcta.com/project/diesel-multiple-unit-to-zero-emission-multiple-unit-pilot/.

117 SBCTA. "ZEMU Facility Fact Sheet," https://www.gosbcta.com/wp-content/uploads/2022/12/ZEMU-facility-Fact-Sheet-ENG-120522.pdf

Figure 18: Zero-Emission Multiple Unit (ZEMU) Train

Credit: Stadler

The SBCTA pilot brought momentum to the state's interest in zero-emission hydrogen rail service. In September 2022, CalSTA, Caltrans, and Stadler entered a contract for the design and delivery of four hydrogen zero-emission trains, with an option to provide 25 additional trains.[118]

The Tri-Valley — San Joaquin Valley Regional Rail Authority is leading implementation of the Valley Link project, a 42-mile passenger rail service that would provide a transit alternative to the congested Interstate 580 corridor. The Valley Link project seeks to explore expanding on transit agencies' models of self-produced clean hydrogen and a production center able to support other transit and HD FCEV operators. The vision is to offset the project cost by producing its own clean hydrogen and selling the excess to other users. Construction of the initial operating phase, a 22-mile segment between Dublin/Pleasanton and Mountain House, is anticipated to begin in 2025.[119]

Maritime Demonstrations

Zero-emission maritime vessels are predominantly in the research and development phase in California, but a recently completed project demonstrated a pathway for zero-emission options.[120]

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118 Fender, Keith. September 21, 2022. "California Orders 29 Hydrogen Trains for Inter-City Services." *International Railway Journal*, https://www.railjournal.com/fleet/california-orders-29-hydrogen-trains-for-inter-city-services/.

119 Valley Link. "Valley Link Rail Project," https://www.getvalleylinked.com/. (Accessed June 10, 2023).

120 CARB. "LCTI: Zero-Emission Hydrogen Ferry Demonstration Project," https://ww2.arb.ca.gov/lcti-zero-emission-hydrogen-ferry-demonstration-project#:~:text=The%20Sea%20Change%20is%20a%2070%2Dfoot%20aluminum%20catamaran%2C%20designed,Marine%20shipyard%20in%20Bellingham%2C%20WA. (Accessed April 25, 2023.)

Figure 19: "Sea Change" Hydrogen Fuel Cell Ferry

Credit: All American Marine

Figure 19 shows the first hydrogen-powered fuel cell ferry in the United States, a 70-foot, 75-passenger vessel named *Sea Change*, which will soon be operating along the San Francisco waterfront, pending clearance by the U.S. Coast Guard. The vessel is equipped with a hydrogen fuel cell power package composed of 360 kilowatts (kW) of fuel cells and hydrogen storage tanks with a capacity of 246 kg. The system is integrated with 360 kWh of a lithium-ion battery and a 2x 300 kW electric propulsion system.[121] The project received a $3 million grant through CARB and is administered by the Bay Area Air Quality Management District (BAAQMD). Including matching funds, the total project cost was about $14 million.

CALSTART was awarded funding to develop an actionable fuel cell-powered tugboat design that will be ready for construction and implementation for tugboat operations at the Port of Los Angeles. Due to space constraints on the vessel and high fuel usage requirements, liquid cryogenic hydrogen (LH2) is a more feasible on-board storage solution than gaseous hydrogen for a fuel-cell-powered tugboat.

Aviation Demonstrations

Early developments to decarbonize the aviation sector are ongoing. Aviation operations are looking to diversify and exploring electrified options and sustainable aviation fuels (SAF), including hydrogen and other low-carbon fuels. This exploration will take time and resources as the interdependencies and relationships between aviation support systems require a holistic assessment and development of solution set pathways to achieve full decarbonization.[122]

In November 2021, the Federal Aviation Administration (FAA) published the *United States Aviation Climate Action Plan*, which identified electrification, and potentially hydrogen, as

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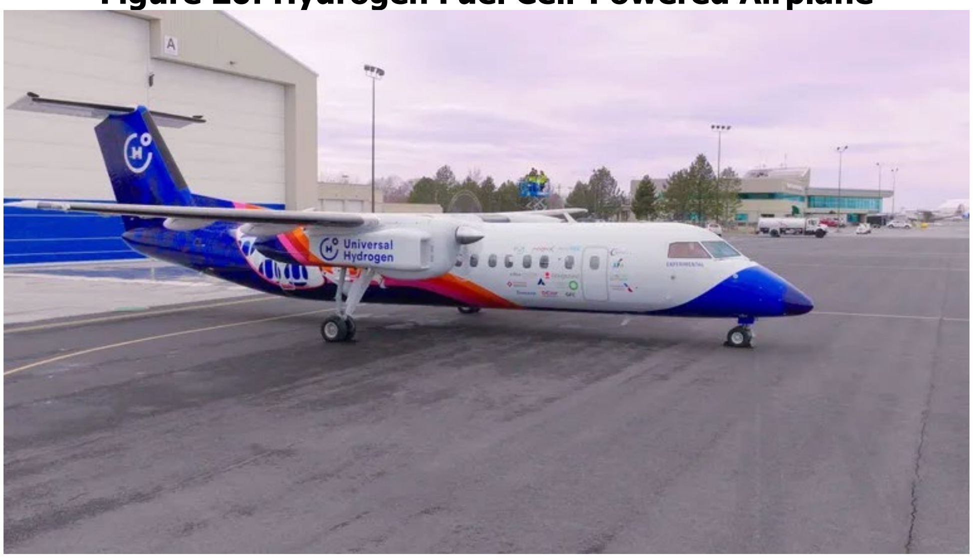
121 All American Marine. "AAM + SWITCH Maritime Announce the Launch of Sea Change, the World's First Commercial Vessel Powered 100% by Hydrogen Fuel Cells," https://www.allamericanmarine.com/hydrogen-vessel-launch/.

122 Oakleaf, Brett, Scott Cary, Darin Meeker, Doug Arent, John Farrell, Marc Day, Robert McCormick, Zia Abdullah, Stanley Young, Jacquelin Cochran, and Chris Gearhart. 2022. *A Roadmap Toward a Sustainable Aviation Ecosystem*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A60-83060. https://www.nrel.gov/docs/fy22osti/83060.pdf

solutions for short-haul aviation.[123] In 2022, Airbus stated an ambition to develop the world's first hydrogen-powered commercial aircraft by 2035. Airbus is considering using hydrogen propulsion — the combustion of hydrogen through modified gas-turbine engines — coupled with hydrogen conversion into electrical power that complements the gas turbine via fuel cells, creating a hybrid-electric propulsion chain powered entirely by liquid hydrogen.[124]

At the International Air Transport Association (IATA) 77th Annual General Meeting, the IATA approved a resolution for the global air transport industry to achieve net-zero carbon emissions by 2050. IATA estimates that to serve the needs of the 10 billion people expected to fly in 2050, at least 18 gigatons of carbon must be abated that year. One of the discussed strategies, as proposed by Airbus, is the potential of hydrogen as a new propulsion technology to help abate carbon emissions.[125]

Figure 20: Hydrogen Fuel Cell-Powered Airplane



Credit: Universal Hydrogen. Dash-8-300 testbed aircraft.

Early demonstrations of hydrogen applications in aviation are occurring globally, including in the United States. In March 2023, Universal Hydrogen successfully demonstrated the largest hydrogen fuel cell-powered airplane, shown in Figure 20, ever to be airborne and the largest airplane to fly principally on hydrogen.[126] The flight was conducted under an FAA Special Airworthiness Certificate, was the first in a two-year flight test campaign anticipated to

123 Federal Aviation Administration. November 2021. *Aviation Climate Action Plan*, https://www.faa.gov/sustainability/aviation-climate-action-plan#:~:text=On%20November%209%2C%202021%2C%20the,net%2Dzero%20emissions%20by%202050.

124 Airbus. "Hydrogen: An Important Decarbonisation Pathway," https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen. (Retrieved June 8, 2023.)

125 International Air Transport Association. October 4, 2021. "Net-Zero Carbon Emissions by 2050," https://www.iata.org/en/pressroom/pressroom-archive/2021-releases/2021-10-04-03/. (Accessed May 14, 2023).

126 Gates, Dominic. February 7, 2023. "FAA Clears Hydrogen-Powered Airplane for First Flight at Moses Lake." *The Seattle Times,* https://www.seattletimes.com/business/boeing-aerospace/faa-clears-hydrogen-powered-airplane-for-first-flight-at-moses-lake/.

culminate in 2025 with entry into passenger service of ATR 72 regional aircraft converted to run on hydrogen.[127]

127 Business Wire. March 2023. "Universal Hydrogen Successfully Completes First Flight of Hydrogen Regional Airliner," https://www.businesswire.com/news/home/20230302005768/en/Universal-Hydrogen-Successfully-Completes-First-Flight-of-Hydrogen-Regional-Airliner.

CHAPTER 5: Hydrogen Supply — Production, Storage, and Distribution

This chapter assesses existing clean hydrogen production infrastructure, including storage, distribution, and dispensing. Through an assessment of the potential projected demand for clean hydrogen by MDHD FCEVs, FCEBs, and off-road applications, supply requirements were estimated from the demand scenarios in Chapters 2 and 3.

Clean hydrogen has the potential to reduce GHG emissions from many of the most polluting sectors of the world but will prove sustainably successful only if production can keep up with demand. Further, hydrogen must reduce the associated GHG emissions by moving away from using fossil fuels to create it. Relying on book and claim or other accounting methods is not sufficient.

In 2023, the greatest demand for hydrogen in California, by far, is at refineries, with more than 1 million tons per year in use.[128] Due in part to the lower cost of production, most hydrogen produced in California is produced from fossil fuels through SMR. With SMR, methane molecules are split to extract hydrogen with carbon dioxide (CO_2) as a by-product; methane and CO_2 are GHGs. The types of production that support California's clean energy future goals are not through large-scale natural gas reforming.

A resilient, diverse, and reliable hydrogen supply chain is vital to developing the hydrogen refueling network. The hydrogen supply chain refers to the production of hydrogen molecules and the delivery of those molecules to refueling for trucks and goods movement, and emerging opportunities in other sectors. Clean hydrogen production in California is relatively scarce, and public-private partnerships are needed to drive the market. Other potential sources of demand — including power generation and storage, heat, industrial processes, and ammonia production — are not assessed in the 2023 SB 643 Staff Report but are recognized as important in driving the scale up in clean hydrogen production.[129]

The BIL dedicated $1.5 billion for technological advancements in qualified clean hydrogen production. The DOE is encouraging investments in research and development of technologies that can reduce the cost of clean hydrogen.[130]

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128 UC Davis Institute of Transportation Studies. 2022. *California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California*, https://escholarship.org/uc/item/27m7g841.

129 Reed, Jeffrey, Emily Dailey, Brendan Shaffer, Blake Lane, Robert Flores, Amber Fong, G. Scott Samuelsen. 2020. Roadmap for the Deployment and Buildout of Renewable Hydrogen Production Plants in California. CEC. Publication Number: CEC-600-2020-002, https://www.energy.ca.gov/publications/2020/roadmap-deployment-and-buildout-renewable-hydrogen-production-plants-california.

130 DOE. Hydrogen and Fuel Cell Technologies Office. "Hydrogen Production Pathways," https://www.energy.gov/eere/fuelcells/hydrogen-production-pathways.

Policy Context

Under AB 32, in 2009, CARB approved the Low Carbon Fuel Standard (LCFS) regulation to reduce the carbon intensity (CI) of transportation fuel used in California by at least 10 percent by 2020 from a 2010 baseline. CARB has amended the LCFS regulation twice, and the current goal is to reduce the CI of the transportation fuel pool by at least 20 percent from the 2010 baseline by 2030. The LCFS requirement encourages through incentives the use of electricity and hydrogen as low-carbon transportation fuels by providing opportunities to generate LCFS credits, which can be traded in the California LCFS credit market. LCFS credits can play an important role in helping develop and maintain the MDHD charging and refueling network in California. Opportunities with clean hydrogen can be summarized into two categories:[131]

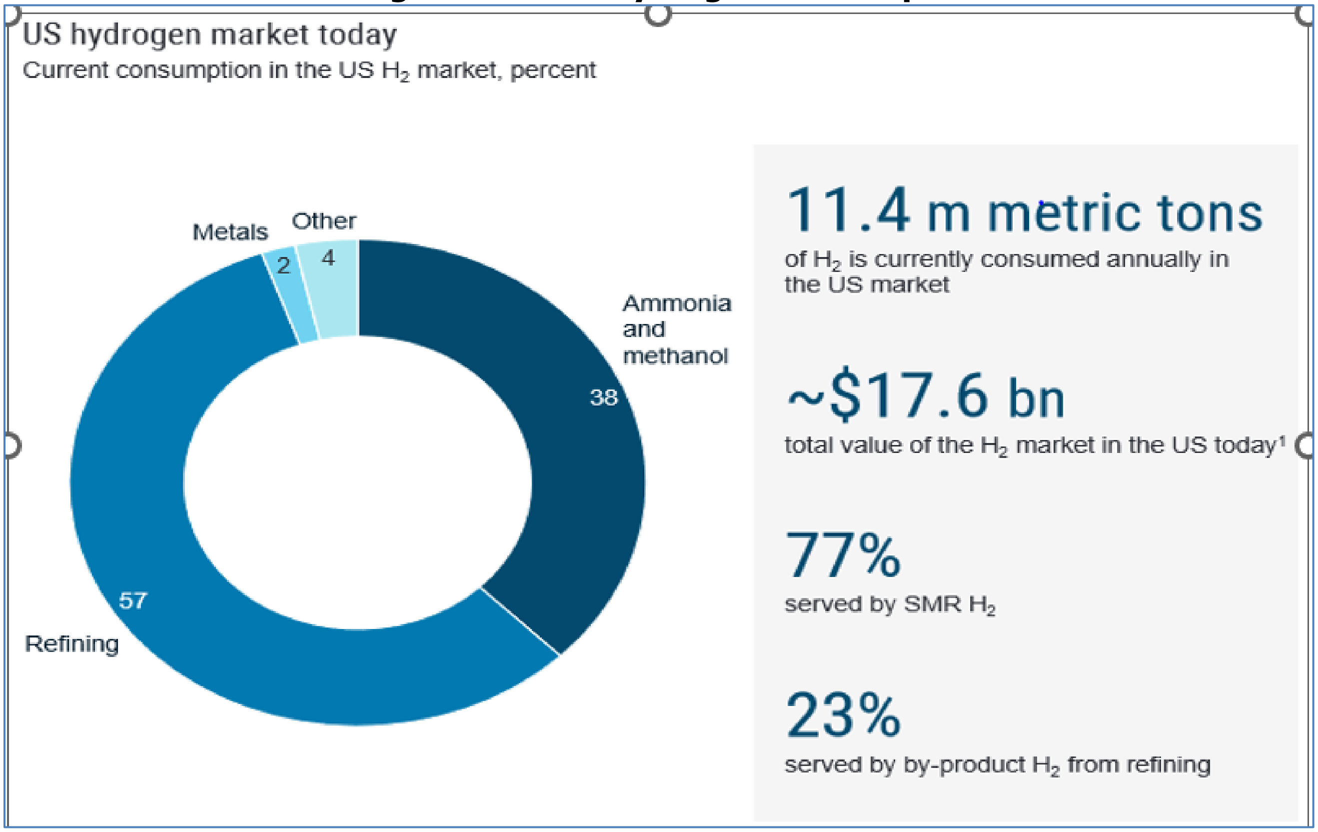
- An eligible fuel reporting entity that provides hydrogen as a transportation fuel may generate LCFS credits or designate a third-party to generate credits for the dispensed hydrogen. Eligible transportation applications are LD FCEV, MDHD FCEV, and fuel cell forklifts.
- Entities can claim zero CI or low CI used as transportation fuel using indirectly supplied electricity, claimed using book-and-claim accounting[132]. In this scenario the entity is still creating carbon emissions but using an accounting method to claim zero or low carbon.

Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006) set 33.3 percent as the renewable hydrogen requirement for publicly funded stations. LD or MDHD FCEV refueling stations that have received funding from the CEC or another public agency must meet this requirement. There would be very little clean hydrogen produced if book-and-claim was not allowed. There is no binding target for clean hydrogen production requirements in California.

131 CARB. "LCFS Electricity and Hydrogen Provisions," https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions.

132 Book-and-claim is a model for verified information to flow (a chain of custody model) that allows clean fuel or materials producers to "book" the emissions savings of a good they have produced in one place, and customers to "claim" the emissions benefit from these goods for climate disclosures in a different place.

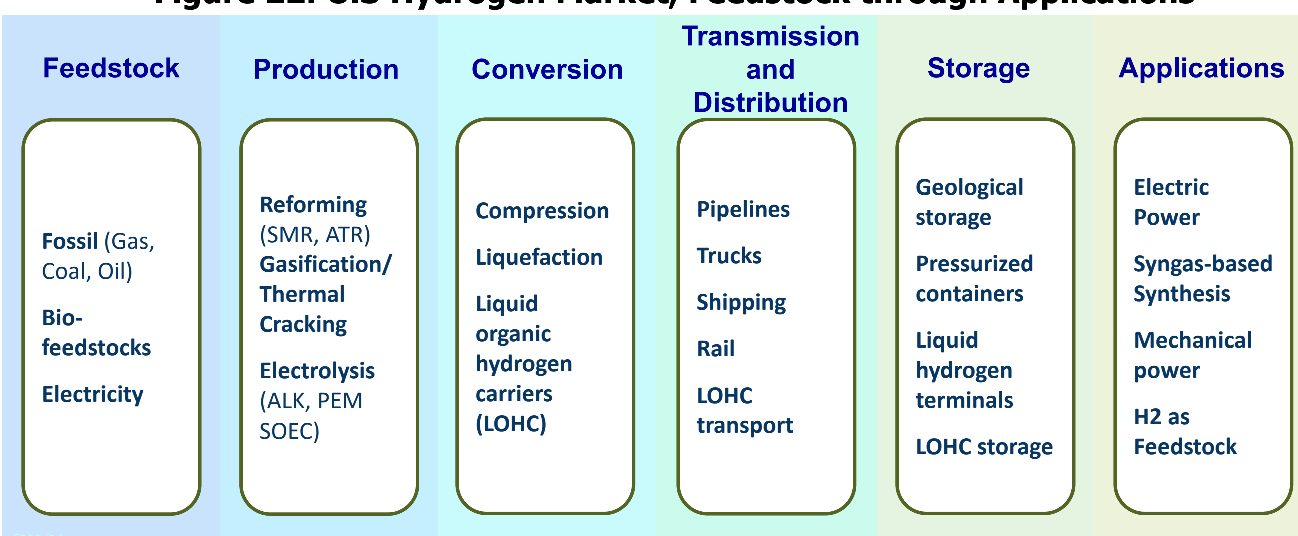
Figure 21: U.S. Hydrogen Consumption



Assuming realized price of $2/kg for hydrogen produced from SMR

Source: Fuel Cell and Hydrogen Energy Association. 2020. Road Map to a US Hydrogen Economy.

Figure 22: U.S Hydrogen Market, Feedstock through Applications



Source: Fuel Cell and Hydrogen Energy Association. 2020. Road Map to a US Hydrogen Economy.

CEC Investments in Clean Hydrogen Production

The Clean Transportation Program has awarded a total of $22 million to six clean hydrogen fuel production projects (four new facilities, two expansions) that will increase in-state production of hydrogen fuel supply for on-road FCEVs (both LD and MDHD) by nearly 40,000 kg/day. Three of the production plants, including the expansion, are currently or will use electrolysis, while two will produce hydrogen through gasification.

- StratosFuel:
  - Awarded nearly $4 million in 2018 to add capacity of 2,000 kg/day[133] produced from electrolyzers using electricity from wind power at its clean hydrogen production plant in Riverside County.
  - "Zero-Impact Production Facility Phase 2 Expansion." Awarded an additional $3 million to expand its existing development of a renewable hydrogen production plant with an additional 5,000 kg/day of production capacity and compression equipment, which will yield a total annual production capacity of 10,000 kg/day. Full development of the plant, which uses proton exchange membrane (PEM) electrolysis technology and will continue to with this expansion, is anticipated to be completed by the end of 2025.
- H2B2: H2B2 was awarded nearly $4 million to provide production capacity of 1,000 kg/day of clean hydrogen using an electrolyzer and on-site solar power in Fresno (Kings County). H2B2 recently announced that the project began commercial production with an initial 1,000 kg/day, and estimates that an expansion of the facility will be completed within the next 18 months and is expected to be one of the largest green hydrogen production plants in the United States.[134]
- Linde, Inc: "Expanding California's Production Capacity for Renewable Hydrogen Transportation Fuel." Linde was awarded $3 million for 2,050 kg/day of hydrogen production capacity to an existing 25,000 kg/day facility in Ontario (San Bernardino County). The existing facility produces hydrogen through steam methane reformation (SMR), but the funded addition will produce clean hydrogen through electrolysis powered by renewable electricity.
- SG H2 Lancaster Holding Company LLC: "Lancaster Waste to Renewable Hydrogen." The company was awarded $3,000,000 for 11,000 kg/day plant in Lancaster (Los Angeles County).
- Yosemite Clean Energy, LLC: "Yosemite Clean Energy Paradise Biomass to Carbon Negative Biofuels Plant." Yosemite Clean Energy was awarded $5 million for 18,000 kg/day of clean hydrogen from 90,000 tons of forest and farm waste biomass annually. The project is in Oroville and will contribute to Butte County's annual forest management goal to treat between 58,000 to 91,500 acres of forested watershed.

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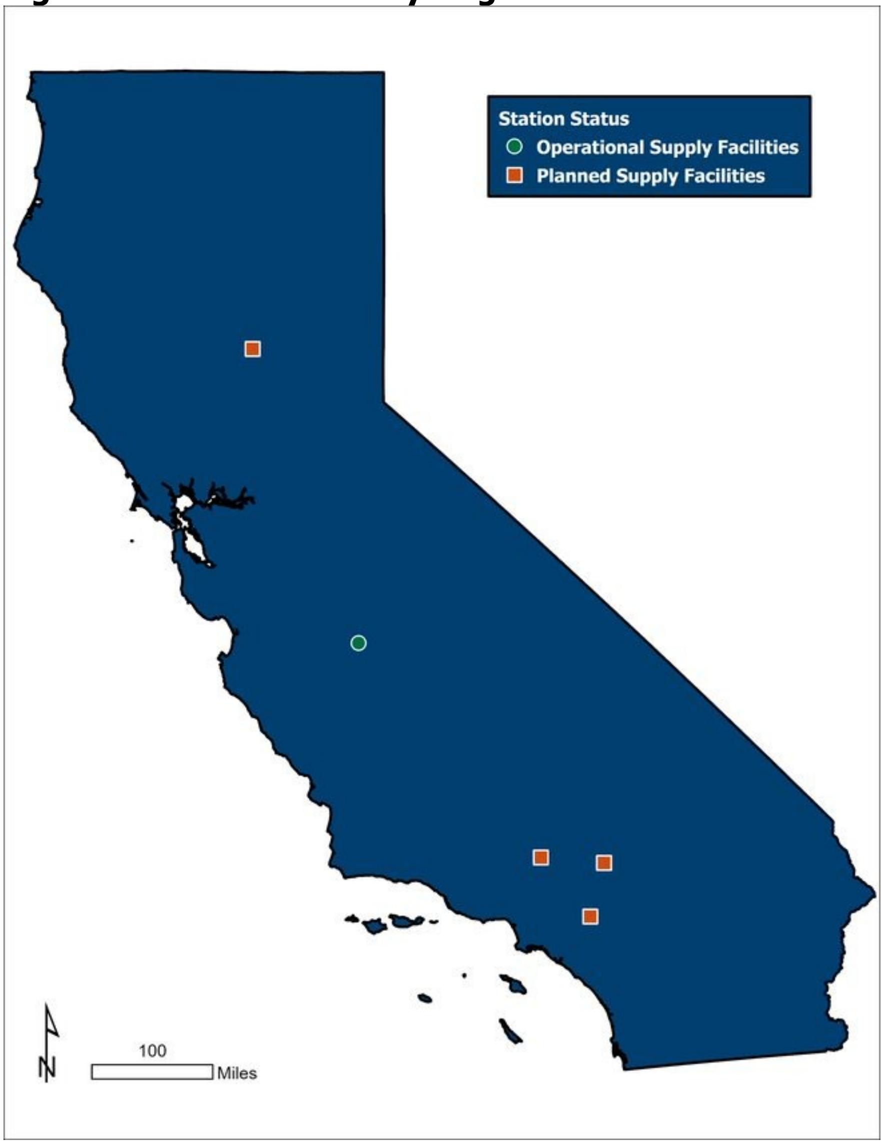
133 In addition to 3,000 kg already planned prior to award from CEC.

134 H2B2 Electrolysis Technologies. June 15, 2023. H2B2's "SoHyCal Project in California Has Started Hydrogen Production," https://www.h2b2.es/h2b2s-sohycal-project-in-california-has-started-hydrogen-production/.

Figure 23: CEC-Funded Hydrogen Production Facilities



Source: CEC staff

CEC Clean Hydrogen Program

In addition to the investments made through the CEC's CTP, Assembly Bill (AB) 209 (The Energy and Climate Change budget bill, Chapter 251, Section 12, Chapter 7.6, Article 4, enacted September 2022) requires the CEC to establish and administer a program to provide financial incentives to eligible in-state hydrogen projects. The projects should demonstrate, or scale-up, the production, processing, delivery, storage, or end use of clean hydrogen derived from water using eligible renewable energy sources. The directives provided by AB 209 established the CEC's Clean Hydrogen Program in 2022, which is administered by the Energy Research and Development Division (ERDD). In May 2023, of the $100 million dedicated to the program, ERDD committed $20 million to cost-share funding for eligible projects to applicants that apply for and receive an award under an eligible federal funding opportunity announcement. ERDD also issued a request for public feedback on a draft solicitation concept in May 2023. The draft concept focuses on large-scale centralized production of clean hydrogen with these primary objectives:

1) Demonstrate production of at least 5 metric tons of clean hydrogen per day.
2) Demonstrate hydrogen storage on-site and delivery off-site.
3) Meet demand for low-carbon fuels and contribute to the overall hydrogen economy in California through distribution networks.
4) Establish a foundation for learning-by-doing to enable economies of scale and knowledge sharing.
5) Lower the cost barrier and carbon impact for clean hydrogen production by co-locating renewable energy production with hydrogen production, delivery, and storage.

Additional Clean Hydrogen Production Projects

In recent years, public and private investments have encouraged new low-carbon and clean hydrogen production projects.

- Plug Power is planning a 30-metric-ton-per-day liquid hydrogen plant in Mendota (Fresno County) for operation in 2024.[135] The project includes electrolyzers, 300 MW of solar generation, 500,000 gallons of liquid hydrogen storage, and a 1.2-million-gallon-per-day tertiary water treatment plant for Mendota.
- Air Products is building a 10-metric-ton-per-day liquid hydrogen plant in Casa Grande, Arizona, which will provide fuel for California's transportation sector. The facility will use two alkaline water electrolyzers to produce gaseous hydrogen, which will be converted to liquid hydrogen. The plant will be powered with zero-carbon renewable electricity.[136]
- Raven SR Inc., Chevron U.S.A. Inc., and Hyzon Motors Inc. are planning a green waste-to-hydrogen production facility in Richmond (Contra Costa County), intended to supply hydrogen fuel to transportation markets in Northern California.[137] The plant is anticipated to produce 4,800 kg (5.3 tons) of hydrogen per day that would be exported offsite with no long-term hydrogen storage onsite. Production is expected to begin by the second quarter of 2024.[138]

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135 Presentation by Brenor Brophy with Plug Power. "Plug Power CEC IEPR Workshop." June 21, 2022, IEPR Commissioner Workshop on Role of Hydrogen in California's Clean Energy Future. https://efiling.energy.ca.gov/GetDocument.aspx?tn=243620.

136 Air Products Press Release. March 8, 2022. "Air Products to Build Green Liquid Hydrogen Production Facility in California," https://www.airproducts.com/company/news-center/2022/03/0308-air-products-green-liquid-hydrogen-production-facility-in-arizona.

137 Chevron. January 9, 2023. "Raven SR, Chevron and Hyzon Motors Collaborate to Produce Hydrogen from Green Waste in Northern California," https://www.chevron.com/newsroom/2023/q1/raven-sr-chevron-hyzon-motors-collaborate-to-produce-hydrogen-from-green-waste.

138 City of Richmond. "Raven SR Bioenergy Project." https://www.ci.richmond.ca.us/4365/Raven-SR-Bioenergy-Project.

- Linde will build, own, and operate the first of several planned 5 MW proton exchange membrane (PEM) electrolyzers to increase hydrogen capacity. Following this initial investment, the new electrolyzer, together with the existing plant, will produce enough green hydrogen to avoid up to 75,000 metric tons of carbon dioxide equivalent emissions per year. Expected to begin production in the second half of 2024, the new electrolyzer is one of several green hydrogen projects Linde is planning across the United States.

Federal Investments

Federal investments in clean hydrogen production have greatly accelerated in recent years. The BIL provides $7 billion toward the establishment of regional clean hydrogen hubs[139] and a tax credit of up to $3.00 per kg of clean hydrogen produced through the IRA. The hydrogen hubs will be one of the largest investments in U.S. DOE history. The historic funding through the BIL is complemented by new incentives in the IRA for qualified clean hydrogen produced with prevailing wages and apprenticeship requirements.

In March 2023, the U.S. DOE also announced the availability of $750 million for research, development, and demonstration efforts to reduce the cost of clean hydrogen. This funding launches the first tranche of implementation of two provisions of the BIL, which authorizes $1 billion for research, development, demonstration, and deployment to reduce the cost of clean hydrogen produced via electrolysis. The BIL authorizes $500 million for research, development, and demonstration of improved processes and technologies for manufacturing and recycling clean hydrogen systems and materials, as well.

In September 2022, the U.S. DOE opened a $7 billion funding opportunity for the regional clean hydrogen hubs. The law defines the term "regional clean hydrogen hub" as "a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity." In response to this opportunity, GO-Biz, the University of California system, the State Building and Construction Trades Council of California, and the Renewables 100 Policy Institute formed ARCH$_2$ES.

As discussed in Chapter 2, ARCH$_2$ES is a public-private partnership created to promote and oversee the design, development, and deployment of hydrogen infrastructure projects in California across at least three sectors, including power, heavy-duty transportation, and marine and inland ports. The overarching goal of ARCH$_2$ES is to reach a total clean hydrogen capacity of 45,000 tons per day by 2045, significantly reduce greenhouse gas and pollutant emissions, and deliver benefits to the state's economy overall. ARCH$_2$ES submitted its proposal to become a national hydrogen hub on April 7, 2023.[140] An announcement of awards by the U.S. DOE is anticipated to occur in fall 2023.

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139 U.S. DOE. Office of Clean Energy Demonstrations. Regional Clean Hydrogen Hubs. https://www.energy.gov/oced/regional-clean-hydrogen-hubs.

140 ARCHE$_2$S. April 7, 2023. "California Submits Application to U.S. Department of Energy for Federal Funding to Become a National Hydrogen (H2) Hub," https://archesh2.org/california-submits-application-to-u-s-department-of-energy-for-federal-funding-to-become-a-national-hydrogen-h2-hub/.

Developments in Electrolysis

Reducing the cost of electrolyzers, which separate water into oxygen and hydrogen, and the cost and availability of renewable energy is essential in producing competitive clean hydrogen. The cost and performance across electrolyzer technologies are not the same. Alkaline exchange membrane (AEM) and PEM electrolyzers are the most advanced and commercially available.

Electrolyzer manufacturers from other countries have announced that they are developing manufacturing plants in the United States. In May 2023, Norwegian company Nel Hydrogen announced that it would build a $400 million hydrogen technology plant in Michigan, stating that it had decided to build another plant in the United States because of the new federal incentives passed through the IRA.[141] Nel's Michigan facility will have a production capacity of up to 4 gigawatts (GW) of both AEM and PEM electrolyzers.

Distribution

Clean hydrogen can be produced on site at refueling stations if the site plan includes sufficient space for an electrolytic system, sufficient storage at the site, and additional cost of retail electricity. A wind or solar installation to power the electrolyzer must be correctly sized for efficient use.

Hydrogen is often produced in one location and then moved to a different location to be sold to consumers. The method of transportation will impact the life-cycle emissions created, such as when a truck that is not a ZEV needs to transport the hydrogen. Methods of transporting hydrogen to FCEB and FCEV refueling stations include gas tube trailer trucks, cryogenic liquid-carrying trucks, and pipelines. Distribution by tube trailers carrying gaseous hydrogen is the most cost-effective option.[142] This option could change if the daily demand at hydrogen stations exceeds 1,000 kg per day, which could make the delivery of liquid hydrogen via cryogenic tankers a more cost-effective option.[143] Refueling stations that have liquified hydrogen storage onsite use tanker trucks that pump hydrogen into an above-ground tank. The hydrogen is held at a cryogenic temperature, and then vaporized, compressed, and stored in above-ground cylinders for dispensing. Pipeline delivery is possible and being looked at with up to 20 percent hydrogen blending. The pipelines would need to be purified and then pressurized.

Liquid hydrogen is less expensive to store and transport and is likely to dominate production, onsite storage, and dispensing in the future. The storage costs and densities of liquid

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141 Beggin, Riley. May 3, 2023. "Michigan to Get $400 Million Hydrogen Technology Facility From Norwegian Company." *The Detroit News,* https://www.detroitnews.com/story/business/2023/05/03/michigan-to-get-400m-hydrogen-technology-facility-from-norwegian-firm/70179864007/.

142 Fulton, L.; Jenn, A.; Yang, C.; Burke, A.; Acharya, T.; Li, X., et al. 2023. *California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California: Final Synthesis Modeling Report.* UC Davis: Hydrogen Pathways Program. Retrieved from https://escholarship.org/uc/item/27m7g841.

143 Argonne National Laboratory. "Enabling Emerging Hydrogen Economies," https://www.anl.gov/aet/article/enabling-emerging-hydrogen-economies.

hydrogen far exceed those of gaseous hydrogen. Most LD and MDHD refueling stations rely on excess gaseous hydrogen from existing industrial applications.[144]

Mobile refuelers are another option for fuel distribution that can benefit high-throughput clusters, such as marine ports, or nomadic off-road applications, such as construction sites, that are not close to refueling infrastructure. OEMs are developing mobile refuelers that are capable of directly fueling FCEVs at locations that meet the needs of the drivers. At the beginning of 2023, OEM Nikola announced that it had developed a heavy-duty 700 bar (10,000 psi) hydrogen mobile fueler that, coupled with its hydrogen tube trailer with a capacity of 960 kg, could refuel MDHD FCEVs back-to-back.[145] In January 2023, Foothill Transit leased a mobile refueler from Air Liquide, a system housed in a 40-foot trailer, with the hydrogen gas supplied from a shorter trailer that contains 400 kg gaseous hydrogen vessels.

Dispensing

Senate Bill (SB) 1505 (Lowenthal, Chapter 877, Statutes of 2006) requires hydrogen refueling stations operating in California to dispense 33.3 percent renewable hydrogen. Hydrogen refueling stations receiving public funding must meet this requirement. Once the annual volume of hydrogen fuel dispensed reaches 3.5 million kg per year, this requirement will apply to all stations regardless of funding source.

According to CARB's *2021 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, roughly 10 million kg per year of hydrogen sales are estimated by 2025. In accordance with SB 1505, 33.3 percent of that hydrogen dispensed will need to be clean. Using data available through the LCFS program for all reporting hydrogen refueling stations, CARB staff estimates that around 44 percent of the hydrogen sold in in 2022 was generated with renewable attributes.

In addition, California's hydrogen refueling station network has experienced fuel shortages and supply constraints to the hydrogen refueling stations, demonstrating the expedited need for dedicated hydrogen production. Reportedly these issues have been caused by hydrogen production plants going offline for maintenance, and fuel delivery trucks have been out of service for repairs more frequently.

Storing and dispensing fuel for MDHD FCEVs, compared to diesel-fueled trucks, is costly in part due to higher compressor costs and additional precooling costs incurred to adjust for increased heat of compression. There are ongoing demonstrations of HD FCEVs using liquid hydrogen rather than gaseous. Some OEMs have stated a preference for liquid hydrogen in the development of hydrogen-based drives. Liquid hydrogen has a higher energy density in relation to gaseous hydrogen, and more liquid hydrogen can be carried by trucks, which increases the range. The cost of liquid hydrogen delivered to transit agencies is reported to be between $7 and $9 per kg.

144 Fulton, L.; Jenn, A.; Yang, C.; Burke, A.; Acharya, T.; Li, X., et al. 2023. *California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California: Final Synthesis Modeling Report*. UC Davis: Hydrogen Pathways Program. Retrieved from https://escholarship.org/uc/item/27m7g841.

145 Nikola Corporation. January 18, 2023. Press Release, "Nikola Launches First Hydrogen Fuel Cell Truck Mobile Fueler." https://nikolamotor.com/press_releases/nikola-launches-first-hydrogen-fuel-cell-truck-mobile-fueler-223.

Equipment issues affect station availability, as well. According to NREL, 61 percent of unscheduled maintenance events from the third quarter of 2014 through the second quarter of 2021 were due to equipment failures. Dispenser failure events were the most common, about half of the total events, followed by compressor failure events. Station operators also reported that they have experienced equipment repair delays because of supply chain issues.

CHAPTER 6: Synergies Across the Sectors and International Developments

This chapter discusses synergies across the sectors and international developments in fuel cell applications and clean hydrogen production. Investments in clean hydrogen are encouraging development of production sites globally as a path to reach climate goals in sectors of the economy that may be hard to decarbonize via direct electrification or other established means, including heavy haul transportation, long-term energy storage, and various industrial processes. Clean hydrogen has potential applications across numerous sectors such as industrial processes, including cement and steel production.

Synergies Across Sectors

There are proposed and existing demonstrations that provide examples of potential synergies across the sectors in using hydrogen as an energy source. These include HyBuild Los Angeles,™ which is the Green Hydrogen Coalition's inaugural initiative to create the first scaled ecosystem for green hydrogen (GH_2) in North America, targeting under $2.00 delivered clean hydrogen in the Greater Los Angeles Area.[146]

There are synergies found at California's ports, including opportunities for shared infrastructure across trucks, cargo handling equipment, passenger vehicles, and possibly rail and marine applications.

Pacific Gas and Electric Company (PG&E) is working with the Northern California Power Agency (NCPA) in Lodi (San Joaquin County) to build an electrolytic hydrogen demonstration project that will test blending up to 30 percent hydrogen into a closed-loop methane stream composed of different pipeline types. The blend will feed into NCPA's Lodi generating plant to produce electricity for NCPA customers. The project will also include refueling stations to test the blend on vehicles including heavy-duty trucks.

International Developments

Globally, clean hydrogen is becoming increasingly recognized as an important option in supporting climate ambitions and enhancing energy security. The drivers for the interest and investments in clean hydrogen vary internationally, most notably the recent invasion of Ukraine by Russia and the goal of energy independence, with clean or low-CI hydrogen becoming a frontrunner to displace hydrogen derived from natural gas, which became cost-prohibitive in affected countries.

The most ambitious strategies for clean hydrogen production are proposed by the European Union (EU) and Japan. The EU has a target of 40 GW by 2030, which is supported by national

146 Green Hydrogen Coalition. *HyBuild Los Angeles Phase 2 Report*, https://www.ghcoalition.org/ghc-news/hybuild-la-phase-2-report.

targets from France, Germany, the Netherlands, Portugal, and Spain.[147] The EU strategy sets a target volume of 10 million tons of clean hydrogen per year by 2030, which would require 40 GW of electrolysis in neighboring countries.[148]

In 2017, Japan was the first country to publish a strategy based on a hydrogen economy, titled *Basic Hydrogen Strategy*.[149] In April 2023, Japan updated its target to increase its hydrogen supply to 12 million tons per year by 2040.[150] The original plan had set a target of 3 million tons per year by 2030 from its current point of 2 million tons per year.

International Developments in FCEVs and Refueling Infrastructure

The European Union (EU), France, Germany, Hungary, the Netherlands, Portugal, Australia, Chile, and Canada have stated that developing medium- and heavy-duty hydrogen refueling infrastructure is a priority as part of their international strategies.[151] A study published by UC Davis reviewed international strategies, targets, and policies for creating a global hydrogen economy.[152] The study reviewed hydrogen policy in eight jurisdictions and then narrowed the focus to four: Japan, Germany, South Korea, and California. The study identified achieving GHG emission reduction targets and ensuring economic and energy stability as the main drivers for these jurisdictions to adopt hydrogen strategies. The study also identified different challenges these jurisdictions face in developing the hydrogen system and pointed to the lack of supporting upstream infrastructure, such as that for hydrogen distribution, to meet projected hydrogen demand as a common challenge for all jurisdictions.[153]

In 2022, CEC staff asked representatives of these national governments and organizations about current and future investments in FCEVs and refueling infrastructure, to present in the *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*.[154] Responses did not

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147 IRENA. 2020. *Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal*. International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf.

148 Ibid.

149 2017. Ministry of Economy, Trade and Industry (METI). "Basic Hydrogen Strategy," https://policy.asiapacificenergy.org/node/3698.

150 Reuters. April 4, 2023. "Japan Aims to Boost Hydrogen Supply to 12 Million T by 2040," https://www.reuters.com/business/energy/japan-aims-boost-hydrogen-supply-12-mln-t-by-2040-2023-04-04/.

151 World Energy Council. 2021. *Working Paper: National Hydrogen Strategies,* https://www.worldenergy.org/assets/downloads/Working_Paper_-_National_Hydrogen_Strategies_-_September_2021.pdf

152 Vijayakumar, V., Fulton, L., Shams, M., & Sperling, D. 2022. *Creating a Global Hydrogen Economy: Review of International Strategies, Targets, and Policies with a Focus on Japan, Germany, South Korea, and California.* UC Davis: Hydrogen Pathways Program, http://dx.doi.org/10.7922/G2N014VF Retrieved from https://escholarship.org/uc/item/9f95p0m1.

153 Berner, Jane, Miki Crowell, and Andrew Martinez. 2022. *Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. California Energy Commission and California Air Resources Board. Publication Number: CEC-600-2022-064. https://www.energy.ca.gov/sites/default/files/2022-12/CEC-600-2022-064.pdf.

154 Ibid.

consistently specify if the stations were LD, HD, or both, but some information can be inferred by the vehicle populations.

Table 3: FCEVs and Refueling Stations in Other Countries

	China	**Germany**	**Japan**	**South Korea**
Stations	147 open; an additional 65 built and awaiting a designated operator; 10 under construction; 8 on pause	96 open and 9 in development	159 open and 15 in development	172 stations built as of March 2022 with a goal to install 138 more stations by the end of 2022
Vehicles	8,941 cumulative sales of commercial vehicles through 2021	1,399 LD FCEVs and 107 MDHD vehicles as of January 2022	7,232 LD FCEVs, 120 FCEBs and MD FCEVs* in demonstration as of April 2022	20,621 LD FCEVs, 152 FCEBs, and 5 MDHD FCEVs as of April 2022

Source: CEC staff[155]

***Described as small trucks**

International Developments in Off-Road Hydrogen Applications

This section provides information on demonstrations of hydrogen fuel cell electric powered off-road applications, which include construction, mining, agriculture, and rail applications.

- In 2022, Volvo Construction Equipment (Volvo CE), following completion of its research project aimed at hydrogen technology application developments, began testing the world's first hydrogen fuel cell electric articulated hauler, a 22-ton construction rock truck, named the Volvo HXO4. The hauler is in testing toward 2024 customer trials.[156]
- In May 2022, international mining company Anglo American unveiled a prototype of the world's largest hydrogen-powered mine haul truck at its mine in South Africa in a 2 MW hydrogen-battery hybrid truck that generates more power than its diesel predecessor and is capable of carrying a 290-tonne payload. About 80 percent of Anglo American's diesel consumption is on its haul trucks. If the pilot is successful, Anglo American

155 Berner, Jane, Miki Crowell, and Andrew Martinez. 2022*. Joint Agency Staff Report on Assembly Bill 8: 2022 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. California Energy Commission and California Air Resources Board. Publication Number: CEC-600-2022-064. https://www.energy.ca.gov/sites/default/files/2022-12/CEC-600-2022-064.pdf.

156 Volvo CE. June 13, 2022. "Volvo CE Starts Testing of the World's First Prototype Hydrogen Articulated Hauler," https://www.volvoce.com/global/en/news-and-events/press-releases/2022/volvo-ce-starts-testing-of-the-worlds-first-prototype-hydrogen-articulated-hauler/.

estimates that it can remove up to 80 percent of diesel emissions at its open pit mines by using the technology across its global fleet.[157]

- Germany, a leader in adopting FCEVs and refueling infrastructure as demonstrated in Table 19, is developing off-road applications as well. At the February 2023 German Hydrogen Summit, advancements in using clean hydrogen for agriculture were demonstrated, including a prototype of the world's first hydrogen tractor.[158]
- In November 2020, Siemens Mobility and Deutsche Bahn presented the H2goesRail project to the public. The first deployed zero-emission train is called the Mireo Plus H, which is refueled using a mobile refueling station. The hydrogen is produced by an electrolyzer that is connected to the railway grid. The Mireo Plus H is a zero-emission train with a range of about 1,000 kilometers that can reach speeds of up to 160 km/h and can be refueled quickly. A single train saves up to 45,000 tons of CO_2 over the estimated service life of 30 years, compared to passenger vehicle trips.[159]
- Canadian Pacific line haul is developing line-haul locomotives capable of operating at speeds and generating horsepower comparable to a road-service diesel locomotive.[160]

International Developments in Electrolysis

In advanced European energy markets, electrolyzers are growing from megawatt to gigawatt scale. Germany and the European Union are using a 10 MW electrolyzer to produce up to 1,300 tons of electrolytic hydrogen per year for Shell's Rhineland refinery complex.[161]

In Canada, Air Liquide completed construction of the world's largest PEM electrolyzer. Compared to the traditional hydrogen production process, this new production unit will avoid the emission of around 27,000 tons of CO_2 per year. Bécancour, a city in Quebec, was chosen as the project location based on its site attributes, including access to renewable power from Hydro-Québec and the proximity to the hydrogen mobility market in the northeast of the continent.

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157 Anglo American. May 6, 2022. Anglo American unveils a prototype of the world's largest hydrogen-powered mine haul truck – a vial step toward reducing carbon emissions over time. https://www.angloamerican.com/media/press-releases/2022/06-05-2022.

158 Fendt, February 2023 Press Release. "Fendt Shows First Hydrogen Tractor at German Hydrogen Summit," https://www.fendt.com/int/fendt-shows-first-hydrogen-tractor-at-german-hydrogen-summit.

159 Siemens Mobility. June 2022. "First Hydrogen-Powered Trains for the Berlin-Brandenburg Metropolitan Region," https://press.siemens.com/global/en/pressrelease/first-hydrogen-powered-trains-berlin-brandenburg-metropolitan-region.

160 Canadian Pacific. March 2021. "CP to Employ Ballard Fuel Cells in Hydrogen Locomotive Project," https://www.cpr.ca/en/media/cp-to-employ-ballard-fuel-cells-in-hydrogen-locomotive-project.

161 Shell. July 2021. "Shell Starts up Europe's Largest PEM Green Hydrogen Electrolyser." https://www.shell.com/media/news-and-media-releases/2021/shell-starts-up-europes-largest-pem-green-hydrogen-electrolyser.html.

CHAPTER 7: Using Clean Hydrogen to Support California's Grid

This chapter discusses the potential of clean hydrogen to support the state's clean energy and reliability goals. Clean hydrogen can play an important role in helping achieve 100 percent renewable electricity by supporting grid reliability. As intermittent renewable resources such as wind and solar become a larger proportion of grid-connected resources, there is a need for resources that can provide grid support, similar to how natural gas power plants provide support. Hydrogen could help support grid reliability through repowering targeted ramping resources running off fossil gas with clean hydrogen made from renewable resources. Clean hydrogen-based resources can also be developed to provide support to the grid at the distribution level by reducing load at the sources through technologies such as fuel cells and linear generators. When part of a microgrid, these resources can also provide resilience. The solutions will be possible only through sufficient generation of clean hydrogen either onsite or generated remotely and transported and stored onsite. The California Independent System Operator's (California ISO) *2022–2023 Transmission Plan* discusses a more coordinated strategic direction and references the memorandum of understanding (MOU)[162] signed by California ISO, CARB, and the CPUC in December 2022, intended to help California meet its reliability needs and clean energy policy objectives.[163]

Using Hydrogen to Support California's Grid

Hydrogen could support California's grid through utility-scale electricity generation (for example, a power plant) or by reducing load at the customer site. Converting renewable energy to hydrogen, which is then stored, can provide an alternative to fossil gas for thermal generation. Some utilities are already upgrading gas turbines for hydrogen combustion to reduce greenhouse gas emissions. The Los Angeles Department of Water and Power's Intermountain Power Plant project in Utah and the Northern California Power Agency's Northern California Pacific H_2ub project at the Lodi Energy Center are shifting to combustion turbines to incorporate hydrogen blending capability.

San Diego Gas & Electric (SDG&E) is developing a power-to-gas-to-power (P2G2P) project that will use hydrogen as the energy storage medium. The energy storage system will use a grid-connected electrolyzer to generate hydrogen. The hydrogen will be stored in high-pressure tanks, and a fuel cell will consume the stored hydrogen to produce grid power. The system will initially provide long-duration (8+ hours) of energy storage, but the duration may be expanded through the addition of more hydrogen tanks to support longer durations. These units will not be 100 percent hydrogen, but plans are to shift to higher levels over time. At the

162 CEC. December 2022. "Memorandum of Understanding Between CPUC, CEC and ISO Regarding Transmission and Resource Planning and Implementation," https://www.energy.ca.gov/sites/default/files/2023-01/MOU_Dec_2022_CPUC_CEC_ISO_signed_ada.pdf.

163 Independent System Operator. April 2023. *Draft 2022–2023 Transmission Plan*. http://www.caiso.com/InitiativeDocuments/Draft-2022-2023-Transmission-Plan.pdf.

power plant level, there is a need to have access to a substantial volume of hydrogen to operate the plant properly.

According to a report by Energy and Environmental Economics (E3), if electrolyzer costs fall and are paired with low-cost renewable electricity, including otherwise curtailed renewable energy, hydrogen could compete with other storage technologies. E3 estimated the potential market size for hydrogen storage to be 1.5–4.5 GW in 2035 and 5–10 GW in 2045.[164] Producing clean hydrogen for end-use markets, as well as for energy storage within the electricity system, can help manage generator dispatching and grid management.

Microgrids and Distributed Energy Resources

Distributed energy resources (DER) are growing in application in California because equipment costs are decreasing, and state and federal incentive further make DERs more attractive to help customers reduce their electricity costs and provide greater resilience. Types of DERs include solar photovoltaics, thermal systems, battery energy storage systems, and fuel cells, which often use natural gas as fuel but could use hydrogen under certain circumstances.

In transportation applications, DERs can provide backup power for hydrogen refueling stations and provide additional benefits including cost reduction and increased renewable usage. A microgrid is a local network of loads and DER that can operate on its own when disconnected from the utility-controlled grid, increasing local electric reliability and resiliency. In the event of a blackout, or a catastrophic event such as a wildfire, microgrids can operate autonomously, and they have the potential to support a wider community during an emergency by exporting power.

The Borrego Springs microgrid is California's first renewable energy-based community microgrid and is connected to SDG&E's grid but can be disconnected and function independently during emergencies, supplying electricity to the local community through its onsite resources. The microgrid consists of SDG&E's substation, a 26 MW photovoltaic system in the Borrego Springs community, customer-owned rooftop photovoltaic systems, distributed generation resources, and storage batteries. Beyond the benefit to the Borrego Springs community of having noninterrupted energy resources, the project has increased microgrid knowledge base, including advanced microgrid controllers and implementing nonutility-owned resources.[165] SDG&E plans to test using clean hydrogen for long-duration (8 hours or more) energy storage. The clean hydrogen would be produced through electrolysis using local solar generation and water, stored in tanks, and converted back to electricity when needed via fuel cells.[166]

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164 E3. June 2020. *Hydrogen Opportunities in a Low-Carbon Future: An Assessment of Long-Term Market Potential in the Western United States*. Energy and Environmental Economics, Inc., https://www.ethree.com/wp-content/uploads/2021/11/E3_MHPS_Hydrogen-in-the-West-Report_Final_June2020.pdf.

165 Katmale, Hilal, Sean Clark, Laurence Abcede, and Thomas Bialek. 2018. *Borrego Springs: California's First Renewable Energy Based Community Microgrid*. California Energy Commission. Publication Number: CEC-500-2019-013. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2019-013.pdf.

166 SDG&E. 2021. "Borrego Springs Microgrid," https://www.sdge.com/sites/default/files/documents/2021%20Borrego%20Springs%20Microgrid%20Green%20Hydrogen%20FINAL.pdf?nid=2. (Accessed July 7, 2023).

Hydrogen fuel cells can provide emergency backup power that can replace diesel generators and provide zero emissions at the point of use. In Sonoma County, the Stone Edge Farm microgrid is a self-contained system of distributed electrical generation including solar panels, fuel cells, and a microturbine, as well as storage resources including batteries and hydrogen, to serve loads at the property. The solar energy of the microgrid powers the farm and uses an electrolyzer to produce clean hydrogen and includes an onsite hydrogen filling station to power three LD FCEVs. During the area's wildfires in 2017, Stone Hedge Farm islanded from the utility grid.[167] While the farm was evacuated, the microgrid was monitored from a safe distance by cell phone and operated the farm for 10 days, running the farm irrigation pumps. In August 2018, the owners of Stone Edge Farm returned the microgrid to island mode, and the farm remains off the grid to this day.[168] Senate Bill 1339 (Stern, Chapter 5, Statutes of 2018) required the CPUC to further develop policies related to microgrids. After a multiyear effort to remove barriers to microgrid development, in April 2023, the CPUC issued the *Decision Adopting Implementation Rules for the Microgrid Incentive Program*.[169] The Microgrid Incentive Program will distribute $200 million to the IOUs for microgrid projects, some of which could use hydrogen.[170]

Fuel cells are an opportunity for backup power under the Distributed Electricity Backup Assets program that the CEC is implementing in accordance with Assembly Bill 205, which established a new voluntary environmental review permitting process for clean energy resources. The CEC will hold environmental review processes for carbon-free generation to a maximum of 270 days, and its approval will stand in lieu of most local, state, and regional permits.

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167 Stone Edge Farm Estate Vineyards & Winery. "Microgrid." https://www.stoneedgefarm.com/microgrid/. (Accessed July 10, 2023.)

168 Stone Edge Farm Estate Vineyards & Winery. "Stone Edge Farm Estate Vineyards & Winery Microgrid," https://sefmicrogrid.com/. (Accessed July 10, 2023.)

169 CPUC. April 2023. Docket No.19-09-009. *Decision Adopting Implementation Rules for the Microgrid Incentive Program,* https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/resiliency-and-microgrids/505732868.pdf.

133 Ibid.

CHAPTER 8: Conclusions

Transitioning medium- and heavy-duty transportation and off-road applications to zero-emissions is key to meeting California's climate change and air pollution reduction goals. Recent unprecedented federal, state, and private investments in clean hydrogen production and MDHD FCEV refueling infrastructure, as well as world-leading regulations such as Advanced Clean Fleets and Advanced Clean Trucks, are accelerating developments in the industry. New models of Class 8 FCEVs have become commercially available in 2023, and the largest deployment of Class 8 FCEVs and refueling infrastructure in North America, through the NorCal ZERO project for drayage operations at the Port of Oakland, is in progress. This project is funded by the CEC and CARB.

This report assesses the potential of clean hydrogen to help meet statewide goals in the medium- and heavy-duty transportation sectors and in nascent off-road sectors that are in early demonstration, and identifies the following areas as key for continued emphasis and review:

1. While the MDHD market is early in development, transportation applications alone may be insufficient to reach the demand scale needed to justify large clean hydrogen plants. Additional sectors with hydrogen requirements may be needed to drive production.
2. The level of uncertainty for future demand for MDHD FCEVs is demonstrated by the variance between refueling infrastructure requirement scenarios presented in this report. Meeting the demand for clean hydrogen for refueling stations will be contingent on available hydrogen fuel supply, which benefits from state and federal policies and investments toward clean hydrogen production, and demand from sectors other than transportation.
3. Private-public partnerships, including government incentives, private investments, public education, and workforce development programs, are needed to overcome barriers to hydrogen refueling infrastructure deployment.
4. The CEC and CARB have identified barriers to widespread light-duty FCEV commercialization and deployment in the *Joint Agency Staff Report on Assembly Bill 8: 2021 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. These barriers include lack of refueling infrastructure, supply disruptions in the nascent industry of hydrogen production for transportation, high hydrogen fuel prices, hydrogen station downtime due to equipment failures and other factors, and the lack of vehicle models and consumer options. Enhancing the hydrogen station network reliability, resiliency, and availability is important to improve the customer experience and scale the market.
5. The hydrogen industry needs to reduce hydrogen fuel costs, especially for clean hydrogen that does not depend on fossil fuels for its production. Further, more transparency is needed on how hydrogen is produced and what accounting is being used to classify it as renewable, clean, or low-, zero-, or negative-carbon.

6. Clean hydrogen in hard-to-electrify transportation and off-road applications can be a key part of a comprehensive portfolio of solutions to meet the clean energy future envisioned for California.

GLOSSARY

Additional Achievable Transportation Electrification 3 (AATE3) – A planning scenario from the 2022 Integrated Energy Policy Report that incorporates the expected impact of the ACT and ACF regulations on ZEV ownership and use.

Authorities Having Jurisdiction (AHJ) – An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

Bay Area Air Quality Management District (BAAQMD) – A public agency that regulates the stationary sources of air pollution in the nine counties of California's San Francisco Bay Area, which are: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, southwestern Solano, and southern Sonoma
Battery Electric Bus (BEB) – Also known as an "all-electric" bus, BEBs use energy that is stored in rechargeable battery packs. BEVs sustain power through the batteries and therefore must be plugged into an external electricity source to recharge.

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

Clean Hydrogen – The standard proposed by the U.S. DOE, which is an initial target for lifecycle GHG emissions of 4.0 kgCO2e/kgH2 and the standard provided in California Public Resources Code Section 25741, which is hydrogen that is produced from water using eligible renewable energy resources or produced directly from eligible renewable energy resources.

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

California Energy Commission (CEC) –The state's primary energy policy and planning agency. It has seven core responsibilities: advancing state energy policy, encouraging energy efficiency, certifying thermal power plants, investing in energy innovation, developing renewable energy, transforming transportation, and preparing for energy emergencies.

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

Disadvantaged Community — Defined by Health and Safety Code 39711 as the most burdened census tracts in California. Burden scoring is determined by 20 pollution/health and socioeconomic factors.

Foothill Transit Authority (Foothill Transit) — A transit agency that serves over 327 square miles of Southern California's San Gabriel and Pomona Valleys in Los Angeles County. As of August 2023, Foothill Transit operates a fleet of 359 buses (307 Compressed Natural Gas, 19 BEBs, and 33 FCEBs).

Fuel Cell Electric Bus (FCEB) — A zero-emission bus that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.
Fuel Cell Electric Vehicle (FCEV) – A vehicle that uses an electric motor for propulsion, much like a BEV, but powers the electric motor using hydrogen fuel cells rather than a large onboard battery. FCEVs are a subcategory of ZEVs.

Golden Empire Transit — A transit agency that serves the greater Bakersfield area in Kern County. Its fleet includes 10 FCEBs.

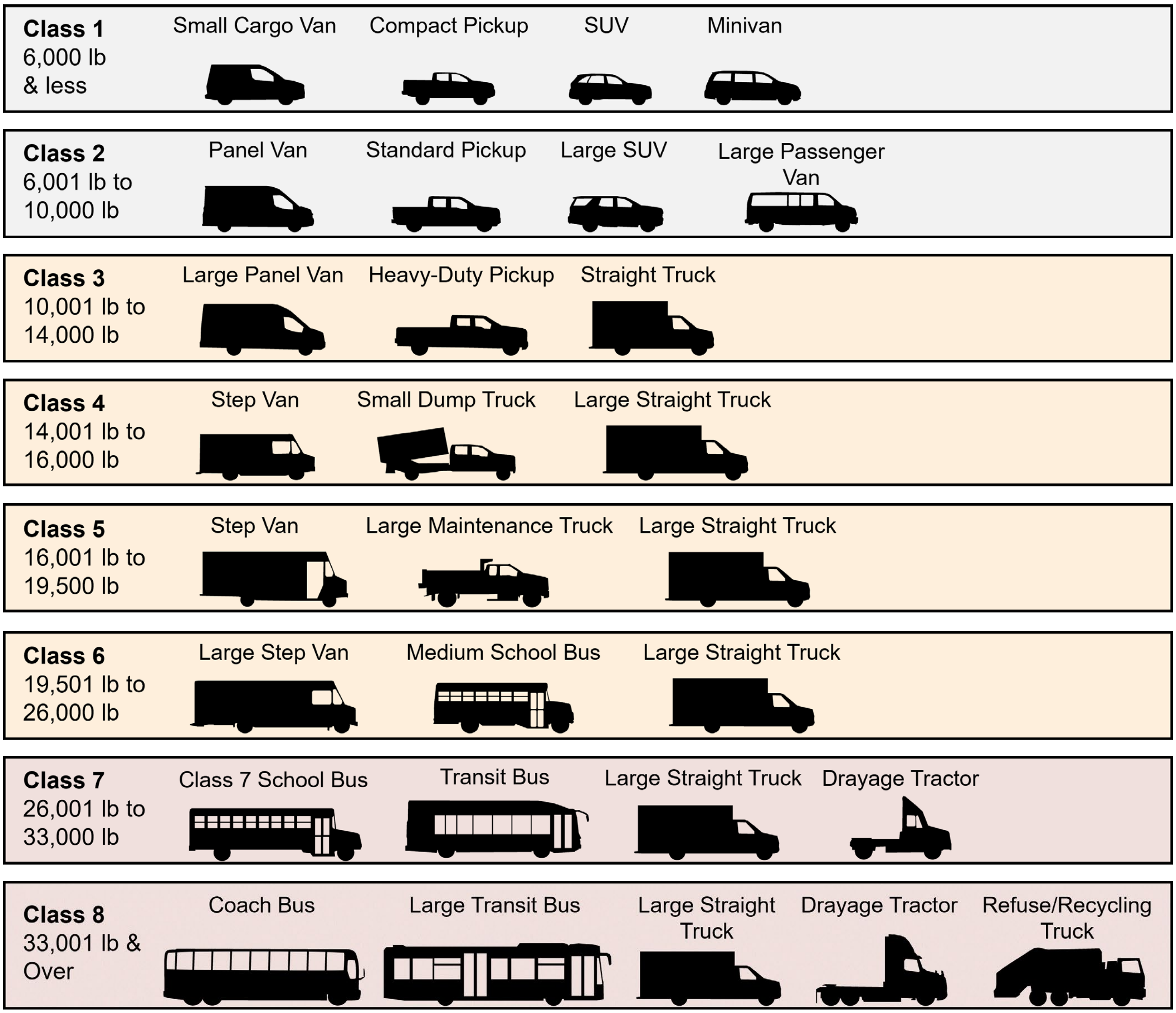
Low Carbon Fuel Standard (LCFS) — Standard developed by CARB to reduce the carbon intensity of transportation fuel used in California.

North Coast Transit District (NCTD) — The agency responsible for public transportation in Northern San Diego County, including fixed-route bus services, commuter rail service, hybrid rail service, paratransit, and on-demand service. The NCTD was recently awarded federal funding to purchase FCEBs and fueling infrastructure

South Coast Air Quality Management District (SCAQMD) – A public agency that regulates air pollution for all of Orange County and the urban portions of Los Angeles, Riverside, and San Bernardino counties.

Zero-Emission Vehicle (ZEV) — A vehicle that emits no exhaust gas from the onboard source of power.

APPENDIX A:
Vehicle Classes



APPENDIX B: Fuel Cell Electric Bus Hydrogen Demand Scenario

The following table includes a current and future hydrogen demand scenario for FCEBs. FCEBs typically carry up to 40 kg of hydrogen and consume about 25-30 kg of hydrogen per day. The assumption that produced the hydrogen demand is that each FCEB consumes 30 kg per day and is operating 365 days per year.

Table B-1 Fuel Cell Electric Buses: Hydrogen Demand Scenario

Transit Agency	Location	FCEBs in Service*	FCEBs on Order	FCEBs Awarded**	Future FCEBs Purchases per 2022 Rollout Plans
Alameda-Contra Costa Transit District	Oakland	31	20	25	458
Butte Regional Transit	Chico	-	-	-	16
City of Santa Clarita	Santa Clarita	-	-	-	18
Eastern Contra Costa Transit Authority	Antioch	-	-	-	34
Foothill Transit	West Covina	33	19	-	Unknown
Fresno Area Express	Fresno	-	-		66
Gold Coast Transit District	Oxnard	-	-	5	159
Golden Empire Transit District	Bakersfield	10	-	-	55
Humboldt Transit Authority	Eureka	-	1	11	95
Lake Transit Authority Small	Lower Lake	-	-	4	47

Transit Agency	Location	FCEBs in Service*	FCEBs on Order	FCEBs Awarded**	Future FCEBs Purchases per 2022 Rollout Plans
Livermore/Amador Valley Transit Authority	Livermore	-	-	-	100
Long Beach Transit	Long Beach	-	-	-	210
Montebello Bus Lines	Montebello	-	-	-	66
Monterey-Salinas Transit District	Monterey	-	-	-	56
North County Transit District	Oceanside	-	-	35	35
Orange County Transportation Authority Large	Orange	10	-	-	340
Omnitrans	San Bernardino	-	-	4	-
Pasadena Transit	Pasadena			25	25
Riverside Transit Agency	Riverside	-	-	5	282
San Diego Metropolitan Transit System	San Diego	-	-	-	277
San Joaquin Regional Transit District	Stockton	-	5	-	-
San Mateo County Transit District	San Carlos	-	10	-	-
Santa Cruz Metropolitan Transit District	Santa Cruz	-	-	12	54

Transit Agency	Location	FCEBs in Service*	FCEBs on Order	FCEBs Awarded**	Future FCEBs Purchases per 2022 Rollout Plans
Sunline Transit Agency	Thousand Palms	21	9	-	169
Victor Valley Transit Authority	Hesperia	-	-	-	109
Western Contra Costa Transit Authority	Pinole	-	-	-	64
TOTAL FCEBs		**105**	**64**	**126****	**2,735**
Demand (kg)		**1,149,750**	**700,800**		**29,948,250**
Annual Demand (kg) by 2040					**31,798,800**

*As reported by the transit agencies and may be different from information reported in the 2022 Rollout Plans due to changes that occurred after they submitted their plans.

**Awarded through the Federal Transit Administration's Grants for Buses and Bus Facilities Competitive Program https://www.transit.dot.gov/bus-program. The hydrogen demand for the awarded FCEBs is not included in the annual demand by 2040, as this is accounted for in the final column of the table.

APPENDIX C: Inputs and Assumptions for Infrastructure Scenarios

This appendix discusses inputs and assumptions used for the four MDHD infrastructure scenarios discussed in Chapter 3, Medium- and Heavy-Duty Fuel Cell Electric Vehicles and Infrastructure.

2022 Scoping Plan Infrastructure Scenario

The 2022 Scoping Plan Scenario uses MDHD FCEV stock from the *2022 Scoping Plan Appendix H: AB 32 GHG Inventory Sector Modeling*,[171] which was informed by the references provided in Table C-1. CARB's Emission Factors Model (EMFAC) 2021 was used to develop baseline on-road energy consumption, providing vehicle miles traveled, vehicle stock shares by fuel type, and vehicle populations.

Table C-1: Transportation References

Description	Transportation Reference
Calibration of fuel demand by subsector	California Greenhouse Gas Emissions Inventory 2021, CARB
Vehicle miles traveled (VMT) on-road	Internal analysis by CARB based on Metropolitan Planning Organization forecasts from second Sustainable Communities Strategies and California Department of Tax and Fee Administration fuel sales data.[172]
Fuel efficiency (on-road)	Vision 2.1 scenario modeling system, CARB
Vehicle stock characterization	Emission Factors Model (EMFAC) 2021, CARB
Vehicle and infrastructure	MHDV: "Driving California's Transportation Emissions to Zero," CA Institute of Transportation Studies, April 2021

Source: CEC staff, using information provided in CARB's 2022 Scoping Plan Appendix H, Table H-4, page 6.

171 CARB. *2022 Scoping Plan Appendix H: AB 32 GHG Inventory Sector Modeling*. https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf.

172 The base year (2019) is estimated based on gasoline consumption data from the California Department of Tax and Fee Administration and fuel economy and vehicle fleet mix data from CARB's EMFAC model. The 2035 and 2045 activity data are based on the Metropolitan Planning Organization (MPO) forecast from MPO's second Sustainable Communities Strategies.

CEC staff used MD FCEV and HD FCEV stock provided in 2022 Scoping Plan's Appendix H. Staff's assumptions for the scenario were that all MD FCEVs would be filled at 10 kg/day, and MD FCEV station capacity would be 1,000 kg/day at 80 percent capacity, allowing some downtime for maintenance. Staff's assumptions for HD FCEVs were that all would be filled at 30 kg/day, and HD FCEV station capacity would be 3,000 kg/day at 80 percent capacity. With varying assumptions – such as different fill amounts or station capacities – the station requirements would change.

Table C-2: Using 2022 Scoping Plan Vehicle Stock and Assumptions to Estimate Infrastructure Scenarios for 2025, 2030 and 2035

Year	MD FCEV Stock	MD stations 80% uptime	HD FCEV Stock	HD stations 80% uptime	Total Stations (MD+HD)
2025	1,449	17	2,484	30	**47**
2030	32,939	395	15,177	182	**577**
2035	94,072	1,129	55,676	668	**1,797**

Credit: CEC staff

This scenario does not differentiate how many stations will be public versus private/depot stations. It's important to note that this information may become available in a future assessment, and that MD FCEV stock in 2025 may be unlikely given that the CEC is unaware of any commercially available MD FCEVs in California at this time.

ARCH$_2$ES Federal Hub Infrastructure Scenario

As noted in Chapter 2, it was challenging to produce an ARCH$_2$ES station scenario given confidentiality considerations. With assumptions and input provided by the University of California, Davis, and others in the ARCH$_2$ES partnership, a scenario of heavy-duty station requirements was produced. Assumptions include that light-duty and medium-duty FCEVs will be able to refuel at light duty stations, with equipment sized and suited to them. Heavy-duty FCEVS will refuel at different stations, with spacing and station sizing that can handle 18 wheelers, and with hydrogen storage and refueling technology for large tank systems. Other assumptions include that a fully utilized HD station will operate at 80 percent of its rated capacity; the HD station capacity will be 3,500-5,000 kg in 2025, and up to 8,000 kg in 2035.

SB 671 Draft Infrastructure Balanced Scenario

SB 671 requires the CTC to prepare a Clean Freight Corridor Efficiency Assessment that identifies freight corridors, or segments of corridors, and the infrastructure needed to support the deployment of zero-emission MDHD vehicles (BEV and FCEV) by December 1, 2023.

Pending release of the final assessment, CEC staff utilized the Senate Bill 671 Infrastructure Needs Assessment issued by CTC staff.[173]

CTC staff found that estimates of zero-emission freight infrastructure needs depend on several variables, and there is uncertainty when predicting what will occur over the next 20 years. Hence, three potential scenarios of infrastructure needs were prepared – a high BEV scenario, a balanced scenario, and a high FCEV scenario The methodology used to develop three possible scenarios of zero-emission infrastructure is described in the assessment. Estimates of the following factors were used:

- Total number of MDHD ZEVs that will be on the road
- Annual vehicle miles traveled by vehicle class type
- Fuel efficiency of BEVs and FCEVs
- Mix of power train adoptions. For example, the percentage of total MDHD ZEVs that will be BEVs versus FCEVs. One scenario tests a higher and faster adoption of battery electric trucks; a second tests a higher and faster adoption of hydrogen fuel cell trucks; and a third scenario is driven by likely total cost of ownership parity with combustion engines, and the resulting powertrain choice by vehicle class and primary trip type.
- Characteristics of BEV charging stations, such as the number of public versus private stations, charging efficiency, capacity factors, and utilization
- Characteristics of FCEV stations, such as the split of public versus private ownership, annual fuel capacity per station, and utilization
- Maximum distance between charging stations and hydrogen fuel stations to form a minimum viable network: Assumptions are held constant across all three scenarios but differ based on the speed and mix of zero-emission truck power train adoption included in each scenario.

Table C-3: SB 671 High BEV Scenario

Stations	2025	2030	2035
FCEV Private	0	0	1
FCEV Public	0	0	3
Total Stations	**0**	**0**	**4**

Credit: CTC staff

173 CTC. "Senate Bill 671 Infrastructure Needs Assessment." https://catc.ca.gov/-/media/ctc-media/documents/programs/sb671/092023-infrastructure-needs-assessment-a11y.pdf.

Table C-4: SB 671 Balanced Scenario

Stations	2025	2030	2035
FCEV Private	7	150	539
FCEV Public	21	451	1,618
Total Stations	**28**	**602**	**2,157**

Credit: CTC staff

Table C-5: SB 671 High FCEV Scenario

Stations	2025	2030	2035
FCEV Private	31	280	717
FCEV Public	93	840	2,150
Total Stations	**124**	**1,120**	**2,867**

Credit: CTC Staff

The 2023 SB 643 Staff Report uses the balanced scenario in its comparison of different infrastructure scenarios based on the current state of the FCEV market. While at least 19 MDHD FCEV refueling stations are either in the design or construction phases, with just a few operating, CEC staff finds that the other two scenarios which include zero stations or 124 stations by 2025 unlikely. The number of FCEV stations estimated in the high BEV scenario does not align with current and near-operational FCEV stations, but CEC staff anticipates that the final SB 671 assessment will adjust for this.

Additional Achievable Transportation Electrification (AATE3) Station Scenario

The *2022 IEPR Update* AATE Scenario 3 (AATE3) shows a low uptake in MDHD hydrogen vehicles due to a range of modeling inputs, including a relatively high hydrogen fuel price received from NREL, which made hydrogen trucks less viable in the truck choice model. As more data for MDHD hydrogen vehicles become available, the inputs for the MDHD models will continue to be refined.

Table C-6: AATE3 Station Scenario

Year	MD FCEVs	MD stations 80% uptime	HD FCEVs	HD stations 80% uptime	Total Stations (MD+HD)
2025	0	0	0	0	**0**
2030	71	1	0	0	**1**
2035	893	10	3	1	**11**

Credit: CEC staff

Staff assumptions to produce the scenario shown in Table C-6 included that all MD FCEVs would be filled at 10 kg/day, and MD FCEV station capacity would be 1,000 kg/day at 80 percent capacity, allowing some downtime for maintenance. Staff's assumptions for HD FCEVs included that all would be filled at 30 kg/day, and HD FCEV station capacity would be 3,000 kg/day at 80 percent capacity. Based on varying assumptions – such as different fill amounts or station capacities, the station scenario would change, but given the level of uncertainty regarding station size and fills, a standard assumption was used.

This scenario does not differentiate how many stations will be public versus private/depot stations. This information may become available in a future assessment.