CALIFORNIA ENERGY COMMISSION

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Joint Agency Staff Report on Assembly Bill 8: 2021 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California

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California Energy Commission

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ABSTRACT

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 is in accordance with Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013), which requires the California Energy Commission (CEC) and California Air Resources Board (CARB) to "jointly review and report on progress toward establishing a hydrogen-fueling network that provides the coverage and capacity to fuel vehicles requiring hydrogen fuel that are being placed into operation in the state."

The CEC's Clean Transportation Program has invested nearly $166 million and currently plans to invest a total of $279 million in hydrogen infrastructure. CEC and CARB staffs expect that California will exceed the 100-station goal in Assembly Bill 8 in 2023, with more than 179 stations by 2027. The General Fund appropriation for zero-emission vehicle infrastructure in the California Budget Act of 2021 is anticipated to support additional hydrogen stations to reach the 200-station goal. As of October 22, 2021, the 52 open-retail hydrogen refueling stations, funded by the Clean Transportation Program, the Volkswagen Mitigation Trust Fund, and the private sector have the capability to serve as many as 36,000 light-duty fuel cell electric vehicles (FCEVs), which exceeds the estimated on-road population of 9,647 FCEVs. Station down time and hydrogen supply disruptions diminished the customer experience. The planned 179 stations will have the capability of serving more than 245,000 light-duty FCEVs, of which at least 13 can serve light-, medium-, and heavy-duty vehicles. As the number of hydrogen stations expands, station deployment should not be a barrier to near-term light-duty FCEV deployment. CEC and CARB staffs intend to continue evaluating the FCEV market and identify metrics to inform potential future funding decisions by examining FCEV deployments, global trends, consumer preferences, and the consumer experience at stations.

Keywords: Assembly Bill 8, California Air Resources Board, California Energy Commission, Clean Transportation Program, fuel cell electric vehicle, hydrogen refueling station

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EXECUTIVE SUMMARY

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* (2021 Joint Report) describes the investment, planning, development, and use of hydrogen refueling stations to support fuel cell electric vehicles (FCEVs) in California as directed by Assembly Bill (AB) 8 (Perea, Chapter 401, Statutes of 2013). AB 8 further directs the California Energy Commission (CEC) to allocate $20 million annually, not to exceed 20 percent of the funds appropriated by the Legislature, from the Clean Transportation Program toward public hydrogen refueling stations until there are at least 100 publicly available stations in California. Governor Edmund G. Brown Jr.'s Executive Order B-48-18 set a goal of 200 hydrogen fueling stations by 2025.

Governor Gavin Newsom's Executive Order N-79-20 sets goals for all new passenger cars and trucks sold in California to be zero-emission by 2035, all medium- and heavy-duty trucks and buses operated in California to be zero-emission by 2045 everywhere feasible, and all drayage trucks to be zero-emission by 2035. The goals will influence the tangible outcomes of policies, requirements, and investments planned by numerous California agencies and municipalities, including the CEC and the California Air Resources Board (CARB).

California anticipates reaching 100 stations by the end of 2023. With the Clean Transportation Program allocating funding to 172 stations (including 16 to be privately funded under CEC agreement) and the private sector announcing an additional 7 privately funded stations, the state expects up to 179 stations by 2026. In addition, the one-time appropriation of General Funds for zero-emission vehicle infrastructure in the California Budget Act of 2021 per Senate Bill 170 (Skinner, Chapter 240, Statutes of 2021) is anticipated to help the state reach the 200-station goal.

When all 179 stations are open, the network will be capable of supporting about 245,000 FCEVs. The CEC projects that once 200 stations are open in the state, about 290,000 FCEVs can be supported, assuming the remaining 21 stations have a capacity of 1,600 kg/day. The state has more forecasted fueling capacity than the forecasted need for the foreseeable future, which provides opportunity for auto manufacturers to accelerate the planning and deployment of FCEVs in California over the coming years. However, the actual network fueling capability depends on the availability of hydrogen supply and the station uptime.

KEY TAKEAWAYS

- **California has 52 open-retail stations.**
- **About 11,269 light-duty FCEVs have been sold or leased and 9,647 light-duty FCEVs are on the road as of the end of the third quarter of 2021.**
- **California will have more than 100 stations by the end of 2023, meeting the AB 8 goal.**
- **The CEC will invest more than $275 million with increasing support from the private sector.**
- **China, Germany, Japan, Republic of Korea, and California have nearly five hundred hydrogen refueling stations with an estimated 32,000 on-road light-duty and 8,000 medium and heavy-duty FCEVs.**

The CEC and CARB also evaluate fueling needs at a regional level to analyze if the specific areas where vehicles are being sold and leased are adequately served by stations. This is particularly important to analyze during early market development, as having infrastructure in places where potential customers need them can influence the decision to adopt FCEV technology. The largest urban areas of the state will experience network capacity increases capable of supporting tens of thousands more FCEVs within the next one to two years. Other urban areas will need stations to open these markets to FCEVs. The CEC has made significant investments in funding grants and incentives for projects in or near California's disadvantaged communities. About 67 percent of California's residents who live in disadvantaged communities are within a 15-minute drive time of an open retail or planned hydrogen station.

According to CEC analysis of DMV data (Zero Emission Vehicle and Infrastructure Statistics, https://www.energy.ca.gov/data-reports/energy-insights/zero-emission-vehicle-and-charger-statistics), cumulative sales or leases of FCEVs in California were 11,269 and 9,647 FCEVs are estimated to be currently on California's roads as of the end of the third quarter of 2021. CARB reported, in their *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, based on the latest auto manufacturer survey responses that the FCEV population in California could grow to 30,800 FCEVs by 2024 and 61,100 FCEVs by 2027. Actual FCEV sales have historically been lower than auto manufacturer projections. This projected FCEV population would be about one-quarter of the 245,000 FCEVs the planned fueling network of 179 stations could ultimately support if operating at full capacity with no downtime.

In addition to light-duty FCEVs, the state is working to support the demonstration and deployment of medium- and heavy-duty FCEVs. At least 13 of the 179 projected stations plan to be capable of fueling light-, medium-, and heavy-duty vehicles, thereby leveraging infrastructure to address multiple markets and accelerating the development of commercial fuel cell electric trucks.

Hydrogen refueling infrastructure for FCEVs, including light-, medium-, and heavy-duty vehicles present significant opportunities for air quality improvements. The ongoing investments in hydrogen vehicles and infrastructure for drayage trucks and transit vehicles will expand with funding from the California Budget 2021-2022. The expected daily hydrogen consumption by the medium- and heavy-duty vehicles that will result from CARB's investment will reach nearly 1,200 kilograms per day. In addition, the CEC has also invested in medium- and heavy-duty hydrogen infrastructure by offering funding of nearly $40 million. The CEC's investment in medium- and heavy-duty infrastructure will yield a daily fueling capacity of about 7,200 kilograms, based on the nameplate capacity of the projects.

In 2021, 7 hydrogen refueling stations opened, bringing the total number of open retail stations developed in California to 52, as of October 22, 2021. This network of open retail stations includes four stations that are considered temporarily non-operational (TNO). The TNO stations previously achieved open retail status but have been unavailable for customer fueling for a period greater than 30 days for various reasons, including the time needed for mechanical upgrades or repairs, station testing, and reviews by local officials. These TNO stations are expected to become available for customer fueling again in the future. Currently the 48 stations are available for customer fueling with the exception of down-time events that can last for periods up to 30 consecutive days due to supply issues or maintenance. Any station downtime diminishes customer experience at the stations.

These open retail stations are capable of supporting nearly 36,000 light-duty FCEVs. Light-duty hydrogen refueling has reached the level it was at before the pandemic. The average daily dispensing level across the network has recovered significantly to almost double from the lowest amount dispensed in 2020 during the height of COVID-19 restrictions. Station development times were decreasing until the COVID-19 pandemic slowed many station development activities.

As directed in AB 8, the CEC has allocated $20 million per year or 20 percent of the total Clean Transportation Program Investment Plan allocation each year and plans to continue allocating funding through FY 2023–24. The Clean Transportation Program investment in hydrogen refueling stations thus far is about $166 million. Clean Transportation Program investment in hydrogen refueling stations will total nearly $279 million.

The private sector has contributed through match funding contributions to station development as well as their independent investments in hydrogen refueling stations and production facilities that are outside CEC agreements. As of October 22, 2021, grant recipients contributed nearly $92 million in match funding and will contribute another $99 million by the end term of the most recent CEC grant agreements. These contributions will bring the total public and private investment in hydrogen refueling stations under the Clean Transportation Program to nearly $470 million.

California should continue to make investments towards the 200-station goal but must also consider other barriers to large-scale commercialization and deployment of FCEVs. These barriers include supply disruptions in the nascent industry of producing hydrogen for transportation, hydrogen station downtime due to equipment failures and other factors, and the lack of vehicle models and consumer options. The hydrogen supply disruptions have diminished consumer confidence as have the lack of geographic coverage and reliability of the station network. Other barriers also include the high price at the pump for hydrogen (especially for renewable hydrogen), high FCEV purchase and lease prices, and lack of consumer awareness about FCEVs. Additionally, expanded use of new and direct renewable resources for hydrogen production will help achieve the goal of a zero-carbon hydrogen future. Low to zero-carbon hydrogen is needed at volumes much larger than seen in today’s market.

Other countries are also investing in FCEV and hydrogen infrastructure markets, globally. For this year’s report, the CEC reached out to lead countries with ambitious FCEV deployment goals: China, Germany, Japan, and the Republic of Korea. Together, California and these countries have funded nearly five hundred hydrogen refueling stations for light-, medium-, and heavy-duty FCEVs and deployed nearly 32,000 on road light-duty FCEVs and nearly 8,000 medium, and heavy-duty FCEVs.

California’s current and planned investment of about $279 million for 179 hydrogen refueling stations ranks second after Japan, which has contributed about $640 million for 166 stations. The Republic of Korea has invested about $199 million for 87 stations; Germany has invested about $118 million for 107 stations; and China has provided per station subsidies of about

$600,000 (the national government policy, which ended in 2015) and about $150,000 to $460,000 (local government subsidies) for its 146 stations.

California also ranks second globally in FCEV deployment after the Republic of Korea. The Republic of Korea has 15,569 light-duty FCEVs and 106 FC buses, compared to California's on-road population of 9,647 light duty FCEVs and 54 FC buses. China has 7,831 cumulative sales of FC commercial vehicles; Japan has 5,800 light-duty FCEVs and 104 FC buses and small trucks; and Germany has 1,273 light-duty FCEVs and 52 medium- and heavy-duty FCEVs.

Staff estimates California will have more than 100 open retail stations by the end of 2023, including those funded by the Clean Transportation Program and those funded by the private sector. California and the CEC are succeeding in doing their parts for the light-duty hydrogen market. Despite barriers related to infrastructure reliability, hydrogen supply, and other factors, the coverage and capacity of the existing and projected hydrogen refueling station network are growing rapidly and exceed vehicle demand and projections. The state is well positioned with regards to hydrogen station deployment to support light-duty ZEVs. CEC and CARB staff intend to continue jointly evaluating the FCEV market and to identify metrics to inform potential future funding decisions. This evaluation shall include examining actual FCEV deployments, global trends, and consumer preferences.

CHAPTER 1: Introduction

Assembly Bill (AB) 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program.[1] Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorized the Clean Transportation Program until January 1, 2024, and directed the California Energy Commission (CEC) to allocate $20 million annually, not to exceed 20 percent of the amount of funds appropriated by the Legislature, toward at least 100 publicly available hydrogen refueling stations.[2]

AB 8 requires annual review and reporting by the CEC and California Air Resources Board (CARB). 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* (2021 Joint Report) is the seventh such annual report.[3] CARB published the *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network* (2021 Annual Evaluation), also required by AB 8.[4] Appendix C lists references for previous reports.

Governor Edmund G. Brown Jr.'s Executive Order B-16-12 directed state agencies to promote the rapid commercialization of zero-emission vehicles (ZEVs) and set a target of 1.5 million ZEVs in California by 2025.[5] Governor Brown's Executive Order B-48-18 established goals of achieving 200 hydrogen stations by 2025 and 5 million ZEVs in California by 2030.[6] On September 23, 2020, Governor Gavin Newsom's Executive Order N-79-20 set goals that all new passenger cars and trucks sold in California be ZEVs by 2035, all medium- and heavy-duty trucks and buses operated in California be ZEVs by 2045 everywhere feasible, and all drayage trucks be ZEVs by 2035. All three imperatives strengthen California's focus and activities for hydrogen refueling infrastructure and ZEVs.

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1 California Legislative Information. Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200720080AB118.

2 California Legislative Information. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB8.

3 Previous Joint Reports included station data from the fourth quarter of the previous year through the third quarter of the reporting year. The 2021 Joint Report includes station data from the fourth quarter of 2020 through the second quarter of 2021.

4 California Air Resources Board. September 2021. *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf

5 Office of Governor Edmund G. Brown Jr. Executive Order B-16-2012. https://www.ca.gov/archive/gov39/2012/03/23/news17472/index.html.

6 Office of Governor Edmund G. Brown Jr. Executive Order B-48-18. https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html. The Governor's Interagency Working Group on ZEVs released a *2018 ZEV Action Plan Priorities Update* in response to the executive order. http://business.ca.gov/Portals/0/ZEV/2018-ZEV-Action-Plan-Priorities-Update.pdf.

The CEC Fuels and Transportation Division and CARB program staffs collaborate with many experts to plan and encourage development of hydrogen refueling infrastructure and deployment of fuel cell electric vehicles, including:

- 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.
- Local agencies including planning, building, and safety officials.
- The United States Department of Energy (U.S. DOE) and national laboratories, including the National Renewable Energy Laboratory (NREL) and Pacific Northwest National Laboratory (PNNL).
- Industry stakeholders, including the Center for Hydrogen Safety under the auspices of the American Institute of Chemical Engineers (AiCHe), California Fuel Cell Partnership (CaFCP), California Hydrogen Business Council, SAE International, and the CSA Group.

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:

- Listservers: https://ww2.energy.ca.gov/listservers/index_cms.html
- Events: https://www.energy.ca.gov/events
- Solicitations: https://www.energy.ca.gov/funding-opportunities/solicitations

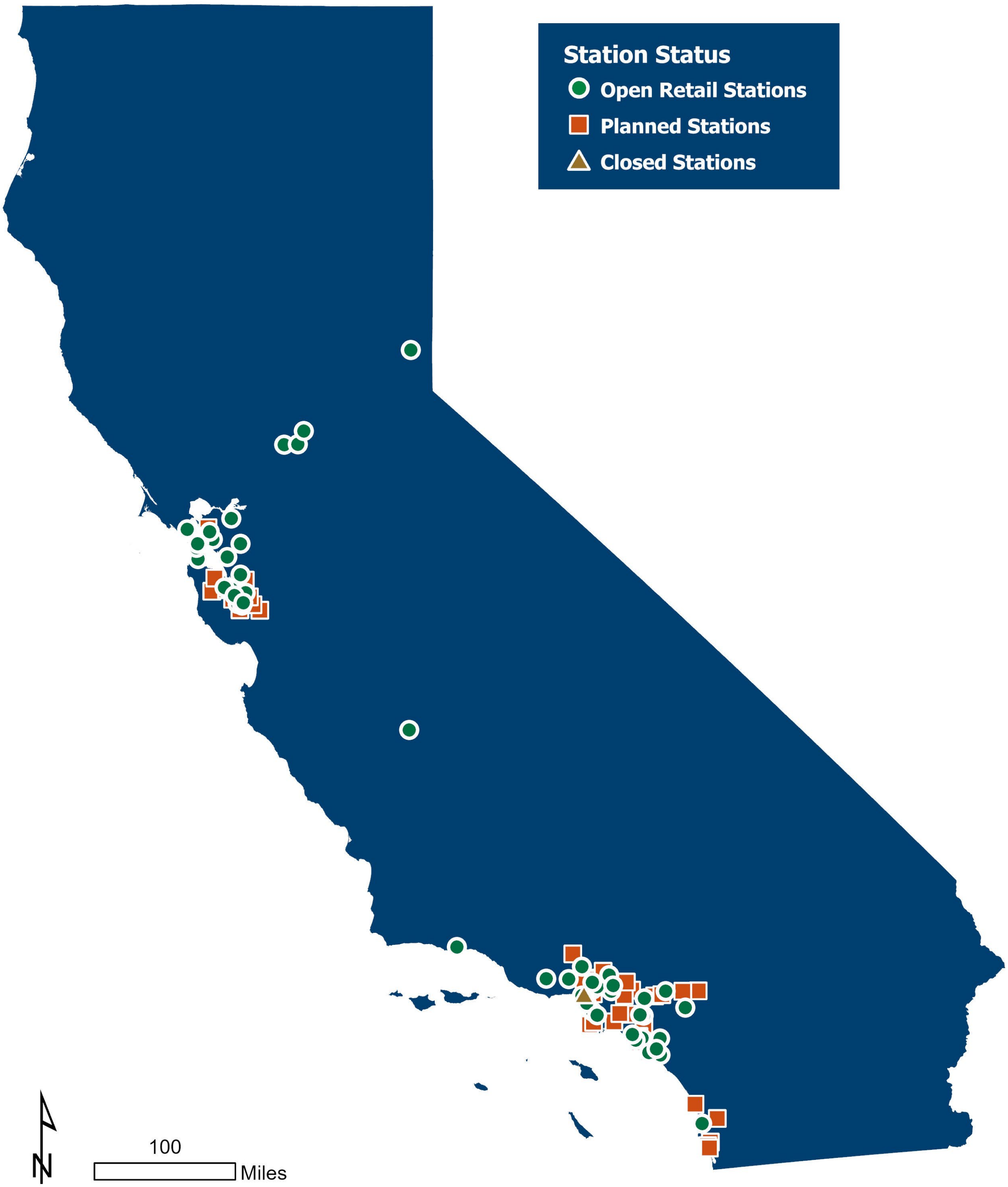
This Joint Report continues with analyses for the coverage and capacity of the hydrogen refueling station network, the time it is taking to develop stations and related cost, and the current and future projections of FCEVs and station implementation in California. CEC and CARB staffs review the year's refueling trends and describe other hydrogen and fuel cell projects that are expanding the potential for FCEVs, including buses and trucks, to serve multiple functions in transitioning to a national and international zero-emission transportation system.

CHAPTER 2: The Coverage and Capacity of the Hydrogen Refueling Station Network

The coverage and capacity of the hydrogen refueling station network continues to grow in California such that the available fueling capacity has exceeded demand historically by at least double. However, the actual network fueling capability depends on the availability of hydrogen supply and the availability of the stations themselves. Figures 1 through 3 show the locations of stations in California's hydrogen refueling station network. CEC has funded 90 hydrogen refueling stations with 52 open to the public. There are 32 stations in Northern California, 55 stations in Southern California, and 3 Connector/Destination stations that are outside the general cluster of stations, allowing FCEV drivers to travel between Northern and Southern California. Appendix A lists the addresses. Appendix B lists the changes in the station network from 2017 to 2021. This network of open retail stations includes 48 stations that are currently available for customer fueling with the exception of brief down-time events. An additional four stations are considered temporarily non-operational (TNO), as they have previously achieved open retail status but have been unavailable for customer fueling for an extended period of time for various reasons. These TNO stations are expected to become available for customer fueling again in the future and are shown as open retail stations in Figures 1 through 3.

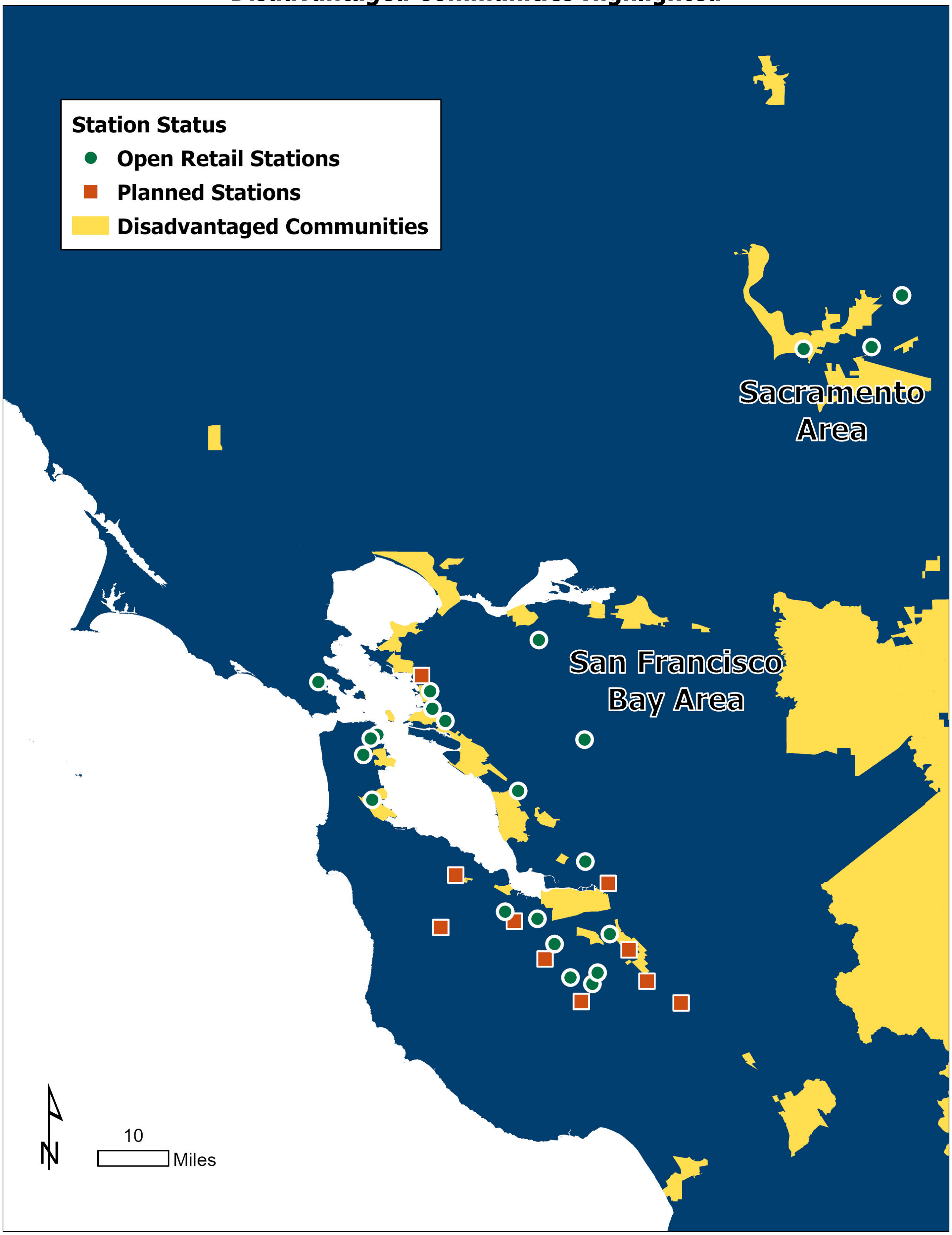
Overall, the current 52 open retail stations have the capability to support 36,000 FCEVs. CEC analysis of DMV data finds that the current stock of FCEVs in California is 9,647. This stock number is obtained by the summation of the 2020 DMV on-road vehicle data and the cumulative sales and leases from the first quarter of 2021 through the third quarter of 2021. The hydrogen station fueling capacity is about quadruple the projected demand by 2027.

Figure 1: Hydrogen Refueling Station Locations in California



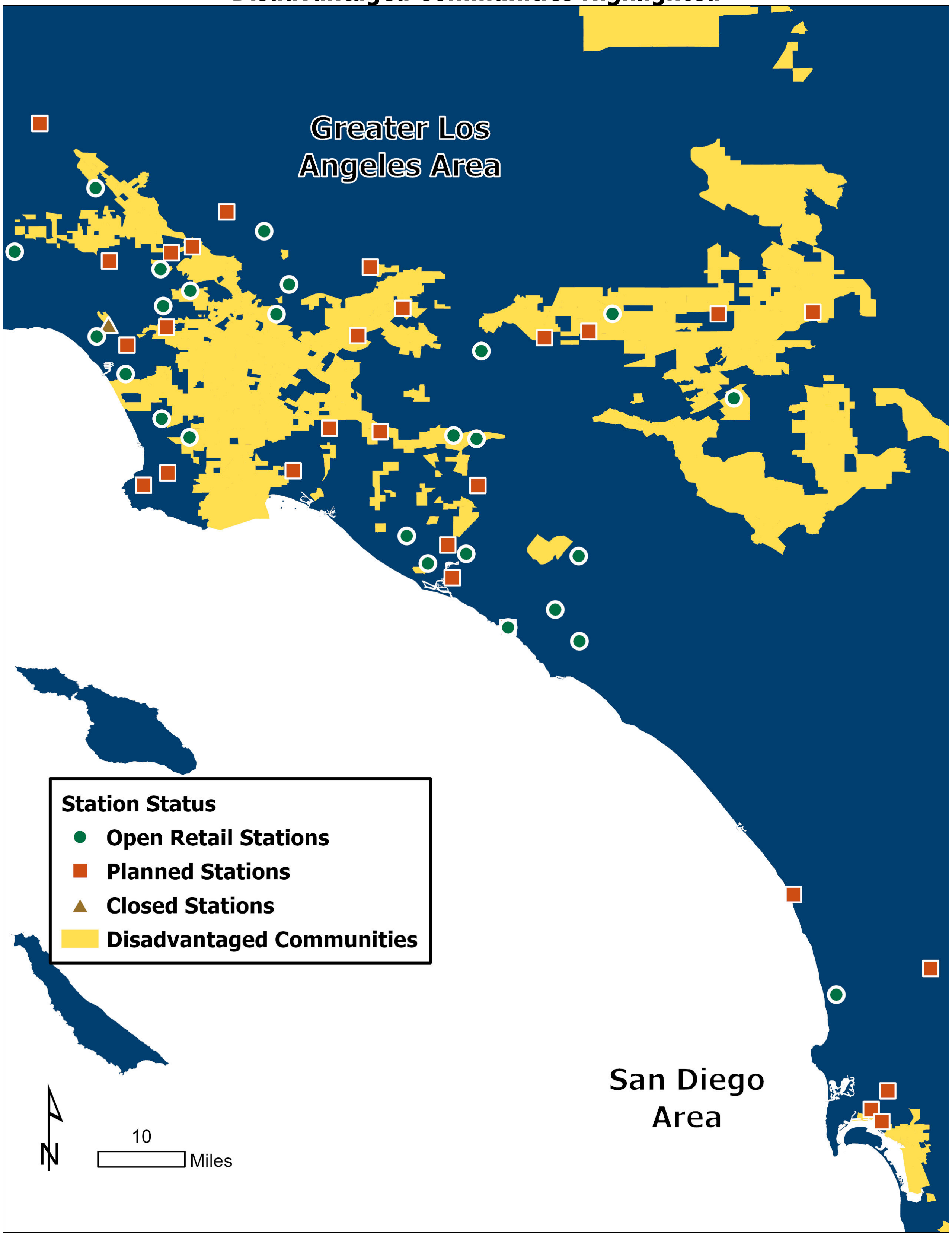
Source: CEC

Figure 2: Hydrogen Refueling Station Locations in Northern California With Disadvantaged Communities Highlighted



Source: CEC

Figure 3: Hydrogen Refueling Station Locations in Southern California With Disadvantaged Communities Highlighted



Source: CEC

The CEC continues to emphasize the importance of serving disadvantaged communities in its solicitations. When all the stations with known addresses under GFO-19-602 and privately funded stations that are proposed are developed, 22 stations will be in disadvantaged communities. These stations will provide coverage so that 67 percent of disadvantaged community population and 62 percent of general population of California will be within a 15-minute driving distance to a hydrogen refueling station. These numbers could increase as addresses for stations in future batches funded under GFO-19-602 are announced.

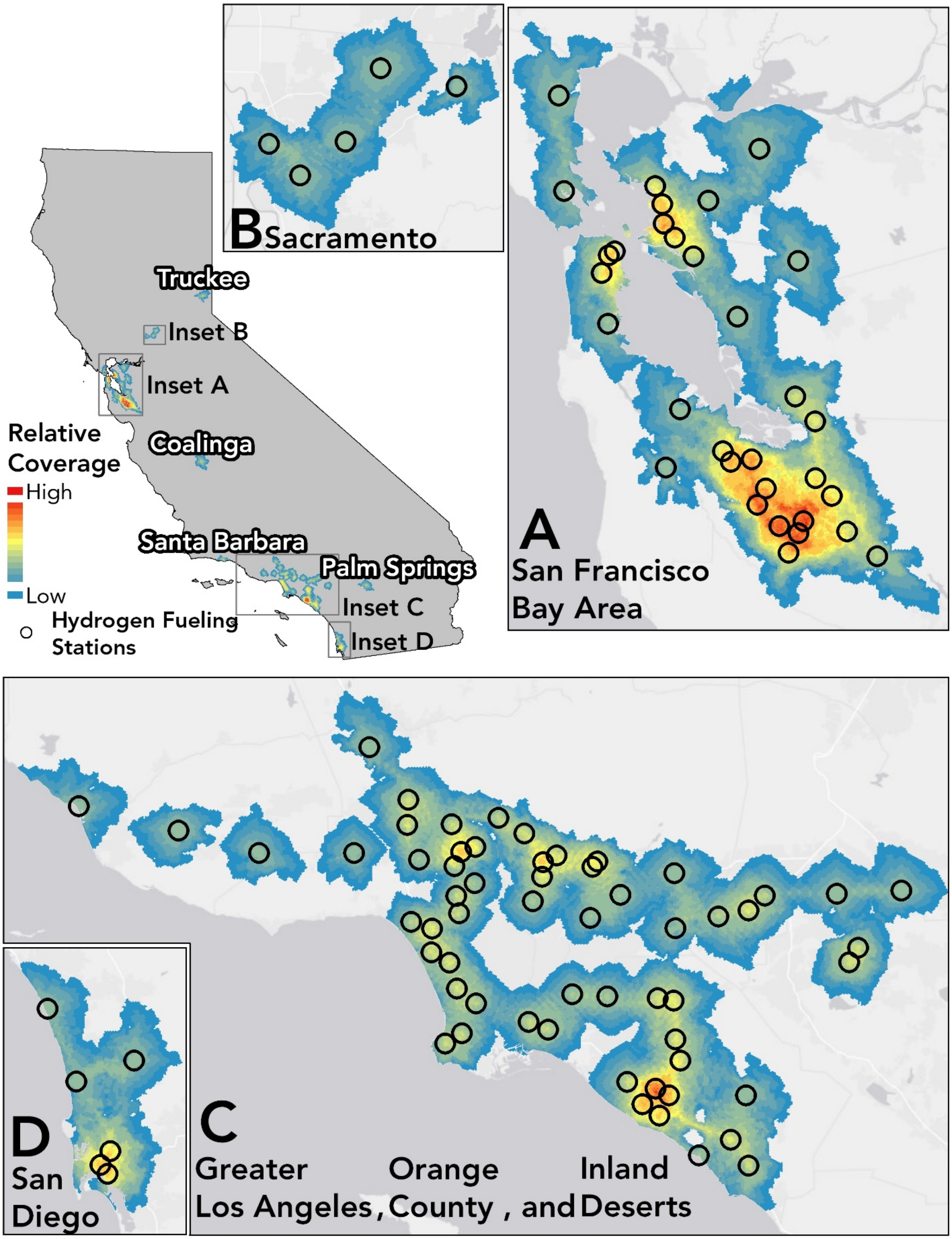
Network Coverage and Fueling Capacity

Figure 4 displays the coverage provided by funded stations and planned stations with known addresses. As awarded station developers notify the CEC of addresses for additional locations, or possible station relocations and other changes, the evaluation of coverage is expected to change. The figure was produced by the CARB California Hydrogen Infrastructure Tool (CHIT).[7] Areas on the map without color are not within a 15-minute drive from any hydrogen refueling station.[8] In the coverage map, the areas shown with the red shading have the highest degree of coverage. These areas often have several stations providing coverage to neighborhoods and communities in the nearby area. The blue areas have less fueling coverage; these areas typically have a small number of available stations or are farther away from the fueling station network.

7 California Air Resources Board. Hydrogen Refueling Infrastructure Assessments. https://ww2.arb.ca.gov/resources/documents/california-hydrogen-infrastructure-tool-chit.

8 California Air Resources Board. September 2020. *2020 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development.* http://ww2.arb.ca.gov/resources/documents/annual-hydrogen-evaluation.

Figure 4: Coverage Map



Source: CARB

With 0.7 kilograms used as the average amount of hydrogen per FCEV daily, the 90 funded stations resulting from CEC agreements, including through the initial batch of GFO-19-602, will have the capability to support nearly 101,000 FCEVs. In practice the number of FCEVs supported depends on the reliability of the hydrogen supply and stations. The reliability of stations is discussed in Chapter 3.

In 2021, there were 48 stations that were available for customer refueling that frequently had brief periods of downtime due to supply disruptions or maintenance issues. There were also four Temporarily Non-operational stations that were down for a period that lasted longer than 30 days. In addition, the disruptions in the hydrogen supply affected the fueling as discussed later in this report. Other factors that influence the quantity of FCEVs that can be supported include the interdependency of the actual FCEV geographical distribution relative to stations, driver habits, vehicle miles traveled, routes traveled, and the station availability.

Table 1: Funded Hydrogen Refueling Stations and Quantity of FCEVs that can be Supported

Station Status	Northern California Station Quantity	FCEVs Northern California Stations can Support	Southern California Station Quantity	FCEVs Southern California Stations can Support	Number of Connector/ Destination Stations	FCEVs Connector/ Destination Stations can Support	Number of Stations, Statewide	FCEVs Statewide Network can Support
Open Retail	22	17,400	27	17,000	3	1,100	52	35,500
Planned	10	19,300	28	45,900	0	0	38	65,200
Totals	***32***	***36,700***	***55***	***62,900***	***3***	***1,100***	***90***[9]	***100,700***

Source: CEC

Table 1 includes information on the 90 stations that have been funded, so far, in Northern California and Southern California and includes connector/destination stations.[10]

9 The 2020 Joint Report erroneously reported one upgrade project as a new station and listed the statewide station quantity as 91 instead of 90. However, this error does not affect the total number count of 179 projected stations.

10 Connector/destination stations help drivers connect from one cluster of stations to another or to travel to a destination. Connector/destination stations include those in Coalinga, Santa Barbara, and Truckee.

As awardees complete the milestones specified in GFO-19-602, subject to future Clean Transportation Program appropriations and Investment Plan allocations, they may develop more stations.[11] Combined with the privately funded stations, the total number of stations is projected to be more than 179, with the one-time funding from the California Budget 2021-2022 providing an opportunity for the CEC to close the gap to 200 stations. These 179 stations will have the capability to support about 245,000 FCEVs and the 200 stations will have the capability to support about 290,000 FCEVs

Hydrogen Dispensing and Station Utilization

Before the COVID-19 pandemic, average station dispensing was increasing in nearly every region of California, and the network of hydrogen refueling stations and number of FCEVs were growing steadily. Before the 2019 fuel shortage, the actual demand for hydrogen by FCEVs sometimes outpaced the available fueling nameplate capacity at high-use stations, requiring several fuel deliveries daily to those locations. During the beginning of the COVID-19 shutdown, the level of hydrogen dispensing decreased but picked up again through 2020 and 2021 as COVID-19 restrictions lifted. Dispensing in the second quarter of 2021 is about equal to the pre-pandemic peak.

The average station uptime has decreased from an average of 87 percent station availability in the first quarter of 2019 to 63 percent station availability in the second quarter of 2021. Decreasing station availability has impacted the quantity of hydrogen dispensed in the network of hydrogen refueling station.

Factors affecting the number of kilograms dispensed across the network during the fourth quarter of 2020 and second quarter of 2021 may include decreased commuting and daily driving, extended time frames for planned and unscheduled maintenance at the stations, and decreased availability of delivered gaseous hydrogen, all exacerbated by COVID-19 restrictions. The existing network of hydrogen refueling stations in California has ample fueling capacity to support the cumulative number of light-duty FCEVs sold or leased, with the average utilization[12] of the overall network now below 20 percent.

The CEC requires grant recipients to report hydrogen dispensing data. Once an agreement term ends, some operators continue reporting data voluntarily. The CEC has received an average of about 90 percent of all quarterly fueling data from developers from the fourth quarter of 2015 to the second quarter of 2021. Figure 5 shows the average daily hydrogen dispensing in California based on the operators' reports. For stations that do not report, staff estimated the average daily dispensing based on the daily regional dispensing (Greater Los Angeles Area, San Francisco Bay Area, San Diego Area, Sacramento Area, and Connector) where each nonreporting station is located. California currently has 52 Open Retail hydrogen

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11 Brecht, Patrick. 2020. *2020-2023 Investment Plan Update for the Clean Transportation Program. California Energy Commission*. Publication Number: CEC-600-2020-003-REV. https://efiling.energy.ca.gov/getdocument.aspx?tn=234959.

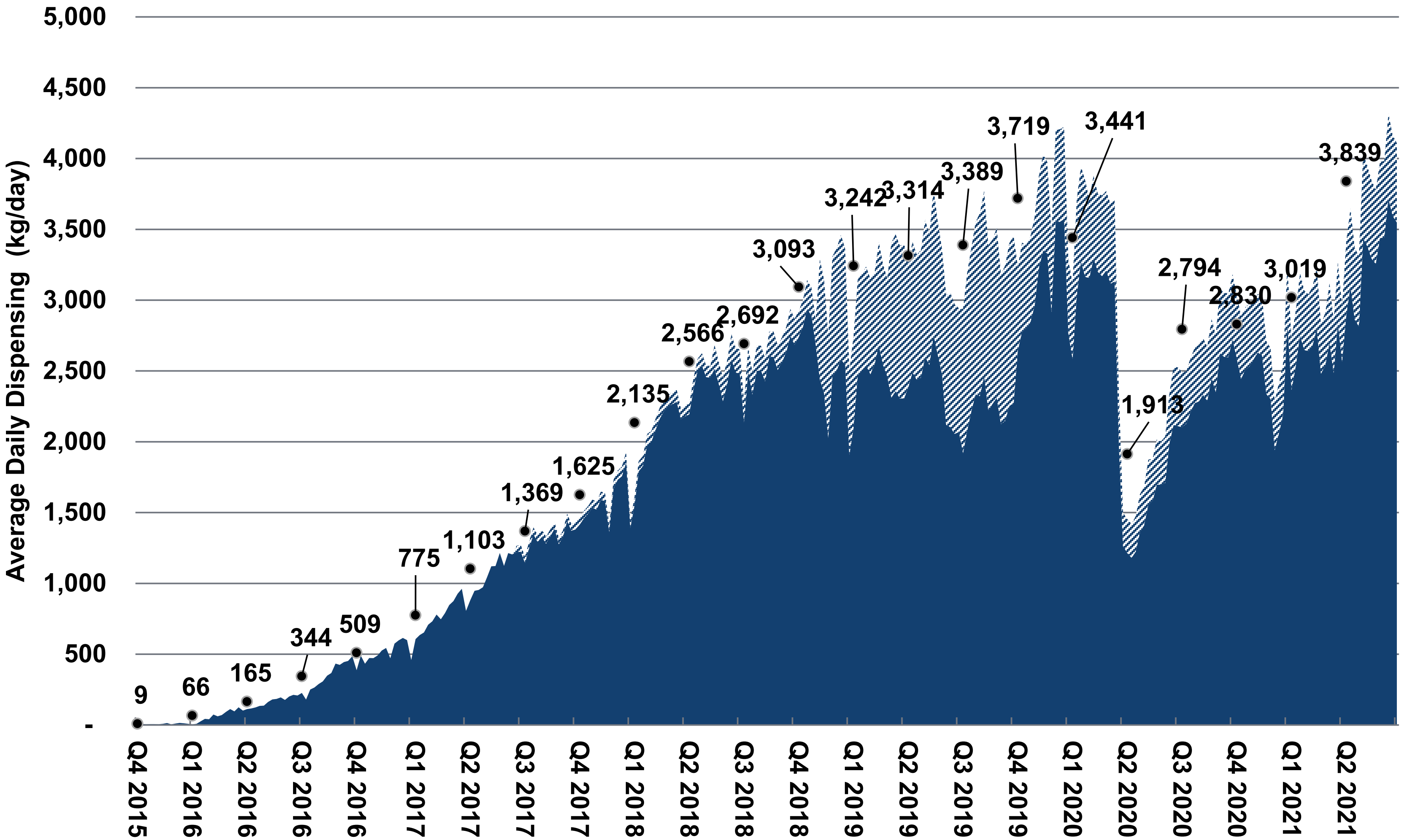
12 The term "utilization" is used in this Joint Report to align with the industry norm to describe the ratio of fuel throughput to the nameplate capacity of the station or the network of stations.

refueling stations. CEC staff received data from 45 stations and estimated dispensing for 7 stations in the second quarter of 2021.

The average weekly dispensed fuel shown in solid color in Figure 5[13] is reported by station operators. The patterned line shows the estimated dispensing for stations that do not report to the CEC. Above each quarter, the quarterly average daily dispensing is shown. In 2019, many agreements reached completion, so stations discontinued reporting fueling data to the CEC; hence, the patterned line is larger in that year. Since, many station developers have agreed to provide the CEC with an abbreviated amount of fueling data. Figure 5 shows that in the second quarter of 2021, dispensing has recovered to levels that are similar to the dispensing that took place pre-COVID-19. Figure 6 shows the percentage of hydrogen dispensed (actual and estimated) in each region from the beginning of the fourth quarter of 2020 to the end of the second quarter of 2021. About two-thirds of all hydrogen dispensed in California is in the Greater Los Angeles Area.

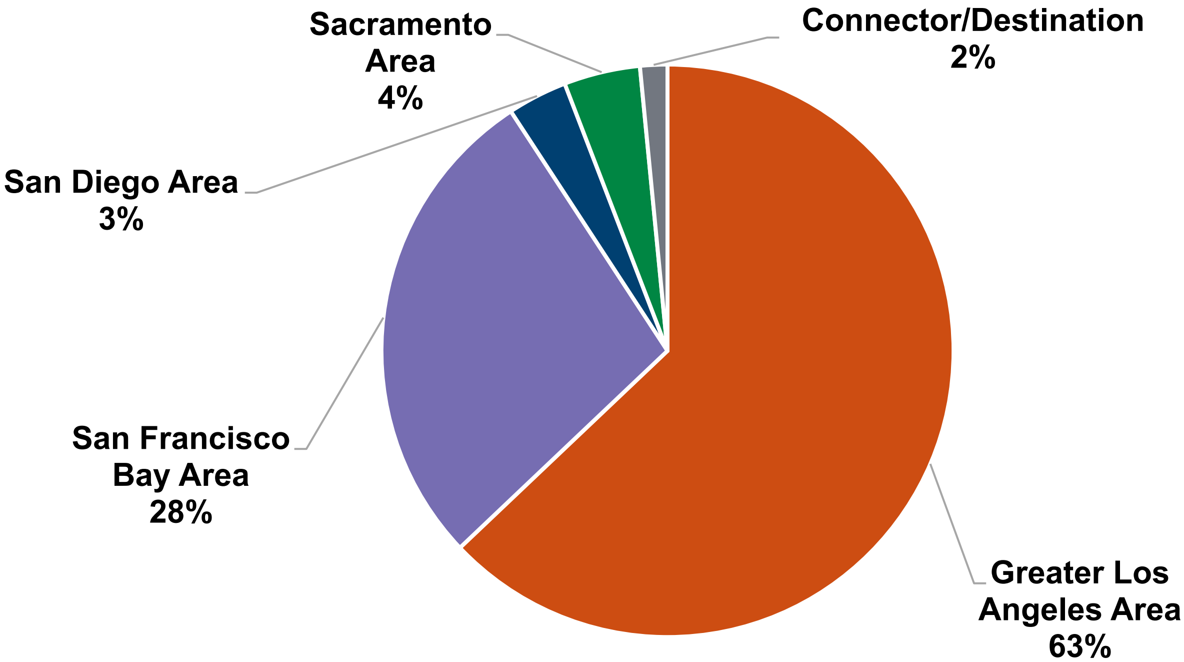
13 Estimated dispensing fluctuates since reporting requirements vary according to CEC agreements.

Figure 5: Average Daily Hydrogen Dispensing



Source: CEC

Figure 6: Percentage of Hydrogen Dispensing by Region

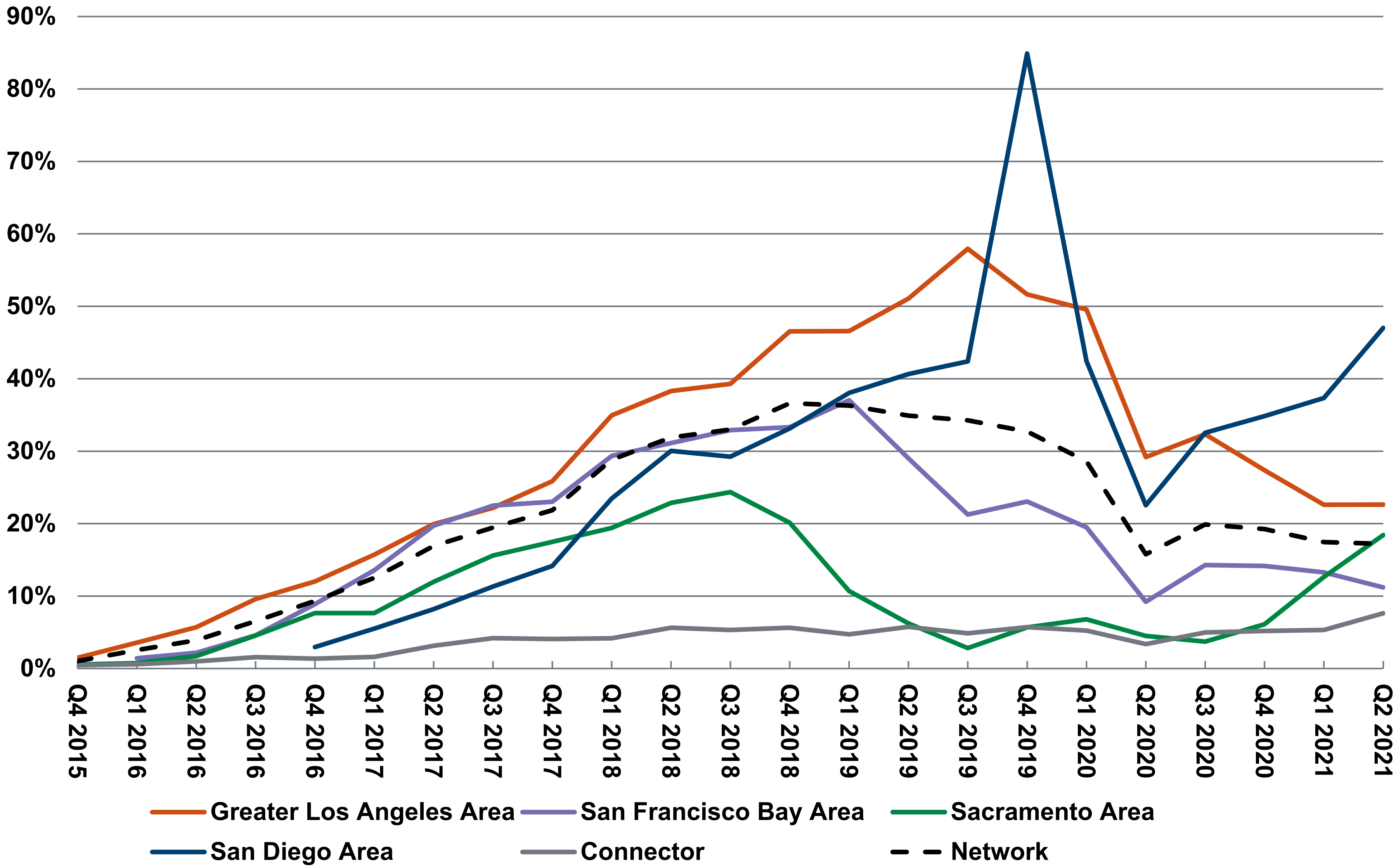


Source: CEC

Figure 7 shows the quarterly hydrogen station utilization rates statewide. The overall network utilization was 17 percent in the second quarter of 2021, lower than the utilization recorded before the COVID-19 pandemic. While the overall demand for hydrogen has recovered to pre-pandemic levels, the statewide fueling capacity continued to increase since the beginning of the COVID-19 pandemic, by about 70 percent. The increased nameplate fueling capacity results in a lower statewide station network utilization rate because FCEV sales have not kept up.

Staff also analyzed the network utilization by looking at the utilization only when stations were available for fueling. The adjusted network utilization was 27 percent in the second quarter of 2021, 10 percent higher than the utilization calculated using only the nameplate capacity of the network. For example, during the hydrogen supply shortage of 2019, many stations were unavailable for long periods of time because they were not receiving regular deliveries of hydrogen fuel. Overall unadjusted utilization in this period was fairly low; in the Greater Los Angeles Area, utilization peaked at 58 percent and in the San Francisco Bay Area, utilization was on a steady decline from a high of 37 percent in early 2019. However, during the limited hours that stations were available, utilization was very high, with a peak of 86 percent in Greater Los Angeles and 63 percent in the San Francisco Bay Area.

Figure 7: Hydrogen Station Utilization by Quarter



Source: CEC

The 2020 Joint Report showed that hydrogen refueling station customers exhibit a similar behavior to gasoline vehicle drivers regarding when the driver selects to refuel. However, hydrogen refueling times do not match up perfectly with gasoline because the California network of open hydrogen stations is small compared with the roughly 8,000[14] gasoline stations reported to be in operation. Having one station down for maintenance has a greater effect on the overall hydrogen station network than it would on the larger gasoline station network. In addition, FCEV drivers sometimes do not fuel at the times that they would normally depending on hydrogen availability.

Price of Hydrogen Dispensed

Figure 8 shows the weighted average retail price of hydrogen and the total kilograms of hydrogen sold per quarter for hydrogen stations that report dispensing data to the CEC. This sample represents about 85 percent of all quarterly fueling data from the first quarter of 2020 to the second quarter of 2021.

The average price of dispensed hydrogen has decreased from $16.68 per kilogram, or $6.67 per gallon of gasoline equivalent, in the first quarter of 2020 to $16.09 per kilogram, or $6.44 per gallon of gasoline equivalent, in the second quarter of 2021. About 70 percent of all of the open retail hydrogen stations in the California network sell hydrogen at above $16.00 per kilogram.

Recently, nine liquid delivery hydrogen stations opened. These stations sell hydrogen for about $13.00 per kilogram, or about $5.20 per gallon of gasoline equivalent, allowing for the average price per kilogram sold in California to decrease. The CEC anticipates at least another 28 planned liquid delivery stations to sell hydrogen at a similar price point, $13.00 per kilogram, allowing for an additional decline in the network's price of hydrogen. Even with a price of $13.00 per kilogram, the price is higher than the average retail price of gasoline used in an internal combustion engine. Based on extensive interviews and surveys with representatives of multiple companies participating in California's hydrogen fuel industry, the CEC and CARB staffs understand that to reach parity with gasoline, stations will need to dispense at about $8.00 per kilogram ($3.20 per gallon equivalent).[15]

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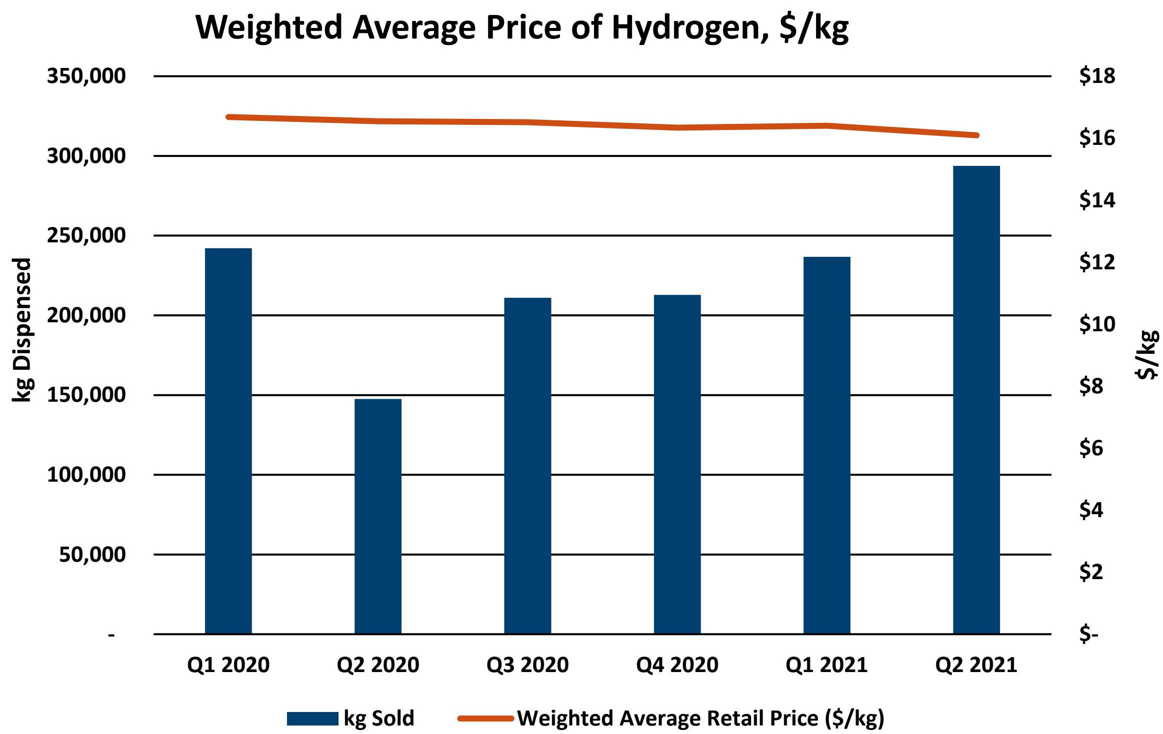
14 California Energy Commission. [California Retail Fuel Outlet Annual Reporting (CEC-A15) Results](https://www.energy.ca.gov/data-reports/energy-almanac/transportation-energy/california-retail-fuel-outlet-annual-reporting). https://www.energy.ca.gov/data-reports/energy-almanac/transportation-energy/california-retail-fuel-outlet-annual-reporting.

15 California Air Resources Board. October 2021. *Hydrogen Station Network Self-Sufficiency Analysis per Assembly Bill 8.* https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf.

Figure 8: Weighted Average Price of Hydrogen and Total Kilograms Sold Per Quarter



Source: CEC

Hydrogen Dispensed

Most of the hydrogen dispensed in the California station network is produced using natural gas steam methane reformation (SMR) and the purchase of biogas credits to receive CARB Low Carbon Fuel Standard (LCFS) credits.

The CARB LCFS Program allows participants in the program to meet the renewable requirements by using either direct renewable content or purchasing renewable attributes, or credits. The CARB LCFS Program defines renewable hydrogen as hydrogen derived from electrolysis of water or aqueous solutions using renewable electricity, catalytic cracking or steam methane reforming of biomethane, or thermochemical conversion of biomass, including the organic portion of municipal solid waste.[16] Renewable electricity, for the purpose of renewable hydrogen production by electrolysis, means electricity derived from sources that qualify as eligible renewable energy resources as defined in California Public Utilities Code sections 399.11-399.36.[17] These code sections define renewable electricity as electricity

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16 CARB lists carbon intensity values of certified pathways that are adjusted using the energy economy ratio of corresponding vehicles on their LCFS website. https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities.

17 California Code of Regulations Title 17, Division 3, Chapter 1, Subchapter 10, Article 4, Subarticle 7, §95481 (a)(131).

produced via many renewable pathways, including solar, wind, geothermal, biomass, landfill gas, municipal solid waste, tidal energy, and others.[18]

The CEC receives data on the kilograms of hydrogen dispensed at stations and the percentage of renewable hydrogen dispensed in attestations provided by station developers, per CEC agreements. The station developers are required to report renewable content, aligned with the definition from the CARB LCFS Program. The stations reporting to the CEC total between 24 to 26 stations (about one-half of the stations), depending on the given reporting period.

The data provided to the CEC reported that about 82 percent of the hydrogen dispensed at stations was renewable hydrogen, as defined by the CARB LCFS Program, for 2020 (mostly through the purchase of biogas credits in lieu of renewable hydrogen produced directly from renewable sources). The CEC has also received dispensing data for the first quarter of 2021 showing 86 percent of the hydrogen dispensed at the stations was renewable hydrogen (again, mostly through the purchase of biogas credits in lieu of renewable hydrogen produced directly from renewable sources). Figure 9 shows the hydrogen dispensed by stations that station operators reported as renewable per the LCFS definition to the CEC.

For stations reporting to the CARB LCFS Program under the hydrogen refueling infrastructure (HRI) provision, [19] the CARB 2021 Annual Evaluation shows 92 percent renewable content in 2021. This reported renewable content most likely includes the purchase of biogas credits, similar to the renewable content reported to the CEC.

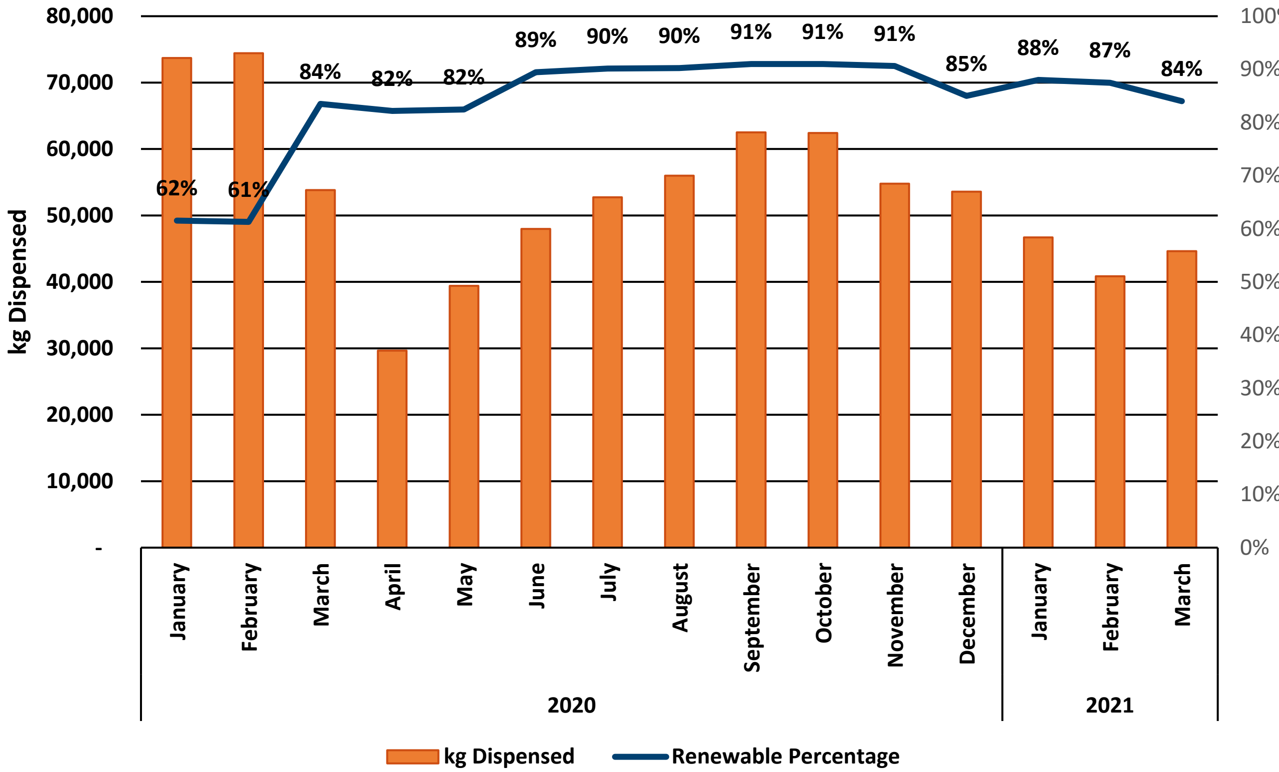
The state of California uses these two data sources, the reports to the CEC from the station operators receiving grants and reports to CARB from station operators generating credits in the LCFS Program, to reach a summary of the hydrogen dispensed in California. Some of the data overlap, but neither data set covers the full hydrogen network in California.

While the percent of renewable hydrogen dispensed is a positive sign for the greenhouse gas benefits of FCEVs, directly producing renewable hydrogen is key to California’s longer term decarbonization goals.

18 California Public Utilities Code sections 399.11-399.36 and California Public Resources Code section 25741.

19 California Code of Regulations Title 17, Division 3, Chapter 1, Subchapter 10, Article 4, Subarticle 7, §95481 (a)(131).

Figure 9: Hydrogen Dispensed and Renewable Content Reported by the Station Developers



Source: CEC

Hydrogen Supply

Having a resilient, diverse, and reliable hydrogen supply chain is critical to serving FCEV drivers and to allowing the hydrogen refueling network to expand and FCEV adoption to increase. Hydrogen supply or production is distinct from hydrogen station capacity, which was discussed above. Hydrogen supply refers to the production of hydrogen and delivery of hydrogen to stations. A disruption in supply, production, or delivery can cause delays in serving driver needs. Having more than one pump per station and stations that are clustered in one area to serve as backup to one another are ways of building resiliency. A diverse hydrogen supply adds resiliency to the network and should be pursued.

The nameplate for the equipment that supplies hydrogen exceeds the current reported hydrogen demand based on the actual dispensing data. However, the availability of fuel in the network has been a problem. Stations experience many issues due to the fact that a large number of the stations in the current retail network rely on few suppliers. Therefore, supply chain issues can affect a large portion of the network, making it difficult for FCEV drivers to find fuel.

The CEC is eager to help mitigate this risk. Therefore, to address this problem in the future, GFO-19-602 requires stations funded under the solicitation to have a second supply agreement as backup to ensure station operators do not rely on a single supply source. In addition, the Clean Transportation Program funded two renewable hydrogen production plants, with a combined nameplate capacity of 3,000 kilograms daily.[20] Both plants are expected to open in 2023. Other hydrogen producers are either developing new production plants or upgrading their existing plants to increase their supply capacity as mentioned in the next section. The Clean Transportation Program also has an open solicitation, GFO-20-609, which will look to fund at least an additional two to three renewable hydrogen production plants.[21]

Figures 10 and 11, respectively, show the unavailability of hydrogen stations in Northern California and Southern California for the 2020 calendar year only.[22] Dates and times that display yellow to red indicate that 10 or more stations were unavailable at the same time during that period. Figure 10 shows that there was a large disruption in station availability in Northern California from November to December 2020. Figure 11 shows a large disruption in station availability in Southern California in November 2020. These outages were due to production plant damage on the Gulf Coast caused by Hurricane Zeta. As a result, many hydrogen stations went offline in the state in November and mainly in Northern California in December.

These charts also show that most stations are available from core hours of 6 a.m. to 10 p.m. with some stations going offline from 10 p.m. to 6 a.m. Some stations are in jurisdictions that have ordinances that require vehicle service stations to close overnight and these present as unavailable in Figures 10 and 11. Stations are also known to close during these off hours for scheduled maintenance. This scheduling of maintenance during nighttime hours limits the effect of station downtime on FCEV drivers.

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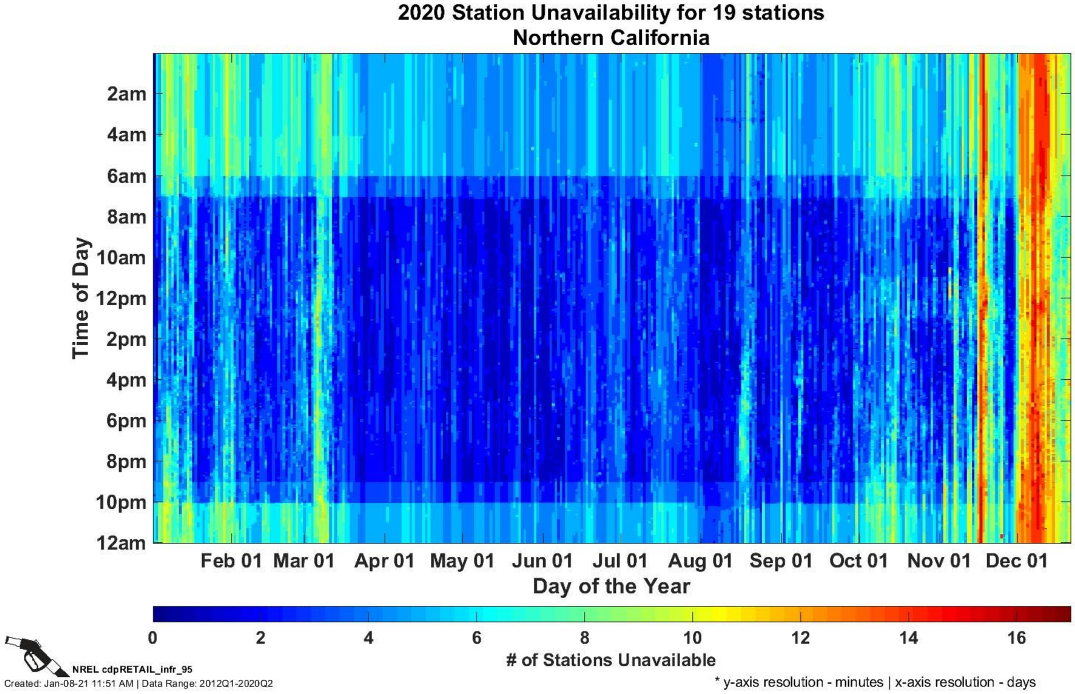
20 The two production plants were funded by GFO-17-602, *Renewable Hydrogen Transportation Fuel Production Facilities and Systems*, released December 2017.

21 California Energy Commission. April 2021. GFO-20-609: *Renewable Hydrogen Transportation Fuel Production*. https://www.energy.ca.gov/solicitations/2021-04/gfo-20-609-renewable-hydrogen-transportation-fuel-production.

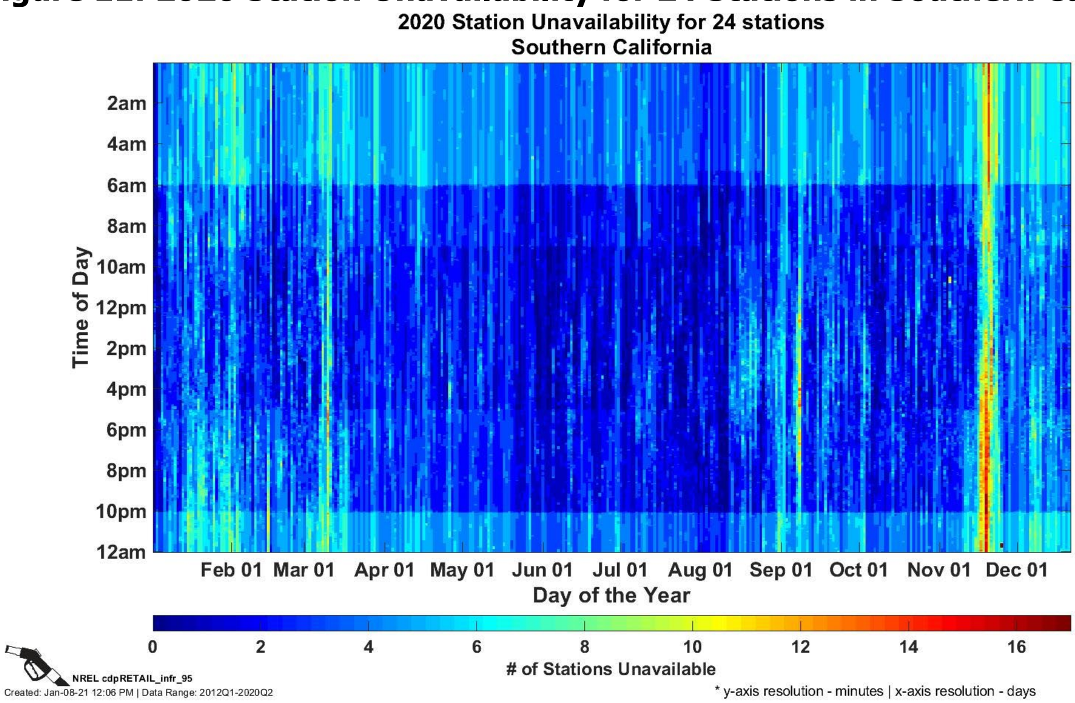
22 National Renewable Energy Laboratory. "Next Generation Hydrogen Station Composite Data Products: Retail Stations." https://www.nrel.gov/hydrogen/infrastructure-cdps-retail.html.

Figure 10: 2020 Station Unavailability for 19 Stations in Northern California



Source: NREL

Figure 11: 2020 Station Unavailability for 24 Stations in Southern California



Source: NREL

Expanding Options for Hydrogen Supply for California

News about expanding options for hydrogen supply for California include announcements from FirstElement Fuel and Air Liquide, among others. In addition to the CEC investment in new hydrogen production mentioned in the previous section, the options for hydrogen supply are increasing from these private sector investments.

FirstElement Fuel has recently entered into a 2,400 kg/day supply agreement with Linde's Ontario hydrogen production plant and a separate 2,000 kg/day supply agreement with Air Liquide for a total of 4,400 kg/day of supply. This supply will be used to fill FirstElement's recently opened 1,500 kg/day fueling hub in Livermore, California and FirstElement's liquid hydrogen refueling stations. The hub will help diversify the supply chain and create in-state jobs. The Livermore fueling hub will also convert some of the liquid hydrogen into gaseous hydrogen to supply gaseous hydrogen stations in Northern California. The hub will also contain facilities for swapping the larger liquid trailers for smaller trailers that will deliver liquid hydrogen to stations with liquid storage.

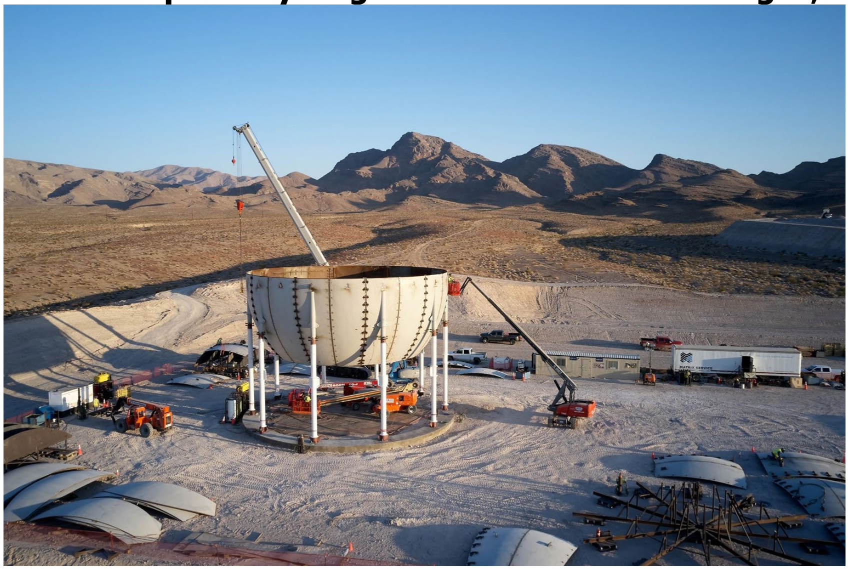
Figure 12: FirstElement Fuel Hydrogen Hub in Livermore (Alameda County)

Source: FirstElement Fuel

Air Liquide announced plans to begin operations at a hydrogen production plant with a capacity of nearly 30 tons per day in Nevada to serve the California FCEV market in 2022.[23] This capacity is enough fuel supply for roughly 40,000 FCEVs.

23 Air Liquide. Hydrogen and Fuel Cell Day 2020 - Exclusive groundbreaking images of the construction of Air Liquide hydrogen plant in Nevada*.* https://energies.airliquide.com/national-hydrogen-and-fuel-cell-day-2020-exclusive-groundbreaking-images-construction-air-liquide.

Figure 13: Air Liquide Hydrogen Plant in North Las Vegas, Nevada



Source: Air Liquide

Other hydrogen production news includes:

- HyDeal North America is a commercialization platform spearheaded by the Green Hydrogen Coalition to create a green hydrogen ecosystem among stakeholders across North America.[24] HyDeal Los Angeles, the first regional initiative in the HyDeal North America platform, has a goal of accelerating high-volume supply chains for green hydrogen at scale with a goal to bring the cost of delivered green hydrogen to $1.50 per kilogram by 2030.[25]
- Plug Power is planning to construct a new green hydrogen production plant in Fresno County with a plan to complete commissioning in early 2024. Plug Power will use a 300-megawatt solar farm to power 120 megawatts of Plug Power polymer electrolyte membrane (PEM) electrolyzers to produce 30 metric tons of liquid green hydrogen daily.[26]
- The Advanced Clean Energy Storage project in Utah, by Mitsubishi Power and Magnum Development, announced its plans to build a storage facility for 1,000 megawatts of clean power, partly by putting hydrogen into underground salt caverns. The plant is scheduled to be operational by 2025.[27]
- SGH2 Energy and the City of Lancaster will co-own a hydrogen plant based in Lancaster (Los Angeles County) that plans to use recycled wastepaper and recycled water to

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24 Green Hydrogen Coalition. "HyDeal North America." https://www.ghcoalition.org/hydeal.

25 Green Hydrogen Coalition. "HyDeal Los Angeles." https://www.ghcoalition.org/hydeal-la.

26 Plug Power, Inc. September 2021. "Plug Power to Build Largest Green Hydrogen Production Facility on the West Coast." https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2021/Plug-Power-to-Build-Largest-Green-Hydrogen-Production-Facility-on-the-West-Coast/default.aspx.

27 CNBC. 2020. "An $11 trillion global hydrogen energy boom is coming. Here's what could trigger it." https://www.cnbc.com/2020/11/01/how-salt-caverns-may-trigger-11-trillion-hydrogen-energy-boom-.html.

produce up to 11,000 kilograms of hydrogen daily. The plant is scheduled to open in the summer of 2023.[28]

- Part of the U.S. DOE's Energy Earthshots, the "Hydrogen Shot" aims to accelerate breakthroughs for clean energy within the decade.[29] DOE announced a framework on June 7, 2021, for clean hydrogen deployment which includes demonstration projects with a goal of achieving clean hydrogen production at $1 per kilogram in one decade to serve new markets for hydrogen, including steel manufacturing, clean ammonia, energy storage, and heavy-duty trucks. Under the framework, stakeholders will seek to research and develop viable hydrogen demonstrations that can help lower the cost of hydrogen, reduce carbon emissions and local air pollution, create well-paying jobs, and provide benefits to disadvantaged communities.

The total fueling capacity of the funded network is approximately 170,000 kg/day, or enough hydrogen fuel for approximately 245,000 light-duty FCEVs. The combined daily production capacity of the Air Liquide facility in Nevada, the Plug Power facility in Fresno, and the SGH2 facility in Lancaster is 71,000 kg/day. This is less than half the capacity of the future light-duty fueling network (though approximately 40 percent more than the anticipated demand of the latest light-duty FCEV projection of 61,000 FCEVs on the road by 2027). Continuing to focus on increasing hydrogen production for the California mobility market should remain a priority.

CEC Solicitations for Medium- and Heavy-Duty Hydrogen Infrastructure

The CEC has released several solicitations related to medium- and heavy-duty fuel cell infrastructure. The CEC's investment in medium- and heavy-duty hydrogen infrastructure is nearly $40 million. Further, the CEC will invest a large portion of the $1.165 billion ZEV Package funding to support electric and hydrogen medium- and heavy-duty vehicle infrastructure. This investment in medium- and heavy-duty hydrogen infrastructure, funded by the Clean Transportation Program, is separate and apart from the annual $20 million investment in light-duty hydrogen infrastructure.[30] In addition to the nearly $40 million investment, the CEC funded a hydrogen refueling station for fuel cell electric busses (FCEB) at the Alameda-Contra Costa Transit District ($3 million).[31]

28 SGH2 Energy Global, LLC. 2021. "World's Largest Green Hydrogen Project to Launch in California." https://www.sgh2energy.com/worlds-largest-green-hydrogen-project-to-launch-in-california.

29 U.S. Department of Energy. Energy Earthshots Initiative. https://www.energy.gov/eere/fuelcells/hydrogen-shot.

30 Brecht, Patrick. 2020. *2020-2023 Investment Plan Update for the Clean Transportation Program.* California Energy Commission. Publication Number: CEC-600-2020-003-REV. https://efiling.energy.ca.gov/getdocument.aspx?tn=234959.

31 The District published a report, *Zero Emission Transit Bus Technology Analysis*, on June 23, 2021, to analyze the various transit bus technologies (fuel cell electric bus, battery electric bus, diesel hybrid bus, and conventional diesel bus technologies) that the district operates. https://www.actransit.org/sites/default/files/2021-06/0604-20%20Report-ZEB%20Perf_FNL_062321.pdf.

Table 2: CEC Solicitations for Medium- and Heavy-Duty Hydrogen Infrastructure

Solicitation	Description
GFO-17-603, Advanced Freight Vehicle Infrastructure Deployment	On November 7, 2018, CEC approved funding for a 1,000 kilograms per day, 100% renewable hydrogen refueling station for heavy-duty fuel cell electric trucks (FCET) at the Port of Long Beach. The station became operational in July 2021 and provides hydrogen for Class 8 drayage and regional haul FCETs.
GFO-20-604, Hydrogen Fuel Cell Demonstrations in Rail and Marine Applications at Ports (H2RAM)	On August 11, 2021, the CEC approved funding for demonstrating a 1,450 kilograms per day, mixed-use hydrogen refueling station that includes two public-facing open retail dispensers for fueling vehicle sizes up to Class 8 FCETs, and a private-facing dispenser dedicated to refueling a demonstration switcher locomotive operated by Sierra Northern Railroad. This project is expected to be operational in January 2024.
GFO-20-602, Zero-Emission Transit Fleet Infrastructure Deployment	On May 12, 2021, the CEC approved funding for two hydrogen refueling infrastructure projects to support the large-scale conversion of transit bus fleets to zero-emission at two transit agencies serving diverse regions in Thousand Palms and Oceanside. Expected to be operational in 2023, these projects can support up to 100 FCEBs and 40 paratransit FCEBs. On August 18, 2021, the CEC approved funding for an additional hydrogen refueling infrastructure project in Oakland for AC Transit. AC Transit will be replacing the existing 9,000-gallon liquid hydrogen tank with a larger 15,000-gallon liquid hydrogen tank, a 1,500 vertical liquid nitrogen tank and cryogenic pump system. The new system will double fueling capacity at Division 4 and support an upcoming delivery of 20 FCEBs.
GFO-20-606, Zero - Emission Drayage Truck and Infrastructure Pilot Project	On April 5, 2021, a Notice of Proposed Awards (NOPA) was released for proposed CEC and CARB cofunding of a demonstration project for a 1,600 kilogram-per-day liquid hydrogen station designed to serve up to 50 Class 8 heavy-duty fuel cell electric trucks per day. The initial project includes demonstration of 30 Hyundai XCIENT Class 8 trucks that have a 500-mile range on 60 kilograms of hydrogen. Truck routes for the demonstration include Sacramento, Stockton, Modesto, and Fresno. This project is expected to be operational by June 2023.
GFO-21-501 - Hydrogen Fuel Cell Truck and Bus Technology Integration and Demonstration	On July 20, 2021, the CEC released a solicitation to fund research, development, and demonstration projects that can improve the cost effectiveness and performance of hydrogen fuel cell-powered heavy-duty trucks and buses with challenging duty cycles.

Solicitation	Description
GFO-20-603 - Block Grant for Medium-Duty and Heavy-Duty Zero-Emission Vehicle Refueling Infrastructure Incentive Projects	On March 17, 2021, the CEC approved funding for the ENERGIIZE project to design, implement, and fund, with CEC oversight, various medium- and heavy-duty ZEV refueling infrastructure incentive projects to address critical barriers to the deployment of MD/HD ZEV infrastructure.

Source: CEC

CHAPTER 3:
Fuel Cell Electric Vehicle Deployment

The cumulative sales and leases of light-duty FCEVs are increasing but still well below what the current network nameplate fueling capacity can support, providing opportunities for faster deployment of FCEVs. However, the actual network fueling capability depends on the availability of hydrogen supply and the availability of the stations themselves. Figures 10 and 11 in Chapter 2 of this report show the station unavailability in California in 2020.

The CEC ZEV Dashboard[32] reports that the on-road population of FCEVs was 7,129 at the end of 2020 and the dashboard also reports the new FCEV sales for 2021, through the end of the third quarter, as 2,518 FCEVs. According to the CEC ZEV Dashboard, cumulative sales or leases of FCEVs in California were 11,269 as of the end of the third quarter of 2021; however, the cumulative sales number of FCEVs does not account for those FCEVs no longer in use due to replacement or attrition. Staff estimates the total on-road FCEV population to be 9,647, the summation of 7,129 and 2,518. The dashboard shows cumulative ZEV sales, including FCEV, BEV, and plug-in hybrid electric vehicles of 991,494 in California, as of the end of the third quarter of 2021.

In addition to the quarterly sales and annual population updates by the CEC, CARB collects and reports the number of FCEVs deployed in April and October each year. CARB's analysis found the population of FCEVs was 7,993, as of April 2021. CARB's analysis, based on DMV data, includes removing vehicles that appear to be no longer registered in state.

Per the provision set forth by AB 8, CARB is: "to aggregate and make available to the public, no later than June 30, 2014, and every year thereafter, the number of hydrogen-fueled vehicles that motor vehicle manufacturers project to be sold or leased over the next 3 years, as reported to the state board, and the number of hydrogen-fueled vehicles registered with the Department of Motor Vehicles through April 30.[33] AB 8 also requires the CEC and CARB to consider "the available plans of automobile manufacturers to deploy hydrogen-fueled vehicles in California and their progress toward achieving those plans, the rate of deployment of hydrogen-fueled vehicles, …" and other factors.

Figure 14, reprinted from CARB's 2021 Annual Evaluation, shows data as provided by auto manufacturers for estimates of vehicles on the road and projected for future deployment from all years of reporting in CARB's Annual Evaluations. CEC staff notes that the material in Figure 14 are projections, per AB 8. Estimated numbers of vehicles on the road per CARB's annual analysis of April 2021 DMV registration data are shown by the red triangles, growing to an estimate of 7,993.

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32 California Energy Commission. "Zero Emission Vehicle and Infrastructure Statistics." https://www.energy.ca.gov/zevstats.

33 California Legislative Information. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB8.

In Figure 14, yellow circles show similar data based on October DMV data. Two shaded areas are also shown in the figure, representing projections made by auto manufacturers for future FCEV deployment in all Annual Evaluations to date. The lower, blue-shaded area shows all projections made for the mandatory reporting period of all past surveys. The mandatory period always covers the current model year and the next three model years. For the 2021 survey, this period covered model years 2021 through 2024. The upper, orange-shaded area represents projections including the optional reporting period, which extends three further model years. For the 2021 survey, the optional period covered model years 2025 through 2027.

The information provided on the survey, by auto manufacturers, represents projected FCEV sales or leases in terms of model years. CARB's analysis translates model year into calendar year by assuming that one-third of all vehicles of a given model year are sold or leased in the prior calendar year. For example, if an auto manufacturer responds with a projection of 900 FCEVs to be sold in model year 2022, CARB's analysis assumes 300 FCEVs will be sold in calendar year 2021 and the remaining 600 FCEVs in calendar year 2022. CARB's analysis also assumes a standard rate at which FCEVs fall out of the fleet such as vehicles being moved to another state, accidents, and other causes. This rate is based on similar assumptions in CARB's vehicle fleet modeling tool EMFAC.

Auto manufacturers' deployment plans in the 2021 annual survey would result in 30,800 FCEVs on the road in California in 2024 and 61,100 on the road in 2027. The projected rates of growth over these periods are an improvement over the 2020 annual survey, which demonstrated delays in vehicle deployment. The rate of projected deployment, particularly in the period 2024–2027, is accelerated from prior survey responses. CARB's 2021 Annual Evaluation reports that the announcement of new awards for station development through GFO-19-602 was likely a significant factor in the year-over-year improvement in survey responses.[34]

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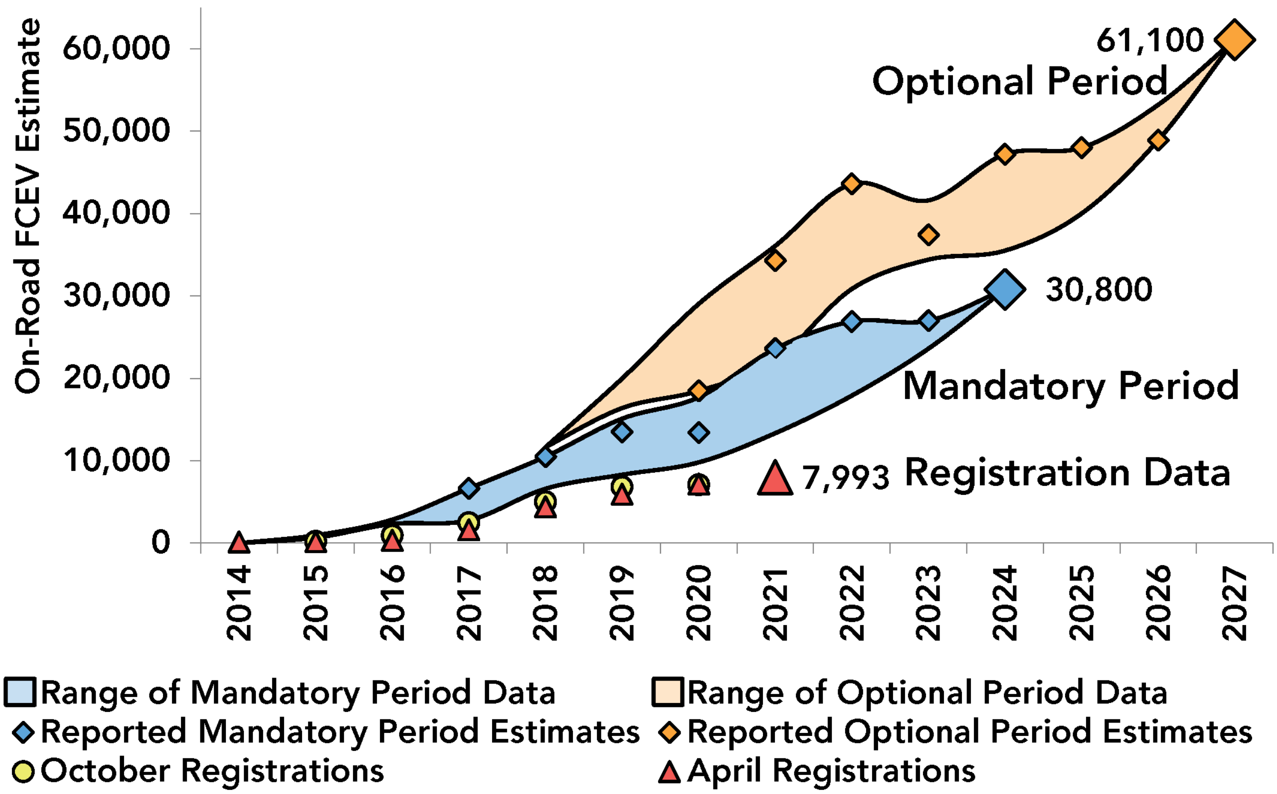
34 California Air Resources Board. September 2021. *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf.

Figure 14: FCEV Projections Based on CARB Analysis of Responses to the Annual Auto Manufacturer Survey



Source: CARB

FCEVs and Stations in Other Countries

The CEC and CARB staff recognize that for fuel cell vehicles and hydrogen infrastructure to scale globally, there must be initial investments by other governments. The CEC staff asked representatives of national governments and public agencies[35] about current and future investments from their governments, station development numbers, fuel cell vehicle population, and goals.

Through 2020, Germany has invested about $118 million in government funding, Japan has invested about $640 million, and the Republic of Korea has invested $199 million, all displaying significant commitments in hydrogen. The Chinese government has also invested by issuing a subsidy policy (ended in 2015) providing about $600,000 per station with local government subsidies ranging from about $150,000 to $460,000. Staff understands that China focuses their efforts to a greater extent on commercial vehicles, as compared with passenger vehicles. Private companies have contributed to hydrogen infrastructure in these countries as the government funds cover two-thirds of station costs in Japan and up to half of station costs in

35 CEC staff communicated via email in July 2021 and August 2021 with representatives of organizations and government agencies in China, Japan, and the Republic of Korea.

the Republic of Korea. As a result, these countries have developed enough stations to serve thousands of vehicles as summarized below.

Table 3: Stations and FCEVs in Other Countries

	China	Germany	Japan	Republic of Korea
Stations	146 built (136 in operation) with more under construction and planning	92 open and 15 in development	147 open and 19 in development	54 stations built and 24 under development, plus 9 stations in operation for demonstrations
Vehicles	7,831 cumulative sales of commercial vehicles, as of June 2021	1,273 light-duty FCEVs and 52 medium-/heavy-duty vehicles as of July 2021	5,800 light-duty FCEVs and 104 city buses and small trucks in demonstration, as of June 2021	15,569 light-duty FCEVs and 106 buses, as of July 2021

Source: CEC

It is informative to compare the CEC's data for 2021 to IEA's *Global EV Outlook*[36] for 2020. According to IEA, stations in China represented 16 percent of 540 worldwide hydrogen refueling stations (about 86 stations), stations in Germany represented 17 percent (about 92 stations), stations in Japan represented 25 percent (about 135 stations) and stations in the Republic of Korea represented 9 percent (about 49 stations) in 2020. In addition, according to the *Global EV Outlook*, Germany had 1,000 light-duty FCEVs, Japan had 4,100 light-duty FCEVs, and the Republic of Korea had 10,000 light-duty FCEVs in 2020. Both station and vehicle numbers have increased in most of these countries since 2020. Also, by comparison, California has nearly 12 percent of the global hydrogen station count with 52 stations, which is nearly 96 percent of the stations in the United States. To build on the investments they have made, these four countries have the following goals.

36 IEA. 2021. *Global EV Outlook 2021*. https://www.iea.org/reports/global-ev-outlook-2021. All rights reserved.

Table 4: Goals for Stations and FCEVs in Other Countries

	China	Germany	Japan	Republic of Korea
Stations	• 1,000 stations by 2025 • 5,000 stations by 2030–2035	• 400 stations by 2025 • 1,000 stations by 2030	• 320 stations by 2025 • 1,000 stations by 2030	• 310 stations by 2022 • 1,200 stations by 2040
Vehicles	• 50,000 to 100,000 vehicles by 2025 • 100,000 FCEVs by 2030–2035	• No goals for vehicle deployment have been set	• 800,000 FCEVs by 2030, including buses and trucks	• 65,000 FCEVs and 2,000 buses by 2022 • 2,750,000 FCEVs, 80,000 taxicabs, 40,000 buses, and 30,000 trucks by 2040

Source: CEC

Hydrogen Strategy and Stations in Other Regions and U.S. States

Regions and states outside California have developed hydrogen strategies and plans for stations. Ongoing activities in the Pacific Northwest, Northeastern United States, and Texas indicate the potential for hydrogen as a transportation fuel and in other sectors.

Seattle City Light (SCL) is collaborating with numerous stakeholders to develop a carbon-neutral Waterfront Clean Energy Strategy for zero-emission infrastructure at port and port-related facilities by 2050. The measures under consideration include renewable hydrogen generation, storage, and dispensing for harbor vessels; backup power; drayage trucking; and grid support. The planned completion for the strategy is the first quarter of 2023.[37]

Another SCL project is the Douglas County Public Utility District 5 MW electrolyzer that will use excess hydropower from the Columbia River to produce hydrogen which will be stored and delivered by truck to Washington's first hydrogen refueling station.[38]

A network of stations in the Northeastern United States, of which four are built, has not yet begun retail sale of hydrogen fuel, pending the outcome of multiple Northeastern states' public regulatory discussions to lift local bans on the transport of hydrogen through tunnels and over bridges. The stations will likely be delayed until FCEVs are allowed to use the tunnels and bridges. As part of the station network, Massachusetts regulators' proposed amendment to the

37 Email correspondence on 8/3/2021 with a representative of Seattle City Light (SCL).

38 Herring, Garrett. 2021. "Washington utility moves forward with 5MW green hydrogen demonstration project." Institute for Energy Economics and Financial Analysis. https://ieefa.org/washington-utility-moves-forward-with-5mw-green-hydrogen-demonstration-project/.

state's existing regulations would allow hydrogen-fueled vehicles to use the highway tunnels, while the transport or carrying of hydrogen would remain prohibited.[39]

A U.S. DOE renewable hydrogen demonstration project will include the University of Texas at Austin (UT-Austin), Frontier Energy, and Mitsubishi Heavy Industries Group. The partners will demonstrate hydrogen applications for transportation, power generation, and other sectors. UT-Austin plans to host commercial renewable hydrogen production that will be piped to a fuel cell to power the Texas Advanced Computing Center and supply a hydrogen fuel station to power an FCEV fleet. UT-Austin will also conduct a feasibility study at the Port of Houston to assess the possibilities of scaling hydrogen production and use. As well as reviewing policy and regulations, the project team will identify prospective hydrogen users, assess available resources and delivery infrastructure, and help industry create a strategic plan for policy makers to develop future heavy-duty fuel cell transportation and energy systems.[40]

These projects for hydrogen strategy and implementation, in addition to California's efforts, provide examples for other regions and states to follow. The CEC plans to continue information exchange with these and experts around the United States in the areas of strategizing and using hydrogen as a transportation fuel and in other energy sectors.

Barriers to Widespread FCEV Commercialization and Deployment

Building the FCEV market from the current early market phase into more widespread technology adoption will require addressing barriers in addition to those related to infrastructure. These barriers include lack of refueling infrastructure, supply disruptions in the nascent industry of producing hydrogen 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. The hydrogen supply disruptions have diminished consumer confidence as have the lack of geographic coverage and reliability of the station network. Other barriers also include the high price at the pump for hydrogen (especially for renewable hydrogen), high FCEV purchase and lease prices, and lack of consumer awareness about FCEVs. Additionally, expanded use of new and direct renewable resources for hydrogen production will help achieve the goal of a zero-carbon hydrogen future. Low to zero-carbon hydrogen is needed at volumes much larger than seen in today's market.

Studies suggest that the lack of consumer awareness of FCEVs and the consumer's understanding of the related environmental benefits, which is also observed for plug-in battery electric vehicles (BEVs), play a role.[41] FCEVs are at a slightly earlier stage of development and

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39 Proposed amendments to Code of Massachusetts Regulations Title 700 is available at https://www.mass.gov/doc/proposed-amendments-to-700-cmr-700-highlighted/download.

40 Forbes. February 25, 2021. "How the Lone Star State is Building a Green Hydrogen Future." https://www.forbes.com/sites/mitsubishiheavyindustries/2021/02/25/how-the-lone-star-state-is-building-a-green-hydrogen-future/?sh=e7f5d187e8a2.

41 Kurani, Kenneth S., Nicolette Caperello, Jennifer TyreeHageman. 2016. *New Car Buyers' Valuation of Zero-Emission Vehicles: California*. Institute of Transportation Studies, University of California, Davis. Research Report UCD-ITS-RR-16-05.

deployment than that of BEVs.[42] To promote brand neutral consumer awareness, GO-Biz released a $5 million request for proposal on November 09, 2021, which is inclusive of both BEVs and FCEVs.[43]

Presently, California has 52 Open Retail hydrogen refueling stations, most located within the Los Angeles, San Francisco, Sacramento, and San Diego areas. A few are located in connector or destination areas that allow for travel to other areas of the state. Building stations in more rural areas of California will help FCEV drivers access more of the state. Additionally, apart from a few northeastern states and Washington state, there is no public hydrogen refueling infrastructure outside of California. This prevents FCEV drivers from travelling to other states.

Consumer choice of models is needed for the widespread deployment of ZEVs. There are currently two FCEV models available in California (one model from Toyota and one model from Hyundai). Compared to the currently available 58 models of plug-in electric vehicles (BEVs and plug-in hybrid electric vehicles) listed by Veloz, there are fewer FCEVs models and body types.[44] The market is still in early development, especially for BEVs and FCEVs. Of the 58 plug-in models, only 18 are BEVs. In addition, CARB tracking of current expected model year 2021 vehicles shows 10 BEV models with long-range capability of 300 miles or more, often cited as a desirable minimum vehicle range (and which all FCEV models exceed). Expansion of model availability, especially for such high-mileage vehicles, across the ZEV market may be a key component to accelerating consumer adoption.

In California, ZEV goals provided by Executive Orders and ZEV mandates provide a supporting framework and environment for new ZEV models, including FCEV models to continue to enter California's market. BMW will begin testing their "i Hydrogen Next FCEV" on public roads in Europe and plans to introduce the vehicle for sale "in small numbers" in California in late 2022.[45] While Honda discontinued production of the Clarity Fuel Cell, the company has stated that FCEVs will play a key role in their zero-emissions strategy.[46] As part of their global hydrogen strategy and economy and new energy paradigm, Hyundai announced three new FCEV light-duty vehicles by 2025, the next-generation NEXO, a multi-purpose vehicle (MPV), and a large sport utility vehicle (SUV). Hyundai will also release a full line up of fuel cell commercial vehicles by 2028, including class 8 tractors, class 6 trucks and below as well as buses.[47] Jaguar Land Rover recently announced that they will begin tests later this year on an

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42 Deloitte China. 2020. *Fueling the Future of Mobility, Hydrogen and fuel cell solutions for transportation, Volume 1*. https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf.

43 Cal eProcure. "ZEV Awareness RFP." https://caleprocure.ca.gov/event/0509/0000021370.

44 "ElectricForAll." https://www.electricforall.org/which-car-is-right/.

45 Roadshow by CNET. "BMW i Hydrogen Next fuel cell vehicle begins testing on public roads." https://www.cnet.com/roadshow/news/bmw-i-hydrogen-next-fuel-cell-vehicle-testing/.

46 American Honda Motor Co., Inc. Fuel Cell Technology Will Continue to Play a Role in Our EV Strategy. https://hondanews.com/en-US/releases/release-53541be6030b25a47a2899aba12d4f66-fuel-cell-technology-will-continue-to-play-a-role-in-our-ev-strategy.

47 Hydrogen Wave: Hydrogen for Everyone, Everything, Everywhere. https://www.hydrogen-wave.com/. Accessed September 10, 2021.

FCEV prototype model based on its Land Rover Defender vehicle as the company plans to expand its zero-emission car options.[48]

Initial (purchase or lease) costs of FCEVs are higher than comparable conventional vehicles and many plug-in electric vehicles. The Clean Vehicle Rebate Project (CVRP) in California and federal tax credits mitigate some of the cost to consumers.[49] As new manufacturing processes for the FCEV come online, the FCEV cost could also decrease. Deloitte China forecasts that total cost of ownership of FCEVs will decrease by almost half in the next 10 years[50], which may help more consumers afford FCEVs and increase the entry of FCEVs into the mass market. A prior study by the US Department of Energy also finds that FCEVs can be cost-competitive with BEVs in large portions of the United States light-duty vehicle market in 2030 and later years.[51]

The price of hydrogen at the pump remains high relative to gasoline that is used in passenger cars that have internal combustion engines.[52] Auto manufacturers provide free fuel in the initial years of ownership or leasing. Even with this support to offset the increased price of hydrogen fuel, the price of hydrogen must still fall over time for FCEVs to become a viable option for widespread adoption beyond today's on-road volumes.

Stations funded under the CEC's most recent solicitation, GFO-19-602, are expected to have lower capital and operation and maintenance costs as compared with previous CEC solicitations. The lower costs of equipment and operation could eventually lower the price of hydrogen at the pump. This solicitation provides developers with Clean Transportation Program funding through 2023, pending appropriation and Clean Transportation Program Investment Plan allocations. The approach in the solicitation gives developers the ability to purchase equipment in bulk for an entire project, potentially reducing equipment prices. This approach to cost reduction through scale appears to be showing early success. New stations that are two to four times as large as older stations (in terms of daily fueling capacity and number of simultaneous fueling positions), currently sell hydrogen at 20 percent less than the typical or average sales price of hydrogen in California's fueling network.

To help establish a global market, the CEC has required compliance with global standards and national standards used as input for global hydrogen refueling protocols. These standards encourage commonality for the station design and functionality for the station developers,

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48 Reuters. 2021. "JLR to begin testing prototype hydrogen Land Rover this year." https://www.reuters.com/business/autos-transportation/jlr-begin-testing-prototype-hydrogen-land-rover-this-year-2021-06-14/.

49 CVRP rebates of up to $7,000 for qualified applicants and the Federal tax credit of up to $8,000 was extended through the end of 2021.

50 Deloitte China. 2020. *Fueling the Future of Mobility, Hydrogen and fuel cell solutions for transportation, Volume 1*. https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf.

51 Morrison, Geoff, John Stevens, Fred Joseck. 2018. *Relative economic competitiveness of light-duty battery electric and fuel cell electric vehicles.* Transportation Research Part C 87 (2018) 183—196.

52 Norton Rose Fulbright. April 2021. "Hydrogen: The next frontier." https://www.projectfinance.law/publications/2021/april/hydrogen-the-next-frontier/.

hydrogen suppliers, and auto manufacturers worldwide. These standards also ensure that customers have consistent and familiar fueling experience at any hydrogen refueling station they may visit. The CEC has also participated in hydrogen safety policy at an international level, which strengthens approaches used worldwide for safety. Further, the CEC staff participates in information sharing with global partners for ZEVs and stations. Standardization may also contribute to lower costs, as larger volumes of similar equipment may be manufactured and achieve economies of scale more rapidly.

The hydrogen dispensed at refueling stations must be produced by extracting the hydrogen molecules from compounds like water (H_2O) or methane (CH_4), which is in most cases done at a centralized plant. The molecules are then usually delivered to the station by truck, similar to how gasoline is delivered. This supply chain for hydrogen production to serve the transportation market is currently strained. Hydrogen is produced in large quantities for various industrial applications, but there is limited excess supply for smaller uses like the transportation market.

California experienced several supply disruptions due to various causes. For example, a hydrogen delivery trailer caught on fire in 2018 and the fuel supplier had to stop delivery until all of their trailers were inspected, causing many stations to run out of fuel. Another example is when a transfill facility in Santa Clara went offline for months after an accident in the summer of 2019, affecting most of the stations in Northern California. Another example is Hurricane Zeta affecting a hydrogen supplier's plant, which resulted in a hydrogen shortage at many California stations in November and December 2020. Most recently, a hydrogen production facility in Sacramento went offline for months. During the most recent hydrogen supply disruption, Hurricane Ida affected a hydrogen supplier's plant, which resulted in another hydrogen supply shortage at many, but not all, California stations lasting from August 2021 until September 2021 when a new hydrogen transfill hub in Livermore (in Alameda County), designed and built by FirstElement Fuel became operational and began deploying hydrogen delivery trailers for gaseous and liquid hydrogen from a different hydrogen source, as mentioned in Chapter 2.

Figure 5 in Chapter 2 of this report shows these incidents, as well as decreased fueling from the pandemic, as "dips" in hydrogen dispensing. The supply disruptions resulted in many of the stations going offline, forcing FCEV drivers to rent non-FCEV cars (the cost of which was often covered by the automaker) and which led to decreased hydrogen dispensing. The major new hydrogen supply facilities and delivery trailers mentioned in Chapter 2 are expected to increase the supply and distribution capacity and therefore individual supply shortages may become less impactful to the state network in the future.

While this report focuses much attention on how many hydrogen refueling stations are funded and their progress towards opening for retail sales, the ongoing operation of these stations is equally important to FCEV drivers. Station operators must maintain equipment and manage logistics for fuel deliveries to ensure the stations remain open to serve customers.

Nozzle freeze-lock at the stations also affects driver confidence. Nozzle freeze-lock occurs during periods of high humidity causing the nozzle to become frozen and unable to disconnect from the vehicle for several minutes. The CEC co-funded a task under the California Hydrogen

Infrastructure Research Consortium Cooperative Research and Development Agreement (CRADA) in which NREL studied the conditions in which freeze-lock most commonly occurs to aid in finding appropriate solutions. The study found that freeze-lock occurrence appears more likely at ambient temperatures of 35 to 40 degrees Celsius (95 to 104 degrees Fahrenheit) with dew point temperatures between 20 and 30 degrees Celsius (68 to 86 degrees Fahrenheit). Station developers have either redesigned or adopted new designs for the refueling nozzles they use to avoid nozzle freeze-lock. In addition, several station operators have installed air blowers on the dispenser intended to evaporate or push moisture off the nozzle when the nozzle is correctly placed in the holder by the FCEV driver. These innovations can help reduce barriers.

Also, on a station-by-station basis, the FCEVs queue differently, based on the station footprint. Stations funded prior to 2015 had one or two fueling positions while many stations funded more recently have four fueling positions. These multiple fueling position stations can accommodate more FCEVs to fill simultaneously. Table 5 shows the progression of back-to-back fueling for CEC hydrogen refueling solicitations.

Table 5: Back-to-Back Fueling Requirements per CEC Solicitation

CEC Solicitation	Description
PON-09-608	20 kg/hour peak fueling
PON-12-606	Five 7 kg H70-T40 fills per hour
PON-13-607	Three 7 kg H70-T40 fills per hour
GFO-15-605	Five 4 kg H70-T40 fills per hour
GFO-19-602	Seven 4 kg H70-T40 fills per hour per fueling position

Source: CEC staff

FCEV drivers sometimes contact CEC, CARB, and GO-Biz when stations go offline or when they feel that a station should have additional or improved signage to assist with identifying safe driving paths inside the station, avoiding pedestrian traffic, and decreasing congestion inside a station. Sometimes, the FCEV drivers offer their solutions to negate the problems around supply disruptions. Some FCEV drivers ask that full-time technician and customer service attendants be present at stations. The attendants would help manage the congestion and help drivers refuel their FCEVs to improve customer experience. The CEC plans to hold public workshops in the future to obtain more input from FCEV drivers and their experiences and also to seek to remedy these concerns.

Workforce training is an important factor that could contribute to improved customer satisfaction. For example, as more auto technicians who are trained to work on FCEVs become available, FCEV customers will have more options of dealerships and repair shops to take their vehicles for maintenance and services.

Medium- and Heavy-Duty Fuel Cell Vehicles

California is working to deploy medium- and heavy-duty FCEVs: buses, trucks, portside equipment, a locomotive, and a commuter rail system. The California Climate Investments Program funds medium- and heavy-duty fuel cell electric vehicles, in addition to the CEC investments in MD/HD fuel cell vehicle infrastructure.

The private sector is also making investments in California. In December 2021, Cummins, Inc., announced that it had opened a Hydrogen Fuel Cell Powertrain Integration Center in the California Fuel Cell Partnership building in West Sacramento. Cummins reports that, "At the West Sacramento facility, the focus is proton exchange membrane fuel cells, which are considered a good solution for high-power transportation applications, like heavy-duty, long-haul trucks."[53]

CARB has invested in several projects for medium- and heavy-duty fuel cell vehicles through the CCI program[54] and Volkswagen (VW) Mitigation Trust Fund.[55] CEC staff considered these projects, shown in Table 6, for this Joint Report to provide a complete perspective. The estimated daily hydrogen consumption for these projects is anticipated to be nearly 1,200 kilograms, based on the annual consumption numbers provided by CARB.

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53 Cummins Newsroom. December 1, 2021. "Cummins Accelerates Hydrogen Innovation for California and Beyond with new West Sacramento Center." https://www.cummins.com/news/releases/2021/12/01/cummins-accelerates-hydrogen-innovation-california-and-beyond-new-west.

54 California Climate Investments. http://www.caclimateinvestments.ca.gov/.

55 California Air Resources Board. Volkswagen Environmental Mitigation Trust for California. https://ww2.arb.ca.gov/our-work/programs/volkswagen-environmental-mitigation-trust-california.

Table 6: CARB Projects for Medium- and Heavy-Duty FCEVs

Project	Description
SunLine Transit FCEB and Hydrogen Onsite Generation Refueling Station Pilot Commercial Deployment (co-funded by the South Coast Air Quality Management District, SCAQMD)	• 5 FCEBs • Upgraded hydrogen refueling station
Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project	• 5 FCEBs at SunLine Transit
Fuel Cell Electric Bus Commercialization Consortium (co-funded by the SCAQMD)	• 20 FCEBs at Orange County Transit Authority (OCTA) and AC Transit • Upgraded hydrogen refueling stations at AC Transit Emeryville and Oakland • Hydrogen refueling station at OCTA's Santa Ana Base
Fast-Track Fuel Cell Truck*	• 5 plug-in hybrid fuel cell-electric trucks at the Port of Los Angeles and throughout the Los Angeles region
Zero-Emission for California Ports Yard Trucks*	• 2 yard trucks at the Port of Los Angeles
Fuel Cell Hybrid Electric Top Loader*	• 1 electric top loader at the Port of Los Angeles
Fuel Cell Hybrid Electric and Next Generation Fuel Cell Delivery Van Deployments*	• 15 fuel cell electric delivery vans in Ontario, 4 vans in West Sacramento
Zero-Emission Hydrogen Ferry Demonstration*	• 1 hydrogen fuel cell ferry in the San Francisco Bay
Port of Los Angeles "Shore to Shore"* (co-funded by the SCAQMD)	• 10 hydrogen fuel cell Class 8 on-road trucks in the Port of Los Angeles
The Commercialization of Port of Long Beach Off-Road Technology Demonstration*	• 1 yard truck at the Port of Long Beach
Drayage Pilot project with the Center for Transportation and the Environment (CTE), Hyundai and First Element (CEC and CARB cofunding)	• 30 Class 8 trucks served by the 1,600 kilogram-per-day liquid hydrogen station proposed for CEC funding under GFO-20-606
VW Mitigation Trust Fund	• 17 fuel cell transit buses

Source: Project information from CARB. Estimated hydrogen consumption from CEC.

Note: Projects indicated by an asterisk (*) are demonstrations and their hydrogen consumption will likely cease once the demonstration periods are over.

In additional to the CARB projects, the SCAQMD is co-funding projects to support hydrogen refueling infrastructure. Table 7 lists a project in which three hydrogen refueling stations, designed and operated for light-duty passenger cars, will be used for medium- and heavy-duty demonstrations.

Table 7: SCAQMD Projects for Medium- and Heavy-Duty FCEVs

Project	Description
Class 8 Fuel Cell Truck Demonstration (SCAQMD and U.S. EPA co-funding)	• To demonstrate two Hyundai fuel cell electric trucks (FCETs) on existing goods movement routes utilizing three existing CEC funded hydrogen refueling stations
High-Flow Bus-Fueling Protocol Development (SCAQMD funded)	• To model, test and validate the application of a protocol for high-flow bus fueling based on the formula originally developed and applied to passenger car fueling
Contract with NREL to Support California Hydrogen Heavy-Duty Infrastructure Research (SCAQMD funded)	• To develop a heavy-duty hydrogen reference station, fueling performance test device concepts, and a heavy-duty hydrogen station capacity model
Zero-Emission Multiple Unit Train (SCAQMD- Mobile Source Air Pollution Reduction Review Committee (MSRC) funded)	• To demonstrate a battery and hydrogen-powered passenger train between San Bernardino and Redlands operated by the San Bernardino County Transportation Authority (SBCTA)

Source: Project information from SCAQMD.

CHAPTER 4: Time Required to Permit and Construct Hydrogen Refueling Stations

The time spent from start of CEC-grant funded project to initial permit application filing continues to decrease significantly. The overall station development times were decreasing until the COVID-19 pandemic slowed many station development activities. This report breaks down station development time into four phases to analyze the trend. Table 8 lists the phases of station development.

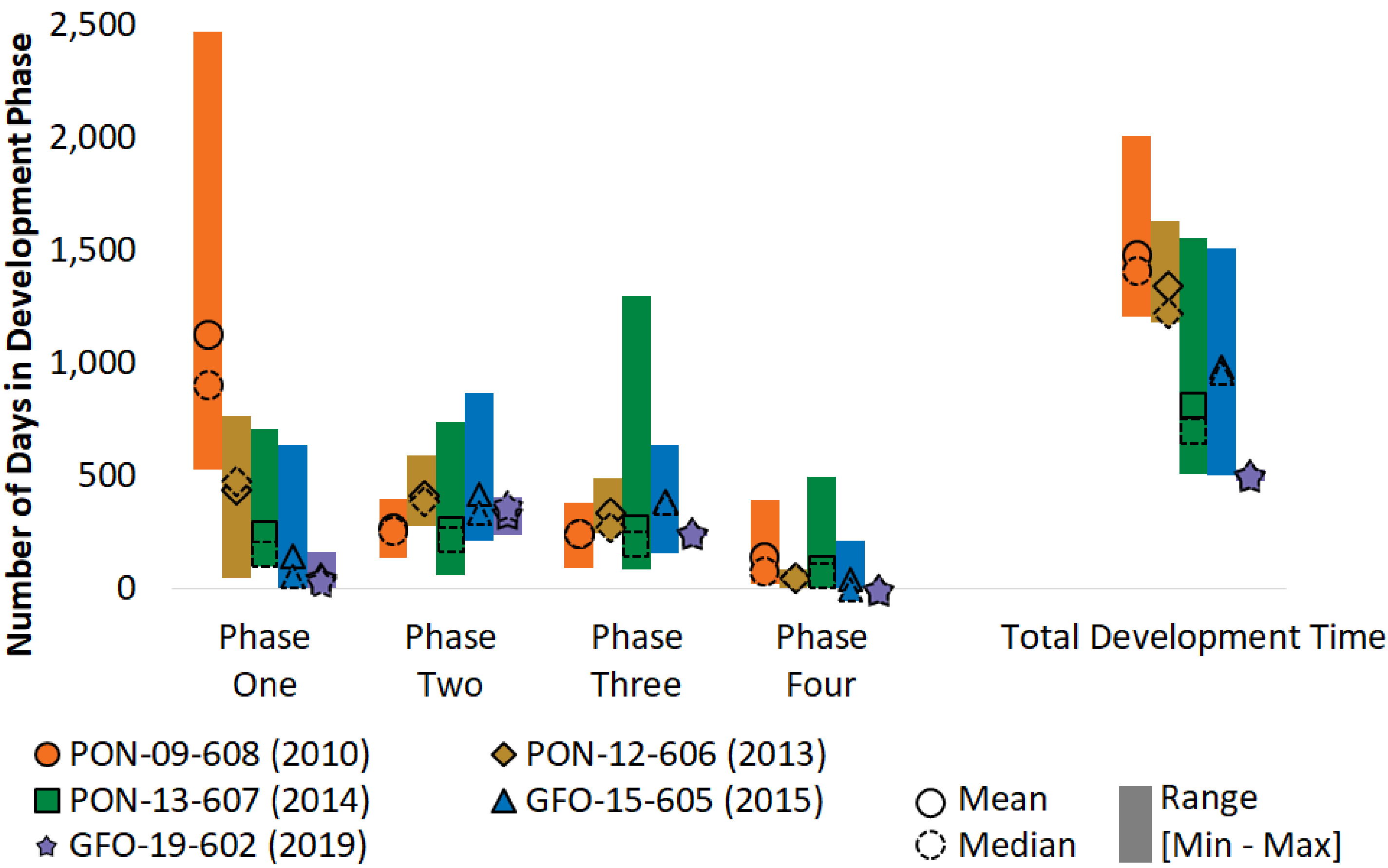
Table 8: Station Development Phases

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

Station development time is presented in Figure 15 showing mean, median, minimum, and maximum number of days for each phase and solicitation. A mean number of days simply represents the average number of days for all stations that completed each phase. Mean numbers can be affected by unusual circumstances some stations experience that lead to atypical station development time. A median number of days represents the middle value of the reported number of days for all stations that completed each phase. Median numbers represent more typical station development time. Minimum and maximum numbers of days represent the minimum and maximum numbers spent in each phase for all stations that completed each phase. The figure includes data from stations that are not yet open for retail fuel sales, but only includes those stations' data for their completed phases. The bars on the far right in the figure show mean, median, minimum, and maximum numbers of days for the *total* station development time for each solicitation and include only stations that have completed all the phases.

Figure 15: Mean, Median, Minimum, and Maximum Days of Each Station Development Phase by Solicitation



Overall, the time spent in Phase One continues to decrease significantly after 2010 for newer solicitations. The mean, median, and maximum of station development time for GFO-15-605 increased as more stations completed. These values are expected to continue increasing as six more stations are completed. The station development for GFO-19-602 is significantly lower than the other solicitations, but only two stations have completed all phases, and the rest of the stations are in development and still affected by the COVID pandemic effects.

Sources: CEC and CARB

The past Joint Reports observed an overall decrease in station development time with each subsequent solicitation. However, the station development time (mean, median, and maximum) in Phases Three and Four for GFO-15-605 has increased since the last joint report as more stations funded under this solicitation completed. As the remaining stations under GFO-15-605 are completed, the mean, median, and maximum numbers for this solicitation will continue to increase.

Stations funded under GFO-15-605 that are still under development have experienced unforeseen delays. The delays included changes in site lease agreements for the stations. Additionally, temporary hydrogen supply disruptions slowed station testing. Energizing stations took longer than expected. The station developers experienced technology problems with equipment. Permitting was slower in some cases due to disruptions caused by the pandemic. Some developers reported that there were scheduling lags for final inspections with utilities due to backlogged work caused by the COVID-19 pandemic. Some developers also reported delays in equipment delivery from overseas due to the pandemic.

This year, the analysis includes the station development time for GFO-19-602. Many stations have completed Phase One, and this phase shows a significant improvement over previous solicitations from the CEC. The station developers started permitting prior to their CEC awards and purchased equipment mostly in bulk for efficiency. However, the rest of the data for GFO-19-602 in Figure 15 reflect a small number of stations because not many stations have completed the rest of the phases, and only two stations have completed all phases. These two stations that have completed all phases are privately funded stations that are counted as match in an agreement resulting from GFO-19-602. These stations opened quickly because the station developer had already started on permitting those stations before they applied for GFO-19-602. The solicitation included benchmarks for developers to receive approval to build from the respective authority having jurisdiction within 18 months of the CEC approving the station and becoming open retail within 30 months of the CEC approving the station. These benchmarks appear to be helping keep station development on track for most stations. Staff expects the station development time for the Phases Two, Three, and Four for GFO-19-602 to increase as more stations complete later development phases. However, staff expects the overall station development time (mean, median, and maximum) for GFO-19-602 to be less than those in previous solicitations as the COVID pandemic effects wind down.

CHAPTER 5:
Amount and Timing of the Growth of the Hydrogen Refueling Network

This Joint Report uses the nameplate capacity of stations to express the potential for fueling and support for FCEVs in ideal situations with 100 percent uptime. The amount and timing of the growth of the hydrogen refueling network in California are also expressed in terms of nameplate capacity. The validity of evaluations of the network fueling capacity depends on the degree to which stations are functioning as planned: they have hydrogen supply available to dispense and are up and running. If stations are down due to broken equipment or because they have run out of hydrogen fuel, the station network cannot support the number of FCEVs that they should on paper. Chapter 2 discusses challenges with hydrogen supply and other factors that have at times significantly affected station network performance.

As of October 22, 2021, California has 52 open retail hydrogen refueling stations that serve California FCEV drivers. These stations can dispense up to 25,000 kilograms of hydrogen per day. However, the actual network fueling capability depends on the availability of hydrogen supply and the availability of stations themselves. Figures 10 and 11 in Chapter 2 of this report show the station unavailability in California in 2020.

As of October 22, 2021, California has built almost 2.5 times more dispensing capacity than the demand needed to fuel its population of FCEVs. The station opening timelines provided to the CEC by hydrogen station developers suggests that by 2027, the network of 179 projected stations will have the capability of serving about 245,000 FCEVs. This is nearly four times the amount of fuel needed to supply the projected 61,100 FCEVs reported in CARB's 2021 Annual Evaluation, based on the latest auto manufacturer survey responses.

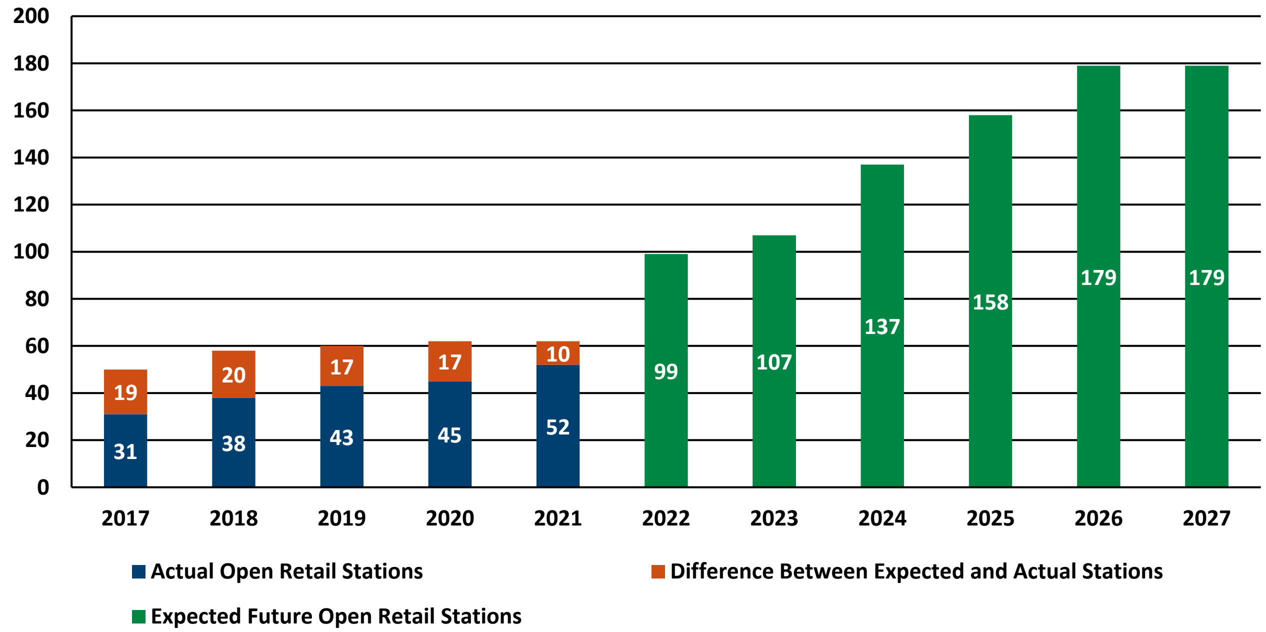
California is on track to meet the AB 8 goal of having at least 100 publicly available hydrogen stations. With private sector support, California is deploying a statewide, publicly available hydrogen network successfully and is on pace to open 107 stations by the end of 2023.

Growth of the Hydrogen Refueling Network

The CEC and CARB have reported on the station developers' projections for the number of open retail stations in previous years. Figure 16 shows the number of stations expected by hydrogen refueling station developers and the actual number of open retail stations that were reported by station developers to the CEC. Projections for stations in successive years since 2017 have been consistently optimistic, but despite the lower number of stations and fueling positions actually deployed, the open retail network's nameplate capacity has always exceeded the demand from the FCEV population.

Differences in the projected number of stations and the number of stations that achieved open retail status reflect various barriers and challenges faced by planners, designers, builders, and operators.

Figure 16: Expected and Actual Open Retail Stations as Reported by the Station Developers



Source: CEC

The number of expected stations reported by station developers exceeded the stations that actually came online between 2017 – 2019. In many cases, station openings fell short of the projections due to changes in station design and equipment. Station design and equipment changes occurred for 12 stations funded under GFO-15-605. For one developer, GFO-15-605 equipment was originally proposed as gaseous delivery and 310 kilograms per day capacity. The developer changed the design from gaseous to liquid hydrogen, which yielded 1,616 kilograms per day instead. This change yielded an increase of nearly 15,000 kilograms per day in network nameplate capacity, though added time to the development process for all stations involved.

Station developers reported other reasons to adjust the number of expected open retail stations. Progress in station development slowed, for example, when a station site owner changed their mind and decided not to host a station. Some stations had to close or postpone station opening due to excessive compressor vibration. Stations changed out some parts and added dampeners to lessen the compressor vibration which will decrease the noise level.

Station development also slowed when permitting issues arose related to COVID-19. Station developers adjusted their schedules to accommodate the schedule changes for reviews of their permitting requests, and the restrictions in international and local travel. COVID-19 restrictions also caused delays due to some inability of the station developer to proceed with site development. In some cases, stakeholders participated in remote permitting meetings and virtual site visits.

The CEC considered and approved no-cost term extensions for 15 stations between the fourth quarter of 2020 and the second quarter of 2021. These factors culminated in the relocations of 23 stations, since 2012. The relocation process involves the station developer requesting a relocation of a site that is no longer viable and proposing a replacement site that meets the requirements of the solicitation to the CEC. If the CEC determines that the new site is adequate, the CEC will post a revised NOPA. Once the revised NOPA is posted, the agreement is amended with a site relocation.

From station developers' reports, staff expects that 2022 will be a year in which the state achieves significant expansion of network nameplate fueling capacity and coverage. The station network has had enough nameplate fueling capacity for more than double the number of FCEVs in the state. The CEC's efforts to advance planning and funding of stations will increase statewide network nameplate fueling capacity to support about 245,000 FCEVs, about four times the number of FCEVs the latest auto manufacturer survey anticipates will be on the road through 2027.

The main metro area markets will continue to have ample capacity to allow for FCEV sales for the foreseeable future. That said, station reliability and fuel supply are key to keeping all completed stations on the network open and available to FCEV drivers.

Regional Analysis

This section of the Joint Report evaluates four major regions of the state: The Greater Los Angeles Area, the San Francisco Bay Area, the Sacramento Area, and the San Diego Area. The regions are defined in the glossary. Also evaluated is the rest of the state, composed of the North Region, Central Coast, Central Valley, Eastern Sierra, and Imperial County.

Table 9 presents projections of vehicle and station rollout in 2027. The stations with known locations that are planned to be opened by 2027 are expected to have sufficient nameplate capacity to serve the number of FCEVs projected will be sold by that year as reported in CARB's 2021 Annual Evaluation based on the latest auto manufacturer survey responses. The total capacity of all 179 anticipated stations will have the nameplate capacity to serve nearly four times the projected number of FCEVs. Also, the one-time funding from the California Budget 2021-2022 provides an opportunity for the CEC to close the gap to 200 stations. As public and private entities work to make this planned station network a reality, the state's intention is to provide the fueling infrastructure that has the capability to support an increased FCEV population to achieve ZEV deployment goals.

Noticeable, however, is the limited opportunity for FCEV deployment in the rest of the state, as defined in Table 9. Because opening new markets, including the larger urban areas around Eureka, Redding, Stockton, Fresno, Bakersfield, Monterey, San Luis Obispo, and Santa Barbara, will be important for FCEV adoption to take hold statewide, station developers may consider locating future planned stations in these areas.

Table 9: Regional Projection of Nameplate Fueling Capacity of Stations With Identified Addresses

Region	Projected # of FCEVs in 2027[56]	Estimated # of FCEVs Stations Could Support in 2027	Additional # of FCEVs that Stations Could Support in 2027
Greater Los Angeles Area	36,700	81,000	44,300
San Francisco Bay Area	17,600	39,100	21,500
Sacramento Area	2,100	4,200	2,100
San Diego Area	4,100	10,100	6,000
Rest of State	600	1,100	500
Total	**61,100**	**135,500**	**74,400**

Source: CEC

The regional analysis in this chapter includes all open retail and planned stations under previous solicitations, the stations resulting from CEC agreements under GFO-19-602 in each station developer's initial batch, and the stations in potential later batches for which the developer provided an address. It also includes planned stations that are privately funded.

In providing station addresses, developers met various milestones to confirm location viability. There are 45 stations with addresses out of the 111 new stations that the CEC expects to result from GFO-19-602, once fully funded. As station developers confirm the addresses for the remaining planned stations, those stations will be added to this analysis in future years' reports. Network nameplate capacity will nearly double from the 2027 capacity listed in Table 9 once all planned station locations are added.

To calculate the projections presented in Table 9, staff used the daily station capacity as determined by the Hydrogen Station Capacity Evaluation (HySCapE) tool (or the stated nameplate capacity, if HySCapE results are not available). Then, staff used the assumption of 0.7 kilogram per day of hydrogen consumed per FCEV to convert the station nameplate capacity into the estimated number of FCEVs supported.

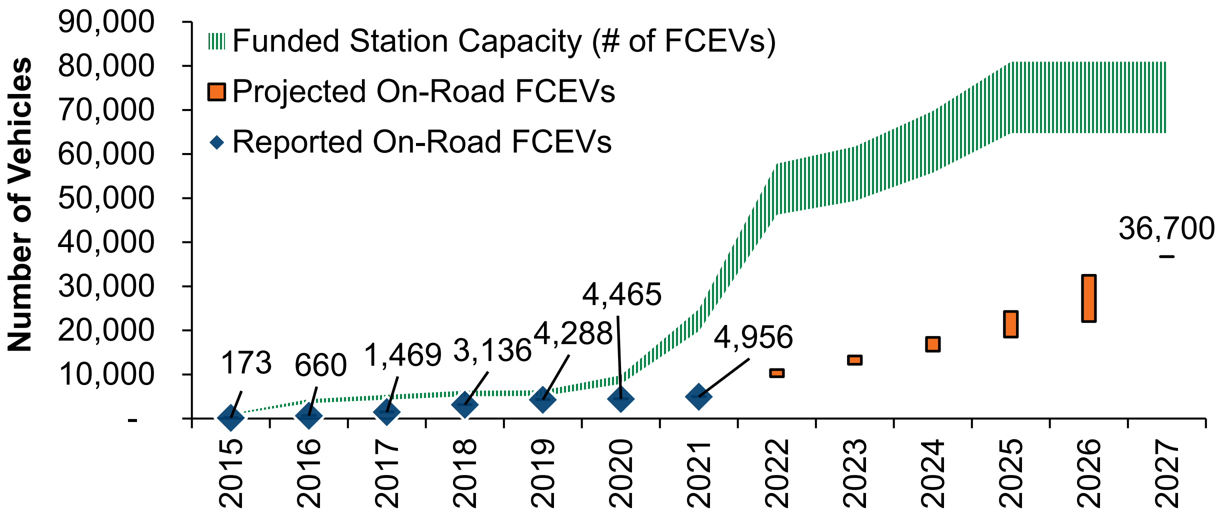
Figures 17 through 20 compare the estimated FCEV rollout, shown in Figure 14, to the estimated regional station deployment based solely on the network of stations with known locations. The orange bars in Figures 17 through 20 show the range of FCEVs projected from auto manufacturer surveys. The figures assume that stations will open according to station developers' timelines.

56 CARB assigned the proportion of projected vehicles based on the auto manufacturers survey responses to each county based on the proportion of network capacity among stations located within the county. This method assumed the regional distribution of FCEV deployment will closely follow the regional distribution of the fueling network.

The green lines in the figures indicate the estimated number of FCEVs that could be supported by a region's stations. The width of the green line represents the difference between using 100 percent of the station nameplate capacity to determine the number of FCEVs supported (the upper bound) and using 80 percent (the lower bound, representing a more sustainable level of fueling).

Figure 17 shows that the FCEV population in the Greater Los Angeles Area has largely followed capacity growth, increasing over time at a similar rate. Now, with the 2021 opening of several next-generation stations that provide greater capacity, the region has the potential to sustain accelerated FCEV deployment, with this potential growing even more in 2022 and beyond. This region, particularly in Los Angeles and Orange Counties, is poised to support 50,000 to 60,000 FCEVs by 2023, at least a tenfold increase from the nearly 5,000 FCEVs in the region as of April 2021.

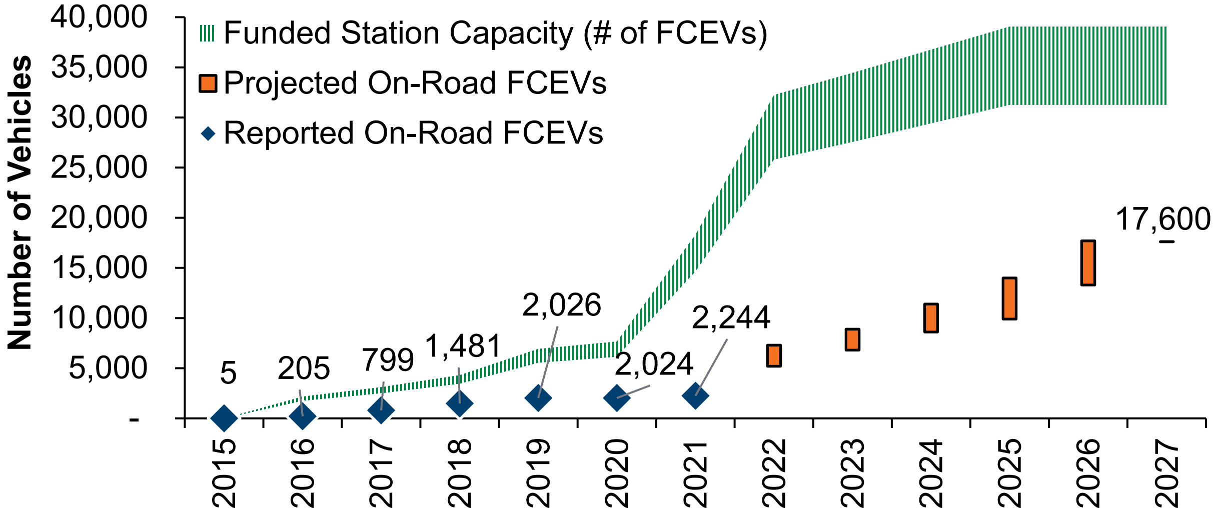
Figure 17: Greater Los Angeles Area Station Capacity and Number of Vehicles



Source: CEC

Figure 18 shows that the network capacity in the San Francisco Bay Area is maintaining a healthy amount of excess capacity to serve FCEVs. With a similar jump in network capacity expected in 2022 as in the Greater Los Angeles Area, the Bay Area should have capacity to serve 25,000 to 30,000 FCEVs. This is again a roughly tenfold increase from today's number.

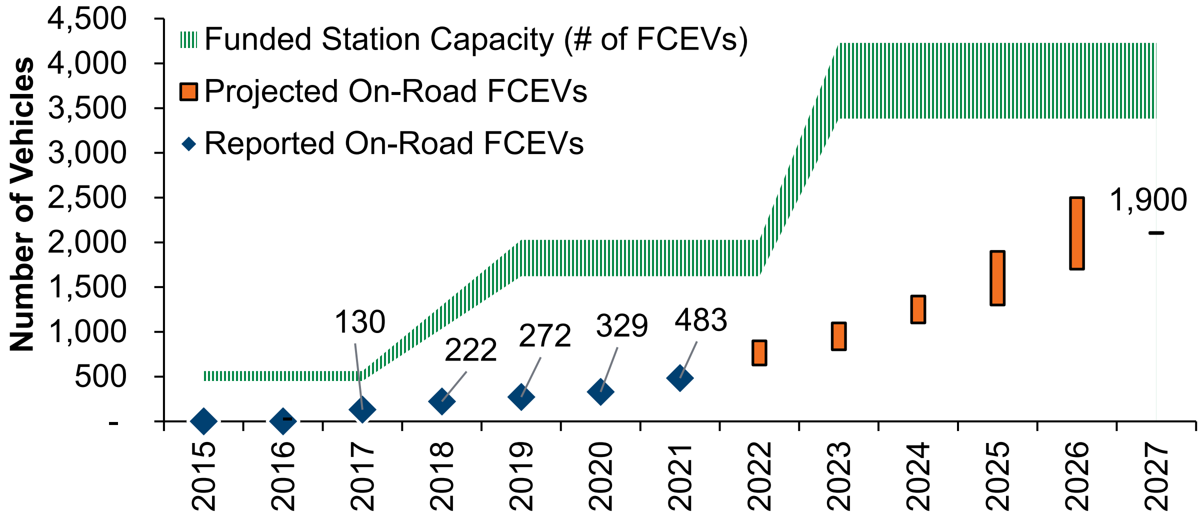
Figure 18: San Francisco Bay Area Station Capacity and Number of Vehicles



Source: CEC

Figure 19 shows that the current network capacity of the Sacramento region is enough to support existing FCEVs. The FCEV population in the region could triple before reaching station capacity. As new stations open in the 2023–2024 timeframe, the network will be able to support 3,000 to 4,000 FCEVs.

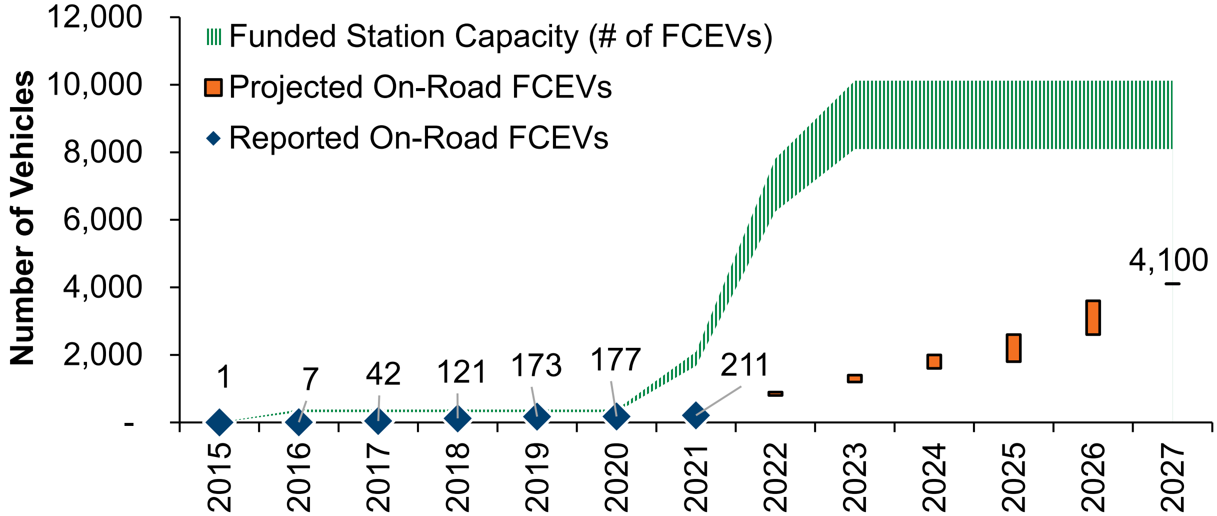
Figure 19: Sacramento Area Station Capacity and Number of Vehicles



Source: CEC

Figure 20 shows San Diego's network has been and continues to operate near capacity, which is 266 kilograms per day at one station near Del Mar. Another station opening is expected this year, which should relieve pressure on the existing station. A handful of new stations are planned for the region and should open in 2022 or 2023. After this point, the region will have more potential to grow.

Figure 20: San Diego Area Station Capacity and Number of Vehicles



Source: CEC

CHAPTER 6: Remaining Cost and Time Required to Establish a Network of 100 and 200 Hydrogen Refueling Stations

The CEC has spent about $166 million to support 90 stations funded by solicitations through the initial batch of GFO-19-602. Staff anticipates awarding another $12 million in public funds to achieve at least 100 hydrogen refueling stations by the end of 2023. The CEC's Clean Transportation Program will have invested nearly $279 million to fund and support more than 172 stations (including 16 to be privately funded under CEC agreement) by the end of the program, subject to future Clean Transportation Program appropriations and Clean Transportation Program Investment Plan allocations and combined with funding from the VW Mitigation Trust Fund.[57] In addition, the CEC intends to use the one-time funding from the California Budget 2021-2022 to help close the gap to 200 stations. Private investment has included nearly $92 million to match public-sector funding to date, and grant recipients have committed more than $99 million in additional match funding by the end of the most recent CEC grant agreements, making the total private investment about $191 million. The total reported public and private investment in hydrogen refueling stations is nearly $470 million; although, this figure may be higher because some private sector investment has not been reported.

The stations funded by the combined expended funds and planned investments will meet and exceed the 100-station goal set by AB 8. In fact, California is well on the way to nearly 200 stations being built and opened. Additional one-time funding in the California Budget Act of 2021-2022 will help close the gap to the 200-station goal. Figure 21 shows the total estimated stations resulting from the Clean Transportation Program and the VW Mitigation Trust Fund. The total estimated stations include 16 privately funded stations that are part of a CEC agreement with FirstElement Fuel. Figure 21 does not include the seven privately funded stations under development by Iwatani Corporation of America.

Other supportive policies, including the CARB LCFS HRI, contribute to the hydrogen refueling station network. Fifty-five stations have been approved to generate LCFS credits through the HRI provision.[58]

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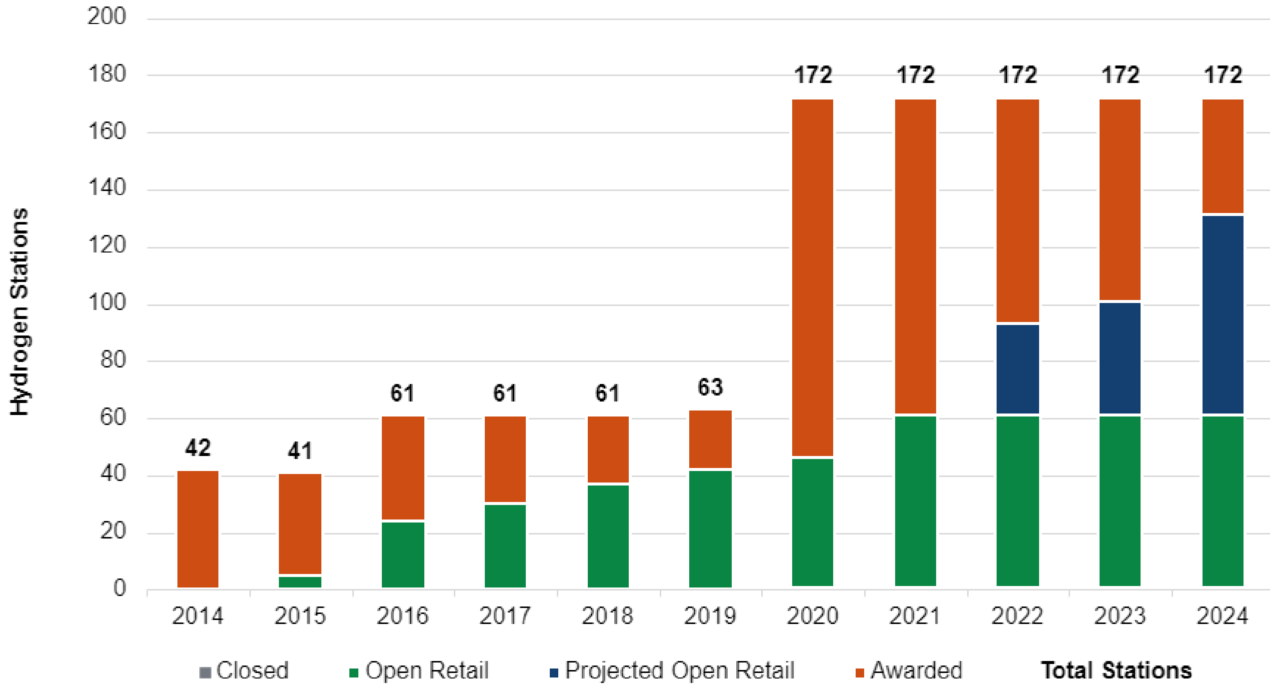
57 California Air Resources Board. Volkswagen Environmental Mitigation Trust for California. https://ww2.arb.ca.gov/our-work/programs/volkswagen-environmental-mitigation-trust-california.

58 California Air Resources Board. September 2021. *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf.

Figure 21: Quantity of Hydrogen Refueling Stations Resulting From the Clean Transportation Program and VW Mitigation Trust Fund



Source: CEC

CHAPTER 7: Conclusions

California is on track to meet the AB 8 goal of having at least 100 publicly available hydrogen refueling stations open for retail operations as early as 2023. Due to strong public/private partnerships, California is successfully launching a statewide, publicly available hydrogen network. California developed and opened 52 hydrogen refueling stations as of October 22, 2021. These stations have excess fueling capacity that is nearly triple today's demand needed by about 9,647 FCEVs in California. The hydrogen station network nameplate fueling capacity of today would also be sufficient to meet the 2024 projected demand of 30,800 FCEVs as reported in CARB's 2021 Annual Evaluation.

By 2027, the network of more than 179 projected stations will have the capability of serving about 245,000 FCEVs, nearly four times the 2027 projected 61,100, as reported in CARB's 2021 Annual Evaluation.

About 67 percent of California's residents who live in disadvantaged communities are within a 15-minute drive time of an open retail or planned hydrogen station. When the 200-station goal is met, potentially more hydrogen installations will be near or in disadvantaged communities.

Some of the early barriers to expeditious station completion — such as the time required to plan, site, and permit stations — are diminishing and affecting station development time less than they used to relative to earlier stations funded by the Clean Transportation Program, on a per station basis. However, general barriers, in addition to the location of infrastructure, to overall widespread FCEV commercialization and deployment remain.

These barriers include supply disruptions in the nascent industry of producing hydrogen for transportation, high hydrogen fuel and FCEV prices, hydrogen station downtime due to equipment failures and other factors, and the lack of vehicle models and consumer options. Studies also note the lack of consumer awareness. The need for a reliable hydrogen supply and reliable stations also presents a barrier to widespread FCEV commercialization and deployment, as does expanded geographic coverage of the stations. FCEV adoption may increase at a higher pace when these barriers are addressed. Additionally, expanded use of new and direct renewable resources for hydrogen production will help achieve the goal of a zero-carbon hydrogen future. Low to zero-carbon hydrogen is needed at volumes much larger than seen in today's market.

California continues to increase investments in medium- and heavy-duty fuel cell electric vehicles and hydrogen infrastructure. The CEC has invested nearly $40 million in medium- and heavy-duty hydrogen infrastructure. Further, the CEC will invest a large portion of the $1.165 billion ZEV Package funding to support electric and hydrogen medium- and heavy-duty vehicle infrastructure. In addition, developers plan as many as 13 stations already funded under the light-duty investment as multi-purpose stations to serve medium- and heavy-duty fuel cell vehicles.

When the CEC recently asked a series of questions to representatives of national governments and public agencies about fuel cell vehicle and hydrogen infrastructure markets, current investments, and future investments of foreign governmental representatives, staff learned of common interests on approaches to decarbonize the transportation sector. California together with China, Germany, Japan, and the Republic of Korea have funded nearly five hundred hydrogen refueling stations, including light-, medium-, and heavy-duty hydrogen refueling stations and deployed nearly 32,000 light-duty FCEVs and 8,000 medium and heavy-duty FCEVs. Through 2020, Germany has invested about $118 million in government funding, Japan has invested about $640 million, and the Republic of Korea has invested $199 million. The Chinese government has also invested by issuing a subsidy policy (ended in 2015) providing about $600,000 per station with local government subsidies ranging from about $150,000 to $460,000. Staff understands that China focuses their efforts to a greater extent on commercial vehicles, as compared with passenger vehicles.

Since 2010, the CEC’s Clean Transportation Program has invested nearly $166 million and will have invested nearly $279 million in hydrogen infrastructure by the end of the program. As a result, California is expected to meet the 100-station goal of AB 8 by the end of 2023. In addition, the state has an opportunity to help close the gap to the 200-station goal set forth by Executive Order B-48-18 with the one-time funding from the California Budget 2021-2022. The CEC and CARB intend to continue to jointly evaluate the FCEV market, identify metrics to inform potential future funding decisions, identify and address barriers beyond infrastructure fueling capacity, and examine various vehicle segments including light-, medium, and heavy-duty vehicle opportunities and market conditions.

GLOSSARY

California Hydrogen Infrastructure Tool (CHIT) — a geographical information system-based tool developed using ArcGIS software to assess the spatial distribution of the gaps between the coverage and capacity provided by existing and planned stations and the potential first adopter market for fuel cell electric vehicles.

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.

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 zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.

Greater Los Angeles Area — the counties of Los Angeles, Orange, Riverside, San Bernardino, and Ventura.

Hydrogen Refueling Infrastructure (HRI) credits — Low Carbon Fuel Standard (LCFS) credits that allow eligible hydrogen stations to generate infrastructure credits based on the capacity of the station minus the quantity of dispensed fuel.

Hydrogen Station Capacity Evaluation (HySCapE) model — a tool for verifying the dispensing capacity of a hydrogen refueling station, based on the Chevron profile. CARB uses HySCapE to verify station capacity for the LCFS HRI program, and the CEC used it to verify station capacity under GFO-19-602.

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

Nameplate capacity — Rated capacity, nominal capacity, installed capacity, or maximum effect, is the intended full-load sustained output of a hydrogen refueling station.

Sacramento Area — the counties of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba.

San Diego Area — the area of San Diego County.

San Francisco Bay Area — the counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma.

Temporarily non-operational (TNO) station — a hydrogen refueling station that has previously achieved open retail status but has been unavailable for customer fueling for an extended period of time for various reasons. A TNO station is expected to become available for customer fueling again in the future.

Zero-emission vehicle (ZEV) — a vehicle that emits no exhaust gas from the onboard source of power.

APPENDIX A: Hydrogen Refueling Stations in California

Table A-1[59] lists the 52 open retail hydrogen refueling stations (48 stations available for customer fueling and 4 TNO stations), with street address and open retail date. Table A-2 lists the stations in the process of becoming open retail. Real-time status is available to drivers via the Station Operational Status System maintained by the California Fuel Cell Partnership and accessible at the website, https://m.cafcp.org.

Table A-1: Open Retail and Temporarily Nonoperational Stations Resulting From Clean Transportation Program Investments and Private Sector Investments

Station Address (A to Z by city)	Open Retail Date
2618 La Paz Road, Aliso Viejo, CA 92656	6/22/2021
3731 East La Palma Avenue, Anaheim, CA 92806	11/29/2016
1250 University Avenue, Berkeley, CA 94702	1/12/2021
337 E. Hamilton Avenue, Campbell, CA 95008	5/24/2021
2855 Winchester Boulevard, Campbell, CA 95008	6/9/2016
6141 Greenback Lane, Citrus Heights, CA 95621	12/18/2018
24505 West Dorris Avenue, Coalinga, CA 93210	12/11/2015
605 Contra Costa Boulevard, Concord, CA 94523	5/28/2021
2050 Harbor Boulevard, Costa Mesa, CA 92627	1/21/2016
21865 East Copley Drive, Diamond Bar, CA 91765	8/18/2015
1172 45th Street, Emeryville, CA 94608	11/19/2018
18480 Brookhurst Street, Fountain Valley, CA 92708	7/6/2020
41700 Grimmer Boulevard, Fremont, CA 94538	9/7/2017
391 West A Street, Hayward, CA 94541	4/27/2016
19172 Jamboree Road, Irvine, CA 92612[60]	11/12/2015
550 Foothill Boulevard, La Cañada Flintridge, CA 91011	1/25/2016
20731 Lake Forest Drive, Lake Forest, CA 92630	3/18/2016
15606 Inglewood Avenue, Lawndale, CA 90260	6/22/2017
3401 Long Beach Boulevard, Long Beach, CA 90807	2/22/2016
10400 Aviation Boulevard, Los Angeles, CA 90045	12/21/2018
5151 State University Drive, Los Angeles, CA 90032	11/20/2019
5700 Hollywood Boulevard, Los Angeles, CA 90028	11/10/2016
7751 Beverly Boulevard, Los Angeles, CA 90036	5/2/2016
8126 Lincoln Boulevard, Los Angeles, CA 90045	8/18/2016
570 Redwood Highway, Mill Valley, CA 94941	6/16/2016

59 This list does not include a station in West Los Angeles that opened but closed.

60 The new station will be located at the intersection of California Avenue and Academy Way on the UCI campus in Irvine (Orange County).

Station Address (A to Z by city)	Open Retail Date
15544 San Fernando Mission Boulevard, Mission Hills, CA 91345	10/26/2020
830 Leong Drive, Mountain View, CA 94043	2/28/2018
350 Grand Avenue, Oakland, CA 94610	9/20/2019
1850 E. Holt Boulevard, Ontario, CA 91761	4/24/2018
3601 El Camino Real, Palo Alto, CA 94306	12/20/2018
313 West Orangethorpe Avenue, Placentia, CA 92870	5/7/2021
8095 Lincoln Avenue, Riverside, CA 92504	3/8/2017
3510 Fair Oaks Boulevard, Sacramento, CA 95864	5/22/2019
3060 Carmel Valley Road, San Diego, CA 92130	12/2/2016
1201 Harrison Street, San Francisco, CA 94103	12/2/2019
3550 Mission Street, San Francisco, CA 94110	2/14/2020
551 Third Street, San Francisco, CA 94107	11/6/2019
2101 North First Street, San Jose, CA 95131	1/15/2016
26572 Junipero Serra Road, San Juan Capistrano, CA 92675	12/23/2015
4475 Norris Canyon Road, San Ramon, CA 94583	7/26/2017
150 South La Cumbre Road, Santa Barbara, CA 93105	4/9/2016
1819 Cloverfield Boulevard, Santa Monica, CA 90404	2/1/2016
12600 Saratoga Avenue, Saratoga, CA 95070	3/14/2016
1200 Fair Oaks Avenue, South Pasadena, CA 91030	4/10/2017
248 South Airport Boulevard, South San Francisco, CA 94080	2/12/2016
3780 Cahuenga Boulevard, Studio City, CA 91604	4/26/2021
1296 Sunnyvale Saratoga Road, Sunnyvale, CA 94087	2/11/2021
3102 Thousand Oaks Boulevard, Thousand Oaks, CA 91362	3/30/2018
2051 West 190th Street, Torrance, CA 90501	8/18/2017
12105 Donner Pass Road, Truckee, CA 96161	6/17/2016
1515 South River Road, West Sacramento, CA 95691	7/7/2015
5314 Topanga Canyon Road, Woodland Hills, CA 91364	10/5/2016

Source: CEC

Table A-2 lists the locations of stations resulting from CEC agreements, under the Clean Transportation Program, in planning, permitting, or under construction. The stations are listed in alphabetical order by city. Also provided is the CEC solicitation or contract under which the station received funding.

Table A-2: Stations Resulting From Clean Transportation Program in Development in Planning, Permitting, or Under Construction

Station Address (A to Z by city)	Solicitation or Contract
102 East Duarte Road, Arcadia, CA 91006	GFO-19-602
17325 Pioneer Boulevard, Artesia, CA 90701	GFO-19-602
14477 Merced Avenue, Baldwin Park, CA 91706	GFO-19-602
6392 Beach Boulevard, Buena Park, CA 90621	GFO-19-602
145 W. Verdugo Avenue, Burbank, CA 91502	600-12-018
800 North Hollywood Way, Burbank, CA 91505	GFO-19-602
2911 Petit Street, Camarillo, CA 93012	GFO-19-602
7170 Avenida Encinas, Carlsbad, CA 92011	GFO-19-602
12610 East End Avenue, Chino, CA 91710	PON-12-606
2600 Pellissier Place, City of Industry, CA 90601	GFO-19-602
2995 Bristol Street, Costa Mesa, CA 92626	GFO-19-602
11284 Venice Boulevard, Culver City, CA 90230	GFO-15-605
21530 Stevens Creek Boulevard, Cupertino, CA 95014	GFO-19-602
3160 Carlson Boulevard, El Cerrito, CA 94530	GFO-19-602
13397 Folsom Boulevard, Folsom, CA 95630	GFO-19-602
16880 Slover Avenue, Fontana, CA 92337	GFO-19-602
47700 Warm Springs Boulevard, Fremont, CA 94539	GFO-19-602
3402 Foothill Boulevard, Glendale, CA 91214	GFO-19-602
104 North Coast Highway, Laguna Beach, CA 92651	GFO-15-605
2589 North Lakewood Boulevard, Long Beach, CA 90815	GFO-19-602
988 North San Antonio Road, Los Altos, CA 94022	GFO-19-602
5164 West Washington Boulevard, Los Angeles, CA 90016	GFO-19-602
666 North Santa Cruz Avenue, Los Gatos, CA 95030	GFO-19-602
705 West Huntington Drive, Monrovia, CA 91016	GFO-19-602
1600 Jamboree Boulevard, Newport Beach, CA 92660	GFO-19-602
5821 Nave Drive, Novato, CA 94949	GFO-19-602
4280 Foothill Boulevard, Oakland, CA 94601	GFO-19-602
2160 South Euclid Avenue, Ontario, CA 91762	GFO-19-602
615 South Tustin Street, Orange, CA 92866	GFO-19-602
67 Moraga Way, Orinda, CA 94563	GFO-19-602
290 South Arroyo Parkway, Pasadena, CA 91105	GFO-19-602

Station Address (A to Z by city)	Solicitation or Contract
475 North Allen Avenue, Pasadena, CA 91106	GFO-19-602
28103 Hawthorne Boulevard, Rancho Palos Verdes, CA 90275	PON-09-608
503 Whipple Avenue, Redwood City, CA 94063	GFO-15-605
3505 Central Avenue, Riverside, CA 92506	GFO-19-602
5551 Martin Luther King Jr. Boulevard, Sacramento, CA 95820	GFO-19-602
1930 South Waterman Avenue, San Bernardino, CA 92408	GFO-19-602
11030 Rancho Carmel Drive, San Diego, CA 92128	GFO-19-602
1666 1st Avenue, San Diego, CA 92101	GFO-19-602
1832 West Washington Street, San Diego, CA 92103	GFO-19-602
5494 Mission Center Road, San Diego, CA 92108	GFO-15-605
1110 West Gladstone Street, San Dimas, CA 91773	GFO-19-602
101 Bernal Road, San Jose, CA 95119	GFO-15-605
3939 Snell Avenue, San Jose, CA 95136	GFO-19-602
510 East Santa Clara Street, San Jose, CA 95112	GFO-19-602
24551 Lyons Avenue, Santa Clarita, CA 91321	PON-09-608
266 College Avenue, Santa Rosa, CA 95401	GFO-19-602
14478 Ventura Boulevard, Sherman Oaks, CA 91423	GFO-15-605
10908 Roscoe Boulevard, Sun Valley, CA 91352	GFO-19-602
24505 Hawthorne Boulevard, Torrance, CA 90505	GFO-19-602
14244 Newport Avenue, Tustin, CA 92780	GFO-19-602
15710 Roscoe Boulevard, Van Nuys, CA 91406	GFO-19-602
2121 Harbor Boulevard, Ventura, CA 93001	GFO-19-602
17287 Skyline Boulevard, Woodside, CA 94062	PON-13-607

Source: CEC

APPENDIX B: Changes in the Planned Network

Since 2017, the planned network changed due to new funding solicitations, station replacements, stations that did not reach completion, and station closures. Table B-1 shows the changes in the planned network resulting from CEC agreements funded by the Clean Transportation Program and the associated number of FCEVs that could be supported. The 50 stations shown in the first row for 2017 were funded under solicitations and contracts before GFO-15-605 and GFO-19-602.

Table B-1: Changes in the Planned Station Network Since 2017

Year	Description	Number of Stations in the Planned Network	Number of FCEVs That Could be Supported
2017	Clean Transportation Program provided Operations and Maintenance funds to CARB-funded CSULA station (60 kg/day), so the station was added to the collection of Clean Transportation Program-funded stations.	50	13,000
2017	The stations planned for Encinitas (180 kg/day), Foster City (350 kg/day), and Los Altos (350 kg/day) were canceled because of lack of clear path to completion, and they were removed from the list of Clean Transportation Program-funded stations.	47	12,000
2017	Sixteen new stations were approved under GFO-15-605 (5,180 kg/day) and added to the list of Clean Transportation Program-funded stations.	63	20,000
2017	Three HyGen Industries stations (130 kg/day each) were addressed at the October 2017 CEC Business Meeting and removed from the list of Clean Transportation Program-funded stations.	60	19,000
2017	Five additional stations (1,600 kg/day) were proposed for funding under GFO-15-605 and added to the list of Clean Transportation Program-funded stations.	65	21,000

Year	Description	Number of Stations in the Planned Network	Number of FCEVs That Could be Supported
2018	FirstElement upgraded 12 stations from 310 kg/day to 500 kg/day liquid technology (+2,280 kg) and the Air Liquide Anaheim station capacity was adjusted in reporting from 100 kg to 180 kg to reflect more realistic operations.	65	25,000
2018	One of the five additional stations proposed for funding under GFO-15-605 did not move forward (360 kg/day) and was removed from the list of Clean Transportation Program-funded stations.	64	24,000
2019	Mobile refueler project (45 kg/day) and Santa Nella (180 kg/day) station ended without completion and were removed from the list of Clean Transportation Program-funded stations.	62	24,000
2019	Station capacities were updated with the numbers reported to the CARB LCFS Hydrogen Refueling Infrastructure (HRI) credit program.[61]	62	35,000
2020	Two more stations (Concord and Redwood City) were approved for HRI credits and station capacities were updated, each using the numbers reported to the HRI credit program. (+1,400 kg/day)	62	37,000
2020	West Los Angeles station (180 kg/day) closed.	61	36,000
2020	30 new stations were approved at the CEC business meeting in December. One of these stations is an upgrade to the station at Torrance.[62]	90	98,000
2021	The station capacities were adjusted using the latest LCFS HRI approved capacities.	90	101,000

Source: CEC

61 California Air Resources Board. "LCFS ZEV Infrastructure Crediting." https://ww3.arb.ca.gov/fuels/lcfs/electricity/zev_infrastructure/zev_infrastructure.htm.

62 The 2020 Joint Report erroneously reported the Torrance upgrade as a new station. However, this error does not affect the total number count of 179 stations.

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