California Energy Commission

California Air Resources Board

# Joint Agency Staff Report on Assembly Bill 8: 2019 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California

**Gavin Newsom, Governor**

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# California Energy Commission



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# ABSTRACT

The *Joint Agency Staff Report on Assembly Bill 8: 2019 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 and California Resources Board 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 2019 Joint Report contains time and cost assessments for the network of publicly available hydrogen refueling stations to support the fuel cell electric vehicle market under the California Energy Commission's Clean Transportation Program, formerly known as Alternative and Renewable Fuel and Vehicle Technology Program.

As of December 27, 2019, California's network of 43 open retail hydrogen refueling stations is capable of dispensing more than 11,800 kilograms of hydrogen each day, enough to support nearly 17,000 light-duty fuel cell electric vehicles with typical use of 0.7 kilograms per day per vehicle. Another 20 stations are in development to become open retail in California. The fueling capacity of this network, once all stations are open, will be nearly 24,500 kilograms per day, enough to support nearly 35,000 fuel cell electric vehicles. The network of these 63 stations meet nearly two-thirds of the Assembly Bill 8 goal of at least 100 publicly available hydrogen refueling stations.

California has nearly 7,000 fuel cell electric vehicles on its roads today, compared with 5,000 last year. Based on industry surveys, the California Air Resources Board projects there will be 48,000 fuel cell electric vehicles by 2025, which would cut global warming emissions by nearly 109,670 metric tons of carbon dioxide equivalent per year in 2025.

The Clean Transportation Program has invested nearly $120 million since 2010 to fund hydrogen refueling stations to support the fuel cell electric vehicle market. The Clean Transportation Program will continue to allocate $20 million per year until there are at least 100 publicly available hydrogen refueling stations in California, per the requirements of Assembly Bill 8. These investments also support the goal of having 200 hydrogen stations by 2025, which was established by Governor Edmund G. Brown Jr. Executive Order B-48-18.

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

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# EXECUTIVE SUMMARY

The *Joint Agency Staff Report on Assembly Bill 8: 2019 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2019 Joint Report) describes the investment, planning, development, and deployment of hydrogen refueling stations to provide hydrogen to fuel cell electric vehicles (FCEVs). Assembly Bill (AB) 8 (Perea, Chapter 401, Statutes of 2013) 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 hydrogen refueling stations until there are at least 100 publicly available stations in California.

**KEY TAKEAWAYS**

- **There are 43 open retail hydrogen refueling stations that sell hydrogen as a transportation fuel and are publicly available.**
- **Another 20 stations are funded and under development.**
- **CARB projects 48,000 FCEVs by 2025.**
- **CARB analysis of DMV data indicates 6,826 FCEVs sold or leased in California as of October 2019, a growth of 36 percent since October 2018.**

In 2019, four new hydrogen refueling stations supported with Clean Transportation Program funds opened. That brings the total number of open hydrogen refueling stations in California to 43. Another 20 stations are funded and under development.

More than 23 percent of disadvantaged community residents are within a 15-minute drive of an open retail hydrogen refueling station. About 35 percent of disadvantaged community residents live within a 15-minute drive of a funded station, whether open retail or planned. By working with diverse stakeholders, the CEC is striving to continuously improve the investment of Clean Transportation Program funds in projects that will effectively benefit disadvantaged communities.

AB 8 requires the California Air Resources Board (CARB) to aggregate and make available to the public the number of FCEVs that auto manufacturers project to be sold or leased over the next three years and the total number of FCEVs registered with the California Department of Motor Vehicles (DMV). As of October 1, 2019, CARB analysis of data provided by DMV indicates that 6,826 FCEVs are registered in California, up 36 percent since October 2018. Industry data show 7,883 FCEVs sold or leased in the United States as of December 1, 2019, and this number is a close proxy for the number of FCEVs in California because there are few FCEVs in other states. The latest auto manufacturer survey, administered and analyzed by CARB, anticipates 48,000 FCEVs in California by 2025. Assuming FCEVs grow according to these survey results, the estimated greenhouse gas emissions reductions from these vehicles fueling at the existing hydrogen refueling station network is nearly 109,670 metric tons of carbon dioxide equivalent per year by 2025.

California needs more hydrogen fueling capacity to support the anticipated numbers of FCEVs in the years to come. The network capacity of the 43 open retail stations is more than 11,800 kilograms per day. Considering the entire funded network of 63 stations that are either open or under development, the capacity is nearly 24,500 kilograms per day. The vehicle projections from the auto manufacturer survey will require another 10,000 kilograms of daily capacity by 2025 at minimum. Ideally, the station network will far exceed this capacity by 2025 to allow unfettered statewide growth in the number of FCEVs and commensurate reduction in the number of internal combustion engine vehicles in California. Released on December 26, 2019, GFO-19-602 stands to fund the deployment of the necessary hydrogen refueling infrastructure to allow for the acceleration of FCEV deployment such that these vehicles can provide significant emissions reductions and help achieve the goal of having 5 million zero-emission vehicles in California by 2030 (established in Governor Edmund G. Brown Jr. Executive Order B-48-18).

This year marked the beginning of the Low Carbon Fuel Standard Hydrogen Refueling Infrastructure credit program. CARB has approved 48 stations to participate in the program thus far. The program encouraged several hydrogen refueling station operators to increase the renewable hydrogen content of their fuel to increase the potential to earn more credits. The CARB *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development* reported that the funded station network will dispense hydrogen with 39 percent renewable content sourcing, based on information available as of June 2019. Since that time, some station operators have secured new hydrogen feedstock sources that will provide 100 percent renewable hydrogen. These new agreements demonstrate that, once station operators are able to secure renewable hydrogen feedstock sources, the percentage of dispensed hydrogen that is renewable can increase nearly instantaneously. Furthermore, this increase in renewable content comes at no additional infrastructure cost to the state.

While the station network, renewable content, and number of FCEVs grew in 2019, the hydrogen station network experienced a setback that constrained this growth. From early June to early October, the plant that is the source of hydrogen fuel for most Northern California stations went offline. This disruption resulted in limited hydrogen supply and led to several Northern California stations temporarily closing because of lack of fuel. Station operators worked diligently to minimize the effect of the fuel shortage, and FCEV auto manufacturers provided valuable support and incentives to alleviate the inconvenience to FCEV drivers when they could not refuel their vehicles, including complimentary rental vehicles. These actions of auto manufacturers and station operators were vital to maintaining FCEV driver confidence in the future of hydrogen transport and are enabling recovery to normalcy as 2019 closes.

The hydrogen supply disruption temporarily halted the continued growth in hydrogen dispensing by the station network, and slowed the completion of several new stations because of lack of fuel to conduct final testing. Disruptions of this nature likely have a negative impact on consumer acceptance of FCEVs and could slow the deployment of vehicles if more should occur, as auto manufactures may be reluctant to put more vehicles into an unstable market.

The supply disruption exposed issues that stakeholders are addressing that should ultimately lead to a stronger, more resilient system. The CEC has developed more comprehensive requirements for hydrogen supply agreements under grant funding opportunity GFO-19-602. Public and private stakeholders are placing additional attention and resources into hydrogen production plant development and hydrogen delivery infrastructure.

In 2019, positive trends continue in the areas of station cost and development time. Overall, the CEC cost per kilogram of station capacity is decreasing. One reason for the decrease is that some station developers opted to add components, efficiency, and new designs and technology to increase station capacity, in some cases quadrupling planned station size. Station developers continue to build the most recently funded stations more quickly than the stations funded by earlier solicitations. For example, developers spent nearly 65 percent less time before filing initial permit applications compared with stations funded in 2013.

The 2019 Joint Report also discusses related projects funded by the Clean Transportation Program, the CARB California Climate Investments Program, and other sources, including renewable hydrogen production plant projects and fuel cell bus and truck projects. All these projects are expanding the use of hydrogen as a transportation fuel. The complementary advancement of fuel cell electric and battery electric technology is enabling California to find suitable zero-emission replacements for more vehicle types and duty cycles.

Hydrogen fuel cells are particularly applicable to heavy-duty applications and long-distance and high-utilization applications. For instance, FCEVs offer advantages to taxi and ride-hailing drivers who want to be able to drive as far as a customer wants to go, and to refuel quickly to minimize time out of service. Having FCEVs used by drivers of ride-hailing companies could be especially important because these services contribute to increased vehicle miles traveled (VMT) for individual trips, therefore potentially increasing overall VMT and emissions from the transportation sector at a time when they need to decrease. FCEVs could effectively convert these VMT to electric VMT and eliminate the tailpipe emissions from those miles driven.

This idea of using FCEVs in ride-hailing is one example of how transportation electrification could serve a particular market need while reducing emissions. The CEC and CARB, in discussion with the private sector, are investigating how to best enable these kinds of zero-emission solutions for the myriad transportation needs of Californians. Finding and implementing such solutions are key to combating climate change and reducing air pollution.

At the end of 2019, with the release of GFO-19-602, there is potential for significant growth in hydrogen refueling station development in the coming years. The CEC incorporated feedback from stakeholders to structure the solicitation to enable economies of scale and cost reduction in station design and equipment procurement. With funding award announcements from the solicitation expected in the first half of 2020, additional stations will be under development soon and the CEC will be able to assess its success in reducing costs.

Current law requires the CEC to invest $20 million per year until there are at least 100 publicly available hydrogen refueling stations in operation in California. The continued cooperation among the CEC, CARB, other public agency partners, and private industry is positioning California to reach this milestone. The Clean Transportation Program funding will support industry in scaling up the necessary supply chains and to reduce cost, and to keep hydrogen refueling station development and operation on the path toward a self-sustaining market.

# CHAPTER 1: Introduction

Assembly Bill (AB) 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program (formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program).[1] AB 8 (Perea, Chapter 401, Statutes of 2013) reauthorized the Clean Transportation Program until January 1, 2024, and directs 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 an annual review and reporting by the CEC and California Air Resources Board (CARB). The *Joint Agency Staff Report on Assembly Bill 8: 2019 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2019 Joint Report) is the fifth such annual report. Table 1 shows how the hydrogen refueling network has changed over time. The growth is substantive; at the time that the CEC and CARB published the first joint report in 2015, there were six open retail stations.[3] Today, there are 43.[4] California continues to make progress in supporting stations that are convenient to residents of disadvantaged communities and having consumers choose to drive FCEVs, which in turn increases station usage and the amount of hydrogen dispensed.

**Table 1: Hydrogen Refueling Network Growth**

| Year-to-Year Growth | 2016 | 2017 | 2018 | 2019[5] |
|---|---|---|---|---|
| Percentage of disadvantaged community population within 15-minutes of an open retail station | 12.8% | 18.6% | 23.0% | 23.3% |
| Number of open retail stations | 25 | 31 | 39 | 43 |
| Average daily hydrogen dispensed (fueling demand) | 280 kg | 1,200 kg | 2,600 kg | 3,300 kg |
| Passenger FCEVs in California based on CARB analysis of DMV data (as of October of each year) | 925 | 2,473 | 5,014 | 6,826 |

Source: CEC

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 Open retail stations are "publicly available hydrogen-fueling stations" as defined in AB 8.

4 Of the 64 stations funded with CEC and CARB funds, 2 cancelled, bringing the count to 62. Of the 62 stations, 42 are open retail. A private company funded 1 station, bringing the total number of open retail stations to 43.

5 The dispensing average for 2019 is only for the first three quarters of 2019 (January 1 – September 30). The dispensing amount was restricted by a hydrogen supply disruption that began in June 2019.

Governor Edmund G. Brown Jr. Executive Order B-16-12 directed state agencies to promote the rapid commercialization of zero emission vehicles (ZEVs), set a target for the number of ZEVs in California by 2025 at 1.5 million, and set a greenhouse gas (GHG) emissions reduction target for 2050 from the transportation sector equaling 80 percent less than 1990 levels.[6] On January 25, 2018, Governor Edmund G. Brown Jr. Executive Order B-48-18 established goals of achieving 200 hydrogen stations by 2025 and 5 million ZEVs in California by 2030.[7]

The CEC released a grant funding opportunity, GFO-19-602, offering up to $115.7 million in funding, on December 26, 2019. With this solicitation, the CEC anticipates meeting the AB 8 goal of at least 100 publicly available stations and setting a direction towards the 200-station goal from Executive Order B-48-18.[8]

The CEC Clean Transportation Program and CARB program staffs collaborate with many experts to plan hydrogen refueling infrastructure, 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 Sacramento Metropolitan Air Quality Management District (SMAQMD).[9]
- 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 the Pacific Northwest National Laboratory (PNNL) Hydrogen Safety Panel (HSP).
- Industry stakeholder groups, including the California Fuel Cell Partnership (CaFCP), the California Hydrogen Business Council, SAE International, and the CSA Group.

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

- Listservers: https://ww2.energy.ca.gov/listservers/index_cms.html
- Workshop Notices: https://ww2.energy.ca.gov/altfuels/notices/
- Solicitations: https://www.energy.ca.gov/funding-opportunities/solicitations

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

7 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.

8 California Energy Commission. December 2019. GFO-19-602 – Hydrogen Refueling Infrastructure. https://www.energy.ca.gov/solicitations/2019-12/gfo-19-602-hydrogen-refueling-infrastructure.

9 Through 2019, SCAQMD provided more than $14 million and BAAQMD nearly $2 million. During its August 2019 workshop, the SMAQMD announced it is investigating using local funds to support public access light-duty hydrogen stations in disadvantaged communities and public hydrogen truck stops in the Sacramento region.

This report continues with analyses for the coverage and capacity of the hydrogen refueling station network, the cost and time it is taking to develop stations, and the current and future projections of FCEVs and station implementation in California. The report summarizes important industry developments in 2019, including a fuel shortage that limited the refueling of FCEVs in Northern California. The CEC and CARB review the year's fueling trends and describe other hydrogen and fuel cell projects that are expanding the potential for fuel cell electric vehicles, including buses and trucks, to serve multiple functions in the transition to a zero-emission transportation system.

## New Station Ownership

This year marked the first occasion in which new owners assumed operation of existing hydrogen refueling stations. Iwatani Corporation of America (Iwatani) acquired four hydrogen refueling stations that were previously owned by Messer (formerly Linde, LLC). The four stations are in Mountain View, San Juan Capistrano, San Ramon, and West Sacramento. Iwatani operates more than 20 hydrogen refueling stations in Japan and the company's entrance into the California market is a positive indicator of growing interest and competition in station development and operation here. Iwatani celebrated its acquisition of stations in California with a grand re-opening and ribbon-cutting ceremony on May 16, 2019, at the West Sacramento station. The photograph in Figure 1 shows Mr. Akiji Makino, Chairman and Chief Executive Officer of Iwatani Corporation, with CEC Commissioner Patty Monahan and West Sacramento City Manager Aaron Laurel, who participated in the event.

**Figure 1: West Sacramento Station Ribbon-Cutting Ceremony**


Source: California Fuel Cell Partnership

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

The coverage and capacity of the hydrogen refueling station network available to the public increased this year when four more stations became open retail, increasing total open retail station capacity to more than 11,800 kilograms per day. The stations that opened this year are located on Fair Oaks Boulevard in Sacramento, Grand Avenue in Oakland, and Harrison Street and Third Street in San Francisco.

FCEV drivers can expect increased coverage and capacity from five more stations that station developers anticipate becoming open retail in early 2020. These stations include an electrolysis station in Woodside, two liquid hydrogen stations on Saratoga-Sunnyvale Road in Sunnyvale and East Hamilton Avenue in Campbell, and two gaseous stations on Mission Street in San Francisco and University Avenue in Berkeley.

When the funded network of 63 stations are all open, the network capacity will be nearly 24,500 kilograms per day.

## The Coverage of the Hydrogen Refueling Station Network

The maps in Figures 2, 3, and 4 show the locations of the 63 stations in California's network. Of the 63 stations, 43 are open retail, 19 are planned (meaning they are in a phase of planning and development to become open retail), and 1 is a legacy retail station at California State University, Los Angeles (CSULA).[10] Of the network of 63 stations, 9 open retail stations and 2 planned stations are in disadvantaged communities.[11]

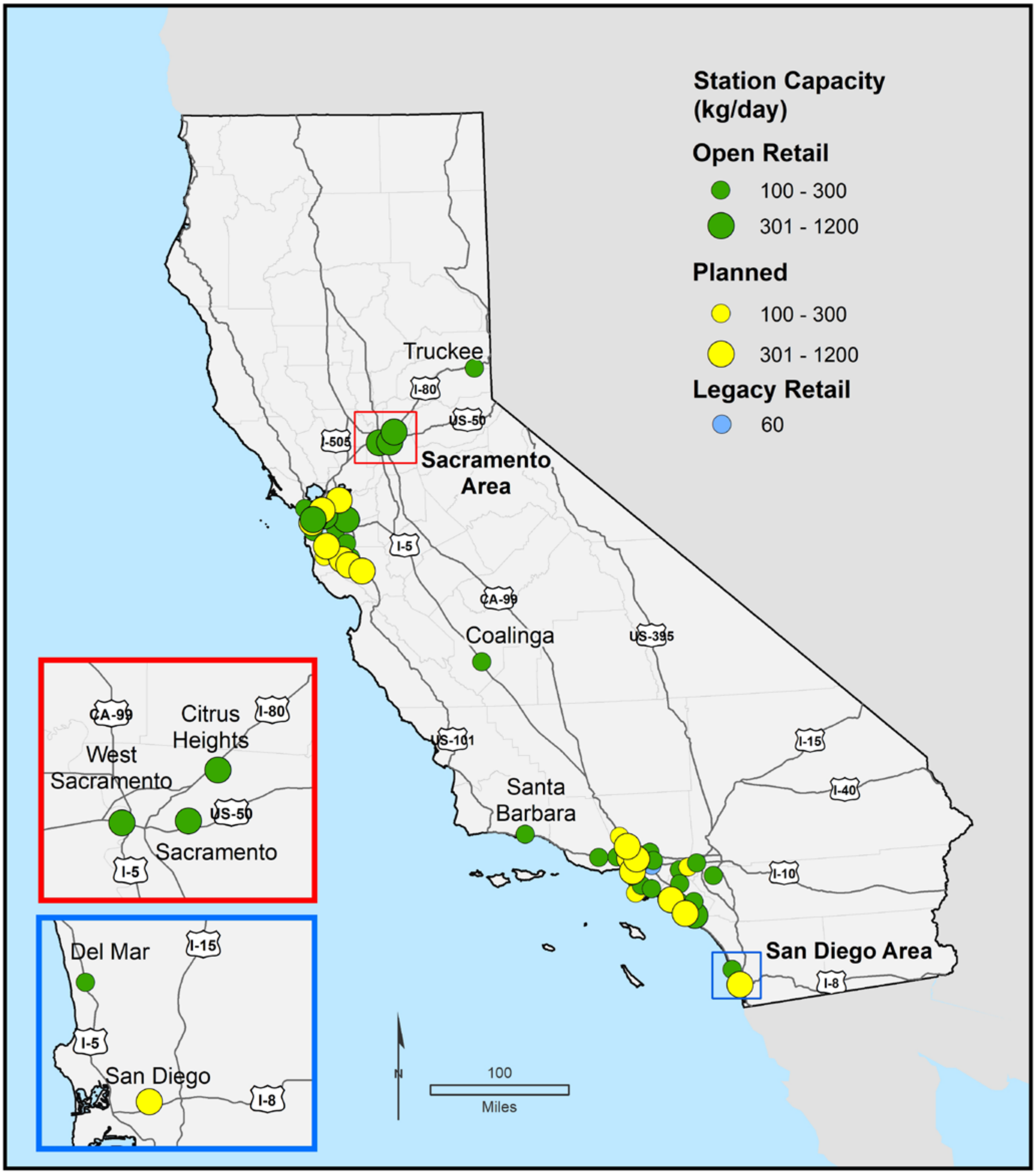
All of the stations received capital expense grants or contracts from either the CEC Clean Transportation Program or CARB with the exception of the station in Newport Beach, which the private sector funded to make open retail. Counting Newport Beach, the open retail station count is 43. In 2019, the Santa Nella station project was cancelled and the mobile refueler project ended without completion.

Figure 2 is a statewide map of the open retail and planned stations. Figures 3 and 4 show the station network in the San Francisco Bay Area and the Greater Los Angeles Area, respectively, and the station placement in relation to disadvantaged communities shown in blue.

10 CSULA is categorized as "legacy retail," meaning the station has served select FCEVs but does not meet the standards of being open retail. For the formal definition of open retail, see: California Air Resources Board. July 2019. *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development.* https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2019_print.pdf, Appendix E.

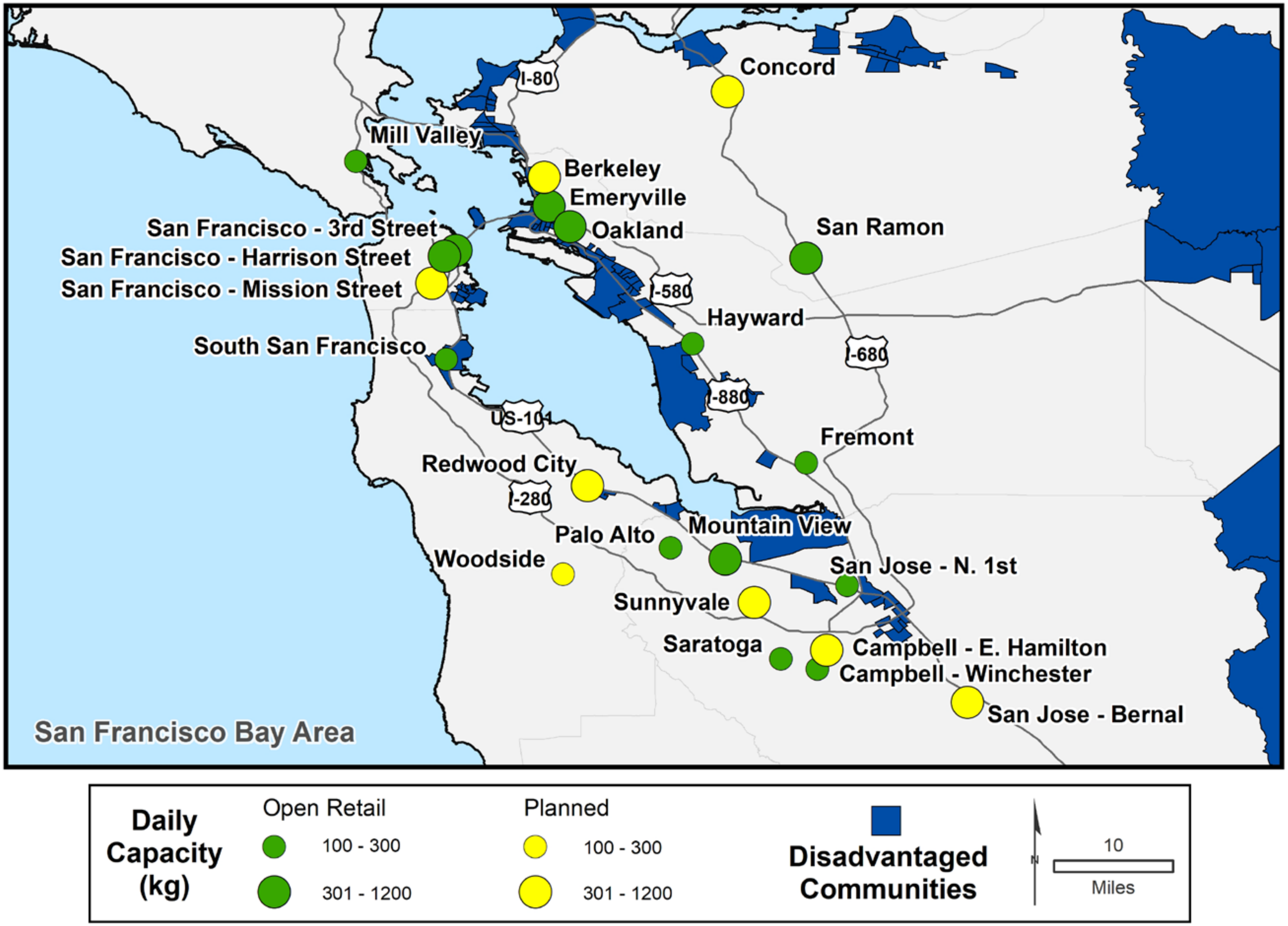
11 The 2018 Joint Report stated 12 stations are in disadvantaged communities. One station that was in a disadvantaged community was cancelled; therefore, the total is now 11 stations.

**Figure 2: Hydrogen Refueling Stations in California**



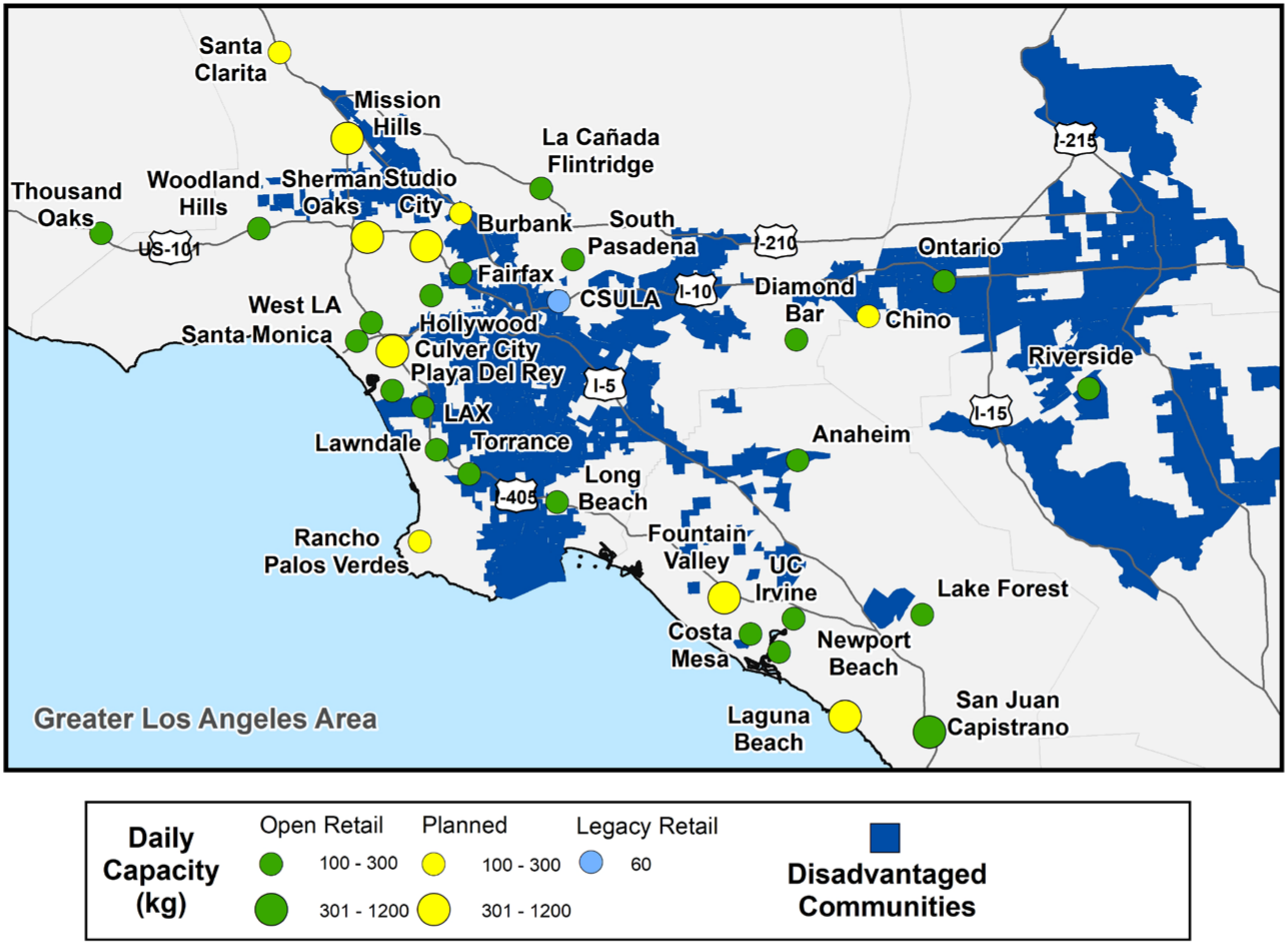

Source: CEC

**Figure 3: Hydrogen Refueling Stations in the San Francisco Bay Area**




Source: CEC

**Figure 4: Hydrogen Refueling Stations in the Greater Los Angeles Area**




Source: CEC

## Station Placement in and Near Disadvantaged Communities

Consistent with Senate Bill (SB) 350, The Clean Energy and Pollution Reduction Act of 2015 (De León, Chapter 547, Statutes of 2015)[12] and CARB's guidance to provide access to clean transportation to individuals in disadvantaged communities,[13] the CEC continues to emphasize the importance of serving disadvantaged communities in its solicitations. CARB's *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development* (2019 Annual Evaluation) shows that about 35 percent of the disadvantaged community population lives within the 15-minute extent of coverage provided by the funded hydrogen refueling network.[14] More than 23 percent of disadvantaged community residents are within 15-minutes of an open retail station.

The disadvantaged community population living within 15 minutes of a hydrogen refueling station is likely to increase significantly because GFO-19-602 requires applicants to propose at least one station in a disadvantaged community per application.[15] The solicitation also encourages station developers to choose projects that provide employment and air quality benefits to disadvantaged communities. By working with diverse stakeholders, the CEC is striving to continuously improve the investment of Clean Transportation Program funds in projects that will effectively benefit disadvantaged communities.

## California Hydrogen Infrastructure Tool (CHIT) Analysis of the Network Coverage

Figure 5 displays the coverage provided by the 63 stations of the hydrogen refueling network in California. Figure 5 was produced by the CARB California Hydrogen Infrastructure Tool (CHIT).[16] The figure reflects the relative coverage provided by the network, as shown with the red-to-blue shading. Areas in red have the highest degree of coverage, often with multiple stations within a short drive of neighborhoods in those locations. The blue areas have less coverage provided by the refueling network; these areas typically have one or a small number of stations available, and they may be relatively far away. Areas on the map without color are

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12 SB 350 establishes the reduction of greenhouse gases as a state priority through the promotion of various clean energy policies, including widespread transportation electrification. SB 350 information is available at California Energy Commission, Clean Energy and Pollution Reduction Act – SB 350. https://www.energy.ca.gov/sb350/.

13 Disadvantaged communities are identified using the California Office of Environmental Health Hazard Assessment's CalEnviroScreen™. Information is available at OEHHA, CalEnviroScreen. https://oehha.ca.gov/calenviroscreen. The CARB guidance is available at California Air Resources Board, CARB Barriers Report – Final Guidance Document, https://ww2.arb.ca.gov/resources/documents/carb-barriers-report-final-guidance-document.

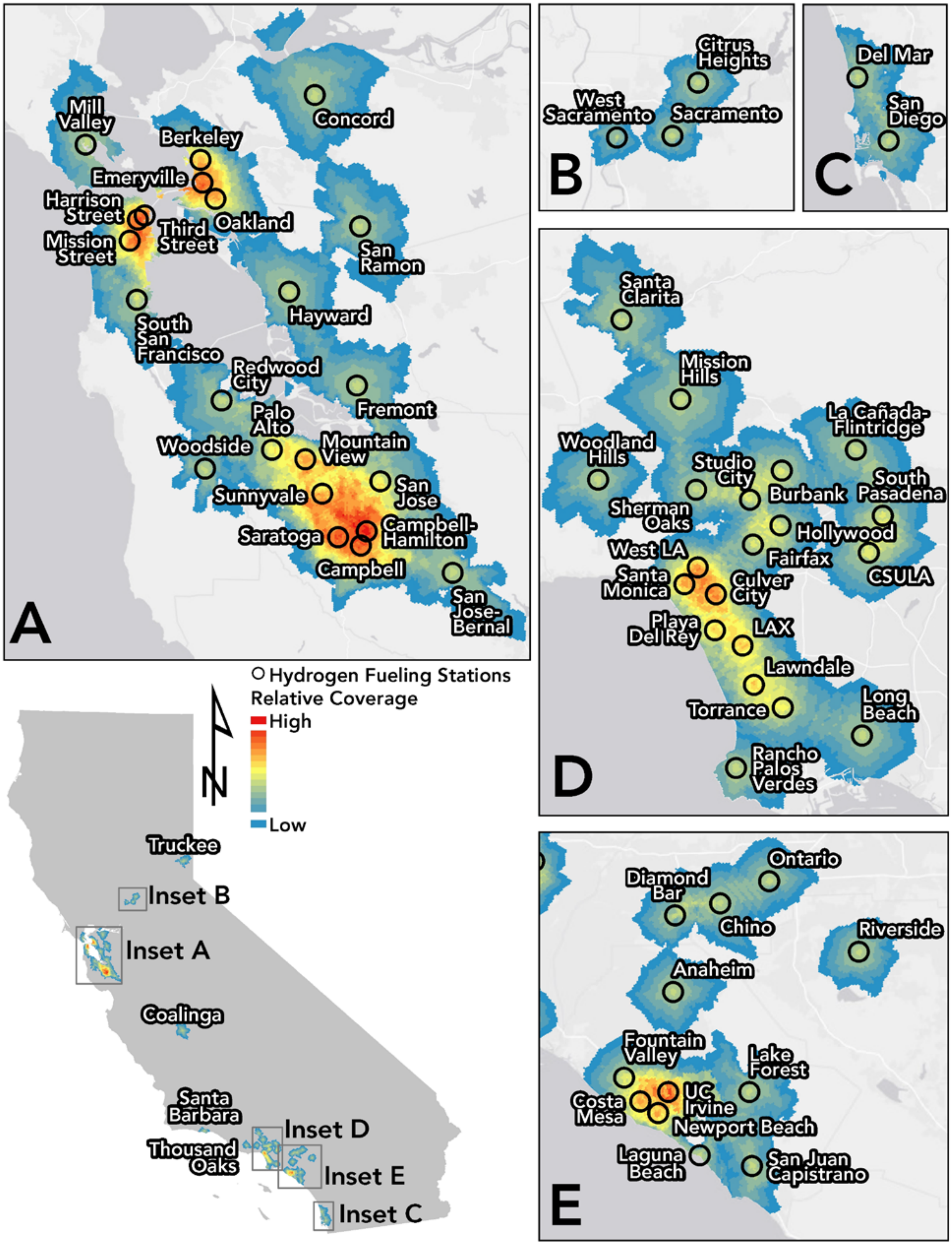
14 California Air Resources Board. July 2019. *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development*. https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2019_print.pdf, p. 24.

15 California Energy Commission. December 2019. GFO-19-602 – Hydrogen Refueling Infrastructure. https://www.energy.ca.gov/solicitations/2019-12/gfo-19-602-hydrogen-refueling-infrastructure.

16 Information on CHIT is available at California Air Resources Board, Hydrogen Refueling Infrastructure Assessments. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/hydrogen-infrastructure/hydrogen-fueling.

not within the coverage of the network. The limits of coverage in this analysis are restricted to a 15-minute drive from any hydrogen refueling station.

**Figure 5: Coverage Map**




Source: CARB

## The Capacity of the Hydrogen Refueling Station Network

The fueling capacity of the funded hydrogen refueling station network is nearly 24,500 kilograms per day, as shown in Table 2. Station capacity is determined using the Hydrogen Station Capacity Evaluation (HySCapE) model, which is the method for determining the 24-hour daily capacity under CARB's new Low Carbon Fuel Standard (LCFS) Hydrogen Refueling Infrastructure (HRI) credit program.[17] If a station is not participating in the HRI program and has not been evaluated by HySCapE, capacity is based on the stated nameplate capacity from the station developer, which may be based on a 12-hour peak-to-peak proprietary estimate.

The 2018 Joint Report stated the station network capacity was nearly 17,000 kilograms per day. The increase in capacity between 2018 and 2019 is largely due to station developers adding equipment and enhancing station design to increase the size of their stations beyond the original nameplate capacity they provided to the CEC when applying for a grant. Station developers may have been motivated to make some of these station design changes by the LCFS HRI program, which enables station owners to receive LCFS credits not only for the hydrogen they dispense, but for any unused capacity. By doing this, the LCFS HRI program reduces the financial risk of having capacity in excess of the current FCEV population need, creating the potential for faster market growth. California continues to pursue a network frontloading strategy, meaning station deployment before FCEV release. This strategy reflects the imperative in the *ZEV Action Plan*.[18]

Using 0.7 kilograms as the average amount of fuel used per FCEV per day,[19] today's station network is capable of supporting up to 35,000 FCEVs, although this number can vary depending on actual FCEV geographical distribution relative to station locations and FCEV driver habits. This reason is why station location, in addition to station capacity, matters.

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17 California Air Resources Board. LCFS ZEV Infrastructure Crediting. https://ww3.arb.ca.gov/fuels/lcfs/electricity/zev_infrastructure/zev_infrastructure.htm. Instructions for downloading HySCapE are at https://ww3.arb.ca.gov/fuels/lcfs/2018-0813_hyscape_download_instructions.pdf. HySCapE was developed by NREL.

18 The *ZEV Action Plan* identifies fueling infrastructure needs and assigns actions to various state agencies. California Governor's Office of Business and Economic Development. *ZEV Action Plan*. http://business.ca.gov/ZEV-Action-Plan.

19 Pratt, Joseph, Danny Terlip, Chris Ainscough, Jennifer Kurtz, and Amgad Elgowainy. 2015. *H2FIRST Reference Station Design Task, Project Deliverable 2-2*. National Renewable Energy Laboratory and Sandia National Laboratories. https://www.osti.gov/biblio/1215215.

**Table 2: Hydrogen Refueling Station Network Quantity and Capacity**

| | Northern California | | Southern California | | Connector/Destination | |
|---|---|---|---|---|---|---|
| | Station Quantity | Station Capacity (kg/day) | Station Quantity | Station Capacity (kg/day) | Station Quantity | Station Capacity (kg/day) |
| Open Retail Stations | 17 | 6,190 | 23 | 4,824 | 3 | 798 |
| Planned Stations | 8 | 5,079 | 12 | 7,536 | 0 | 0 |
| ***Totals*** | ***25*** | ***11,269*** | ***35*** | ***12,360*** | ***3*** | ***798*** |
| | | | | | | |
| ***Statewide Totals*** | ***63 Stations*** | | | ***Capacity: 24,427 kg/day*** | | |

Source: CEC

## Hydrogen Supply Disruption

In 2019, a hydrogen supply disruption that effectively reduced the coverage and capacity of the station network hampered the rollout of FCEVs. The supply disruption occurred when the transfill facility in Santa Clara, the main source for gaseous hydrogen for stations in Northern California, went offline from June 1, 2019 through October 4, 2019. It resulted in several Northern California hydrogen refueling stations also going offline because of the limited fuel availability. The disruption did not affect stations that store hydrogen in liquid form because they do not rely on the transfill facility.

During the supply disruption, the FCEV manufacturers provided rental cars at no cost and support for alternative transportation, that is, ride-hailing services, to FCEV drivers who could not refill their vehicles. The station operators collaborated to minimize the effect of the supply disruption by prioritizing fuel to the Northern California stations where it could serve the most drivers and communicating fuel availability online and through social media. Despite these efforts, disruptions of this nature likely have a negative impact on consumer acceptance of FCEVs and could slow the deployment of vehicles if more should occur. However, the support and incentives that auto manufacturers offered to FCEV drivers to alleviate the inconvenience of the limited fuel supply as much as possible instilled confidence that these auto manufacturers remain committed to FCEVs. Appendix A includes additional discussion of this topic and related figures.

The supply disruption also affected the station network growth this year. With all available fuel going to stations to fill as many FCEVs as possible while the Santa Clara transfill facility was offline, fuel was not available for commissioning. Commissioning is the last step for stations to take before becoming open retail, and it requires fuel to complete various tests. As a result, some stations that developers anticipated opening this year were not able to do so.

## Hydrogen Dispensing Statistics

Table 3 includes statistics on hydrogen dispensing. The effect of the hydrogen supply disruption is not readily apparent, as the growth in fueling in Southern California largely masked the decrease in Northern California. Overall, the quarterly average daily dispensing increased every quarter, even though the increase was small in the third quarter. Table 3 reports the number of open retail stations through Q3 2019. In other places in this report, the number of open retail stations reported is of the time of publication in December 2019.

The supply disruption, however, did not directly affect other statistics. The table shows that the average retail price of hydrogen remains relatively stable at around $16.50 per kilogram. However, some station operators have begun reducing their hydrogen prices. For instance, in October 2019, FirstElement Fuel reported selling hydrogen at its Oakland station for $12 per kilogram plus tax for a total $13.11 per kilogram.[20] The price should continue to decrease as the hydrogen production cost falls.

Given that light-duty FCEVs are typically 2.5 times more fuel-efficient than a gasoline-powered vehicle, reaching parity with the price of gasoline requires that 1 kilogram of hydrogen sell for 2.5 times a gallon of gasoline, so the costs per mile of the two are equal. If hydrogen sells for $8 per kilogram, this cost would equal a gallon of gasoline selling for $3.20.[21]

Figure 6 shows how the average amount of hydrogen dispensed per day across the entire station network has changed over time. This figure reveals how dispensing decreased during the hydrogen supply disruption, especially in Northern California. Before the disruption, the total amount of hydrogen dispensed from all the stations, together as a network, was nearly 3,200 kilograms daily. During the disruption, the network dispensing decreased to nearly 2,600 kilograms daily. This decrease equates to the amount of hydrogen that roughly 850 FCEVs would use daily. Despite the disruption, the statewide network managed to grow slightly in the first three quarters of 2019, with the third quarter reaching nearly 3,400 kilograms dispensed daily. This growth in dispensed hydrogen demonstrates strong demand for hydrogen fuel.

In most cases, station operators report dispensing data to the CEC as required by grant agreements. Some station operators stopped reporting data once their grant agreements ended, and some have continued reporting voluntarily. If the CEC stopped receiving data for a station because the required reporting term ended, then staff calculated the average dispensing per station for each region (Greater Los Angeles Area, San Francisco Bay Area, San Diego Area, and Sacramento Area) and assumed that calculated average was the amount dispensed for any station in that region that did not report. Figure 6 shows the dispensing that staff has estimated using this method for each region using a patterned color labeled "estimate" in the legend of the figure. The dispensing shown in solid color in Figure 6 is the amount of actual dispensing that station operators reported to the CEC.

20 October 23, 2019, email from Tim Brown of FirstElement Fuel.

21 U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. Compare Fuel Cell Vehicles. https://www.fueleconomy.gov/feg/fcv_sbs.shtml.

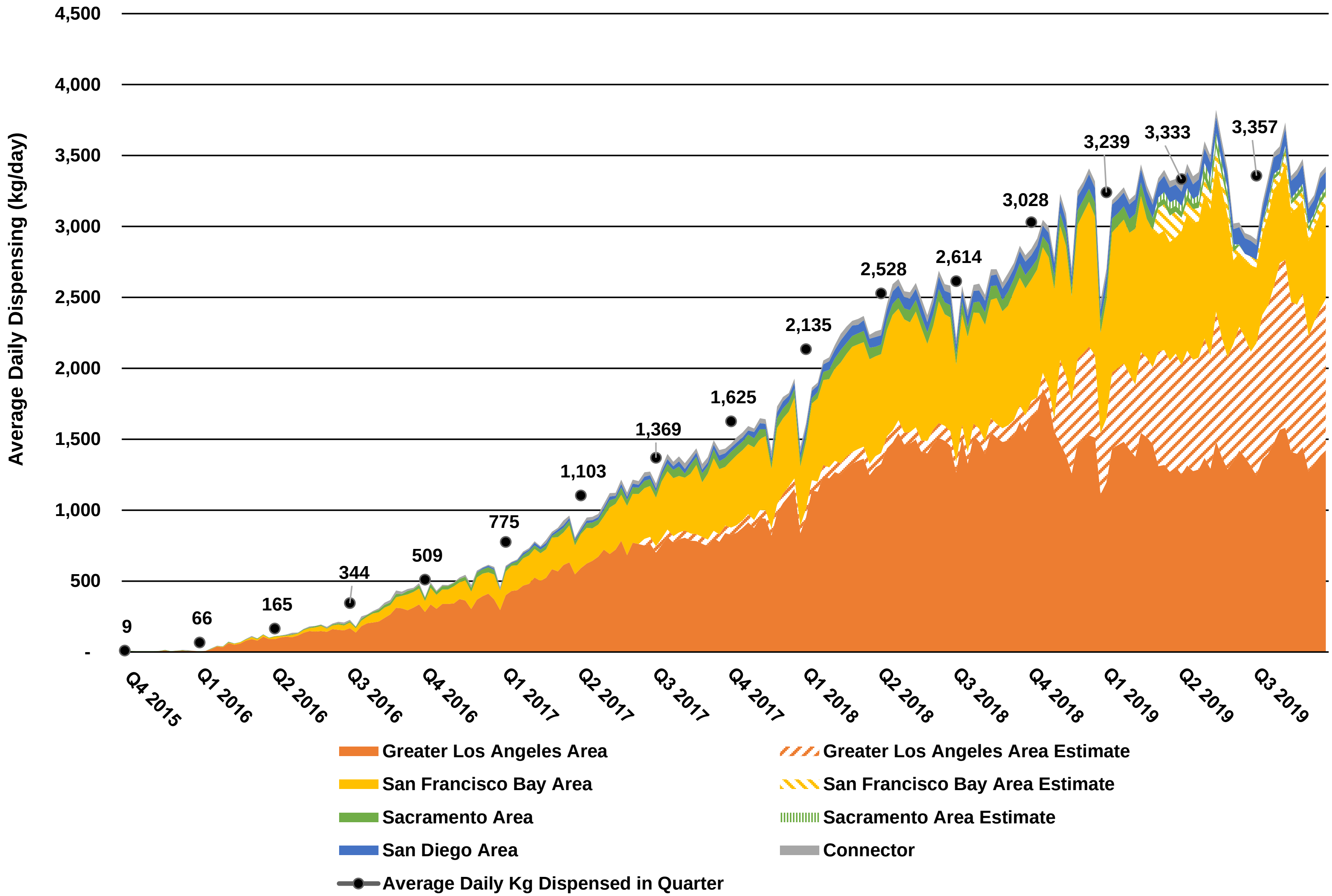
## Table 3: Hydrogen Dispensing Statistics for Stations in California

| Quarterly statistics | Q4 2017 | Q1 2018 | Q2 2018 | Q3 2018 | Q4 2018 | Q1 2019 | Q2 2019 | Q3 2019 | Q4 2018 through Q3 2019 average or total |
|---|---|---|---|---|---|---|---|---|---|
| Number of open retail stations | 31 | 33 | 35 | 35 | 39 | 39 | 40 | 40 | 40 |
| % change over previous quarter | | +6.5% | +6.1% | | +11.4% | | +2.6% | | |
| Average retail price of hydrogen ($/kg) | $16.30 | $16.34 | $16.34 | $16.48 | $16.38 | $16.53 | $16.59 | $16.54 | $16.51 |
| Range of retail prices ($/kg) | 14.99-16.78 | 14.99-16.78 | 14.99-16.78 | 14.99-17.99 | 14.99-18.29 | 14.99-19.99 | 14.99-19.99 | 14.99-18.71 | |
| % change over previous quarter | | +0.3% | -0.0% | +0.9% | -0.6% | +0.9% | +0.3% | -0.3% | |
| Average daily hydrogen sold (kg/day) | 1,625 | 2,135 | 2,528 | 2,614 | 3,028 | 3,239 | 3,333 | 3,357 | 3,239 |
| % change over previous quarter | | +31.4% | +18.4% | +3.4% | +15.8% | +7.0% | +2.9% | +0.7% | |
| Average station capacity utilization (%) | 21.8% | 28.2% | 30.9% | 31.6% | 35.4% | 34.2% | 34.4% | 33.6% | 34.4% |
| % change over previous quarter | | +29.1% | +9.6% | +2.5% | +12.1% | -3.4% | +0.5% | -2.2% | |
| Total number of fueling events | 47,158 | 60,645 | 74,150 | 81,921 | 92,003 | 94,904 | 101,481 | 101,825 | 390,213 |
| % change over previous quarter | | +28.6% | +22.3% | +10.5% | +12.3% | +3.2% | +6.9% | +0.3% | |
| Total hydrogen dispensed (kg) | 149,500 | 192,150 | 230,048 | 240,488 | 278,576 | 291,510 | 303,303 | 308,844 | 1,182,233 |
| % change over previous quarter | | +28.5% | +19.7% | +4.5% | +15.8% | +4.6% | +4.0% | +1.8% | |
| Average fueling quantity (kg/sale) | 3.17 | 3.17 | 3.10 | 2.94 | 3.03 | 3.07 | 2.99 | 3.03 | 3.03 |
| % change over previous quarter | | -0.1% | -2.1% | -5.4% | +3.1% | +1.4% | -2.7% | +1.5% | |

Source: NREL

Note that Q2 2019 and Q3 2019 dispensing and utilization were restricted by a hydrogen supply disruption that began in June 2019. This table reports the number of open retail stations through Q3 2019. In other places in this report, the number of open retail stations is reported to the time of publication in December 2019.

## Figure 6: Average Daily Hydrogen Dispensing



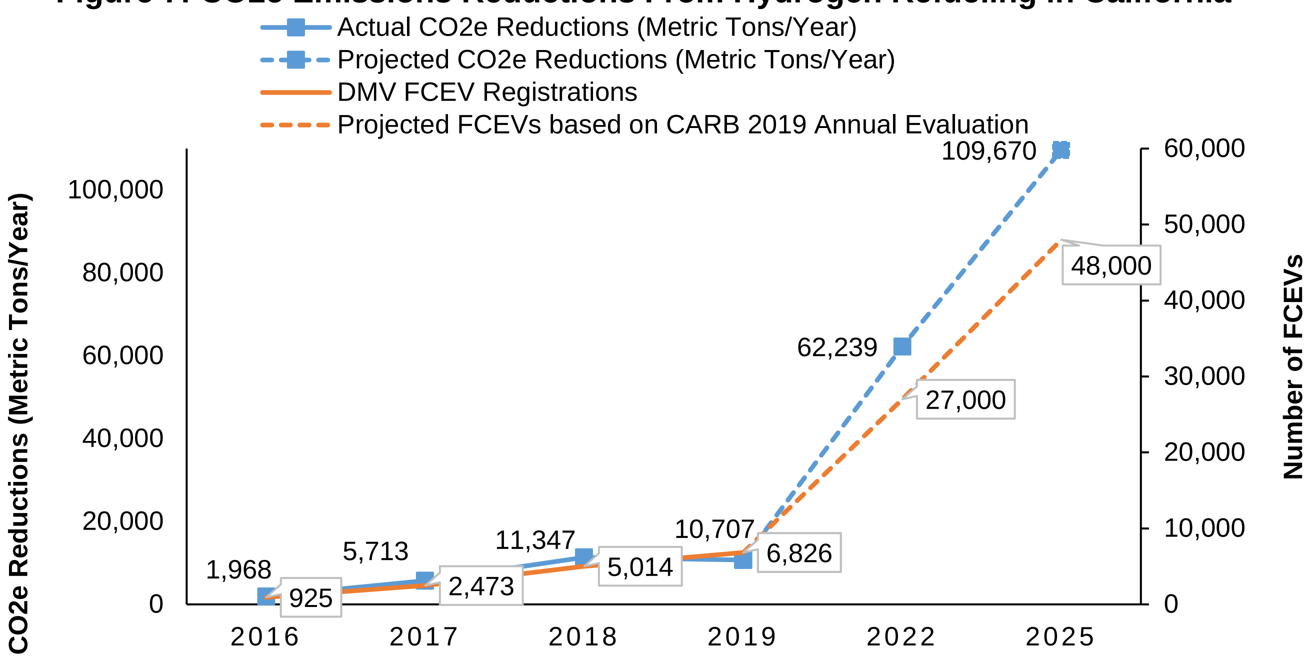

Source: CEC

## Emission Reductions

Hydrogen refueling stations contribute to emissions reductions in greenhouse gases (GHGs), oxides of nitrogen ($NO_x$), and particulate matter 2.5 ($PM_{2.5}$).[22] Figure 7 shows carbon dioxide equivalent ($CO_2e$) emissions reductions from dispensed and consumed hydrogen from 2016 to today, and projected reductions through 2025. For 2020 to 2025, the projected reductions in Figures 7-9 are based on the projected growth of FCEVs in California from CARB's 2019 Annual Evaluation, which is estimated from auto manufacturer survey. The projected hydrogen demand is limited to the nameplate capacity of funded stations. [23] Given these assumptions, the projected GHG emissions reductions from FCEVs is 109,670 metric tons $CO_2e$ per year by 2025.

The reductions represent the difference between the emissions from producing, distributing, and consuming gasoline in a "baseline" gasoline vehicle, and the emissions from producing and distributing hydrogen and consuming hydrogen in an FCEV. The calculations apply the carbon intensity (CI) of hydrogen and gasoline based on the LCFS methods for determining $CO_2e$ emissions reductions.[24]

**Figure 7: CO2e Emissions Reductions From Hydrogen Refueling in California**




Source: CEC

In Figure 7, the estimated emissions reductions in 2019 are based on the first three quarters only (the period of time for which the CEC has actual dispensing data). For the fourth quarter,

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22 *Particulate matter 2.5* are fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller. Source: U.S. Environmental Protection Agency. [Particulate Matter (PM) Pollution](https://www.epa.gov/pm-pollution/particulate-matter-pm-basics). https://www.epa.gov/pm-pollution/particulate-matter-pm-basics.

23 The calculations for GHG reductions include only hydrogen refueling stations funded by public dollars.

24 The calculations use the Low Carbon Fuel Standard current regulation, effective January 2019. The Low Carbon Fuel Standard Final Regulation Order. https://ww3.arb.ca.gov/fuels/lcfs/fro_oal_approved_clean_unofficial_010919.pdf.

the CEC expects the 2019 emissions reductions will exceed the 2018 reductions. The same applies to Figures 8 and 9.

The use of light-duty FCEVs instead of gasoline vehicles results in criteria air pollutant emissions reductions. Staff estimated $NO_x$ and $PM_{2.5}$ emissions reductions using:

- The fuel economy of 74 miles per gallon gasoline equivalent (mpgge) for the light-duty FCEV and 25 miles per gallon (mpg) for the gasoline vehicle.[25]
- The well-to-wheel emissions of 0.106 g $NO_x$/mile and 0.0140 g $PM_{2.5}$/mile for the light-duty FCEV and 0.279 g $NO_x$/mile and 0.0196 g $PM_{2.5}$/mile for the gasoline vehicle.[26]

Figures 8 and 9 show the $NO_x$ and $PM_{2.5}$ emissions reductions projected to 2024 that result from driving zero-emission FCEVs instead of gasoline vehicles. The figures show the time scale increments changing from annual to every three years starting in 2019. Although the amount of $NO_x$ and $PM_{2.5}$ avoided in the regions is relatively modest, the future emissions reductions could be substantive.

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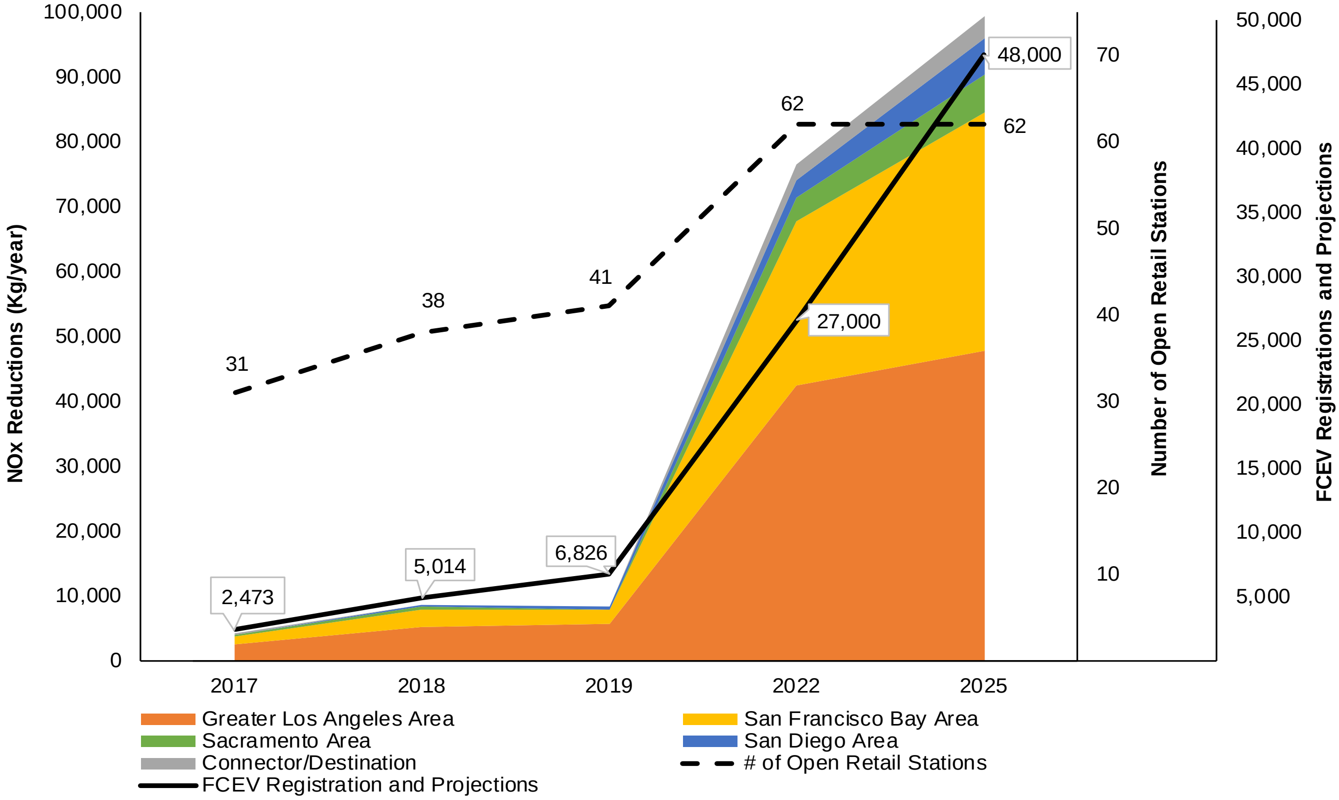
25 California Air Resources Board. March 2009. Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume II, Appendices. https://ww3.arb.ca.gov/fuels/lcfs/030409lcfs_isor_vol2.pdf.

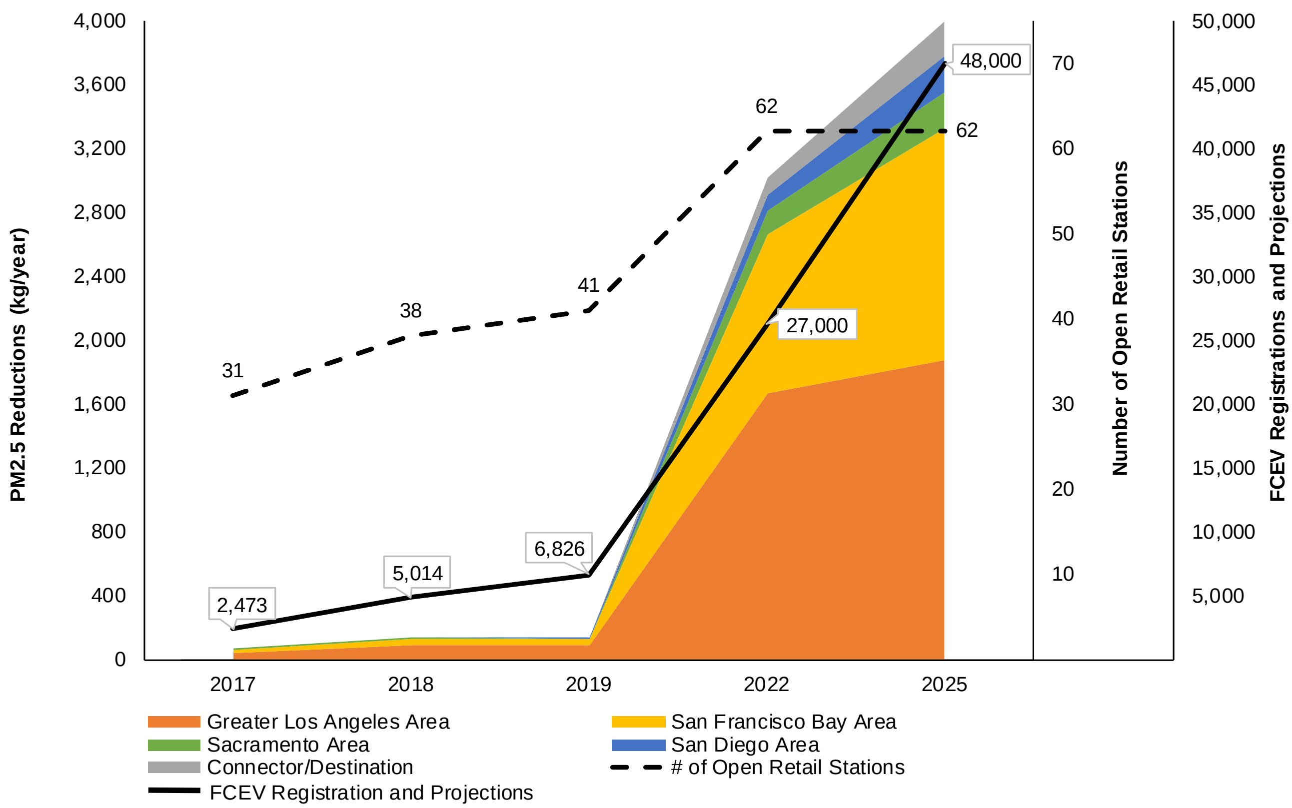
26 The emissions reductions account for oil refinement in the production of gasoline and the associated use in the gasoline automobile, the manufacture of hydrogen through steam methane reformation, and a few electrolyzer stations within the network. Elgowainy, A., et al. 2017. *Life-Cycle Analysis of Air Pollutants Emission for Refinery and Hydrogen Production from SMR.* Argonne National Laboratory. pp 22-24. https://www.hydrogen.energy.gov/pdfs/review17/sa066_elgowainy_2017_o.pdf.

## Figure 8: NOx Emissions Reductions by Region




Source: CEC

## Figure 9: PM2.5 Emissions Reductions by Region




Source: CEC

## Renewable Hydrogen

The greater the amount of renewable hydrogen dispensed by the station network in California, the lower the carbon intensity of the fuel and the greater the emissions benefits. The LCFS HRI credit program already appears to be providing station developers the impetus to find and secure renewable hydrogen sources to reduce the carbon intensity of their fuel and potentially receive more credits.

Some station operators secured new hydrogen feedstock sources that will provide 100 percent renewable hydrogen.[27] These new agreements demonstrate that, once station operators are able to secure renewable hydrogen feedstock sources, the percentage of dispensed hydrogen that is renewable can increase nearly instantaneously. This ability to quickly increase renewable content is one advantage of hydrogen as a transportation fuel, and why the CEC has supported the development of renewable hydrogen plants in California.

27 Email communication with Tim Brown of FirstElement Fuel and Wayne Leighty of Shell Hydrogen on 11/13/2019. With permission.

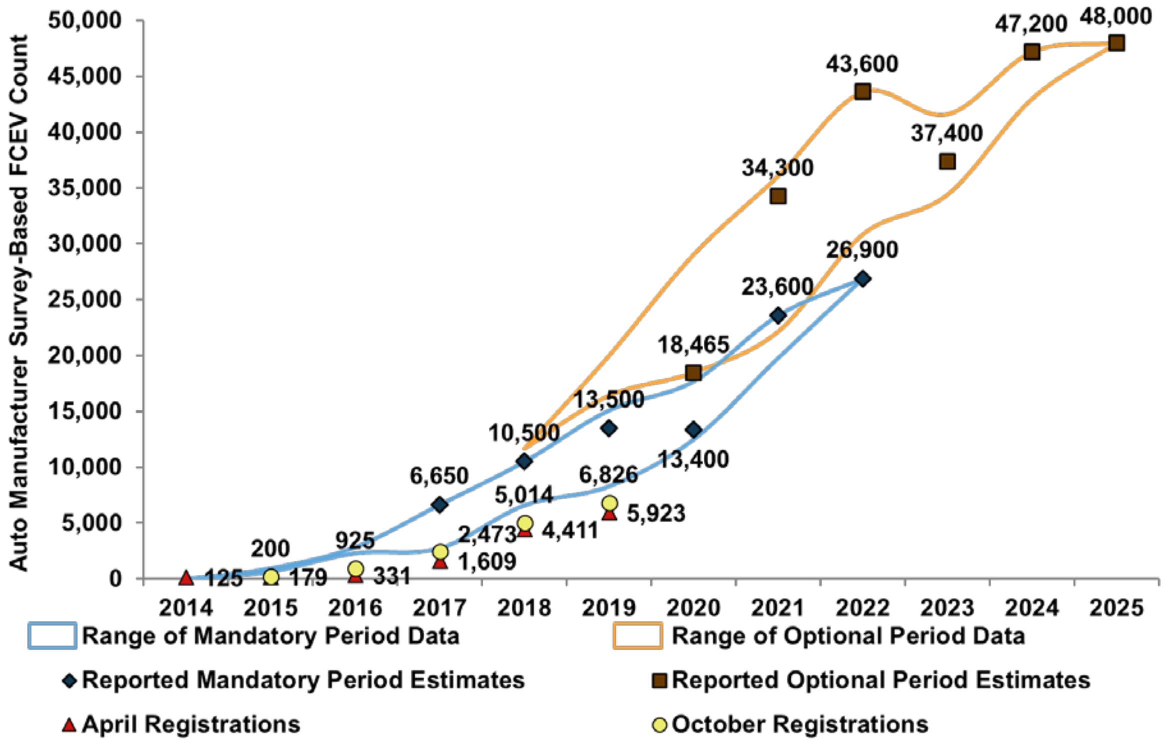
# CHAPTER 3: Fuel Cell Electric Vehicle Deployment

AB 8 requires CARB to collect, aggregate, and report the number of FCEVs to evaluate the need for additional hydrogen refueling stations. To meet this requirement, CARB surveys auto manufacturers on their FCEV production plans for the near future.

## Auto Manufacturer FCEV Projections

The 2019 Joint Report uses the CARB FCEV projections for analyses throughout the report. Figure 10 updates Figure ES3 in CARB's 2019 Annual Evaluation[28] using CARB analysis of data provided by the California Department of Motor Vehicles (DMV) of 6,826 FCEV registrations as of October 2019. In the most recently published FCEV counts, industry reports that 7,883 FCEVs have been sold or leased in the United States as of December 1, 2019.[29] These U.S. sales figures are a close proxy for the number of FCEVs in California because there are few FCEVs in other states.

**Figure 10: FCEV Projections From Auto Manufacturer Survey**




Source: CARB

28 California Air Resources Board. July 2019. *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. https://ww2.arb.ca.gov/sites/default/files/2019-07/AB8_report_2019_Final.pdf. Page xii.

29 The industry-reported FCEV numbers are available at the California Fuel Cell Partnership, By The Numbers. https://cafcp.org/by_the_numbers.

Figure 10 presents FCEV projections in the mandatory reporting period (shown in blue outline, which is the next three model years at the time of survey) and the optional reporting period (shown in orange outline, which is the following three model years after the mandatory period) for auto manufacturers. In the optional period, some auto manufacturers may not have provided data. The FCEV counts shown in Figure 10, represented by the diamond and square-shaped icons, are the end-of-period values from the estimates that CARB received from auto manufacturers in each survey year.

In 2019, the end-of-period years were 2022 for the mandatory period and 2025 for the optional period. The areas outlined in blue and orange represent the range of survey responses obtained from auto manufacturers for each year that the survey covered the given year. For example, considering 2019, it was the end of the mandatory reporting period in the 2016 survey year. Figure 10 shows the 2016 estimate for 2019 was 13,500 FCEVs. CARB's surveys conducted in 2017 and 2018 also collected data on 2019, and the vertical spread of the area outlined in blue represents the range of vehicle projections from these other survey years. The new projections of FCEVs, 26,900 FCEVs by 2022 and 48,000 FCEVs by 2025, indicate that auto manufacturers continue to anticipate growth in FCEV adoption, but only a relatively modest increase from the previous year's projections of 23,600 FCEVs by 2021 (14 percent short-term growth rate) and 47,200 by 2024 (demonstrating a potential shift of deployment plans by one year in the longer term).

## Emerging Market Opportunities

Industry supports the complementary development of light-duty and heavy-duty FCEVs to bring down fuel cell component costs and hydrogen fuel prices across the board. Hydrogen fuel cells provide advantages in terms of volume and weight to current battery technology, and, as such, there is increasing interest in fuel cell technology in heavy-duty, long-haul applications. Fuel cell electric buses offer solutions to transit agencies in meeting the Innovative Clean Transit regulation.[30] There are 42 fuel cell electric buses in operation in California as of December 1, 2019,[31] and the 2019 CaFCP Fuel Cell Electric Bus Road Map[32] is a valuable resource to help transit agencies evaluate the performance and economics of fuel cell technology. The CEC, CARB, and other public agencies are supporting fuel cell demonstrations in a variety of medium- and heavy-duty projects, as summarized in Appendix D.

FCEVs offer attractive features for light-duty uses such as taxis and ride-hailing services. FCEVs provide driving ranges and refueling times nearly equivalent to a typical light-duty internal combustion engine vehicle. The long range and fast refueling is well suited to taxi and ride-hailing drivers that want to be able to drive as far as a customer wants to go, and to minimize the time out of service for refueling. Having FCEVs used by drivers of ride-hailing companies could be especially important because these services contribute to increased

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30 California Air Resources Board. Innovative Clean Transit (ICT)-Regulation. https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-regulation.

31 California Fuel Cell Partnership. By the Numbers. https://cafcp.org/by_the_numbers.

32 California Fuel Cell Partnership. September 2019. *Fuel Cell Electric Buses Enable 100% Zero Emission Bus Procurement by 2029*. https://cafcp.org/sites/default/files/2019-CaFCP-FCEB-Road-Map.pdf.

vehicle miles traveled (VMT) for individual trips that potentially increase overall VMT[33] and emissions from the transportation sector at a time when they need to decrease. FCEVs could effectively convert these VMT to electric VMT and eliminate the tailpipe emissions from those miles driven. This idea of using FCEVs in ride-hailing is one example of how FCEVs could play important roles in transportation electrification to reduce emissions from the transportation sector.

If FCEVs gain traction in some of these particular market applications, FCEV rollout could accelerate.

33 Henao, Alejandro, and Wesley E. Marshall. "The impact of ride-hailing on vehicle miles traveled." Transportation (2019) 46: 2173. https://doi.org/10.1007/s11116-018-9923-2.

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

The decrease in the time required to permit and construct stations observed in the stations funded under GFO-15-605 is partially due to the emphasis the solicitation placed on station developer readiness. The solicitation required applicants to hold a preapplication meeting with the authority having jurisdiction (AHJ) and secure the station site through critical milestones. For the recently released solicitation, GFO-19-602, staff introduced more critical milestones to increase the station developer readiness further. The solicitation requires station developers to complete Critical Milestones 1 and 2 before submitting applications. Table 4 lists the new set of critical milestones in GFO-19-602.

**Table 4: Critical Milestones for Station Development**

| Critical Milestones | When Required |
|---|---|
| 1: Formal or informal preapplication meeting for permits with AHJs, with a representative of the Office of the Fire Marshal, or other similar fire control office in the AHJ, and a representative of the PNNL HSP | At the time of application for stations for which applicants are submitting addresses. For the remaining stations, due on or before the date when addresses for the remaining stations are submitted to CEC. |
| 2: Site control and possession | At the time of application for stations for which applicants are submitting addresses. For the remaining stations, due on or before the date when addresses for the remaining stations are submitted to the CEC. |
| 3: Meeting(s) with the utility company | On or before the date specified in the agreement Schedule of Products and Due Dates. |
| 4: Meeting(s) with the hydrogen supply company | On or before the date specified in the Schedule of Products and Due Dates. |

Source: CEC

Table 5 describes the station development phases that can be potentially shortened with these critical milestones in place.

**Table 5: Station Development Phases**

| Phases | Description | Responsible Entity(ies) |
|---|---|---|
| **Phase One:** Start of Energy Commission 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 prepermitting meetings for confirmation of station design consistency with local zoning and building codes, and filing the initial permit application with the AHJ. Equipment ordering could occur during this phase. | Grant recipient and AHJ |
| **Phase Two:** 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 could start before receiving approval to build depending on risk aversion, given that the approval may take a long time or never come to fruition. | Grant recipient and AHJ |
| **Phase Three:** Approval to build to becoming operational | Includes station construction and meeting operational requirements: the station has a hydrogen fuel supply, passes a hydrogen quality test, dispenses at the H70-T40 pressure and temperature per standard (SAE International J2601), successfully fuels one FCEV, and receives an occupancy permit from the AHJ. | Grant recipient and AHJ |
| **Phase Four:** Operational to 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 fueling protocol, the station is categorized as open retail. | Grant recipient, DMS, CARB (HyStEP), and auto manufacturers |

Source: CEC

Table 6 shows the average time spent in each phase of hydrogen refueling station development and the quantity of stations out of the 19 funded under GFO-15-605 that have completed each phase. Stations funded under other solicitations have mostly completed all the phases and are not included in the figure. When grant recipients worked on Phase One before receiving the grant award, they achieved quicker progress in station development.

**Table 6: Time Spent in Each Development Phase for GFO-15-605 Stations**

| | Phase One | Phase Two | Phase Three | Phase Four |
|---|---|---|---|---|
| Average Time Spent | 85 days | 386 days | 331 days | 70 days |
| *# of Stations That Have Completed the Phase* | *15* | *12* | *5* | *5* |

Source: CEC

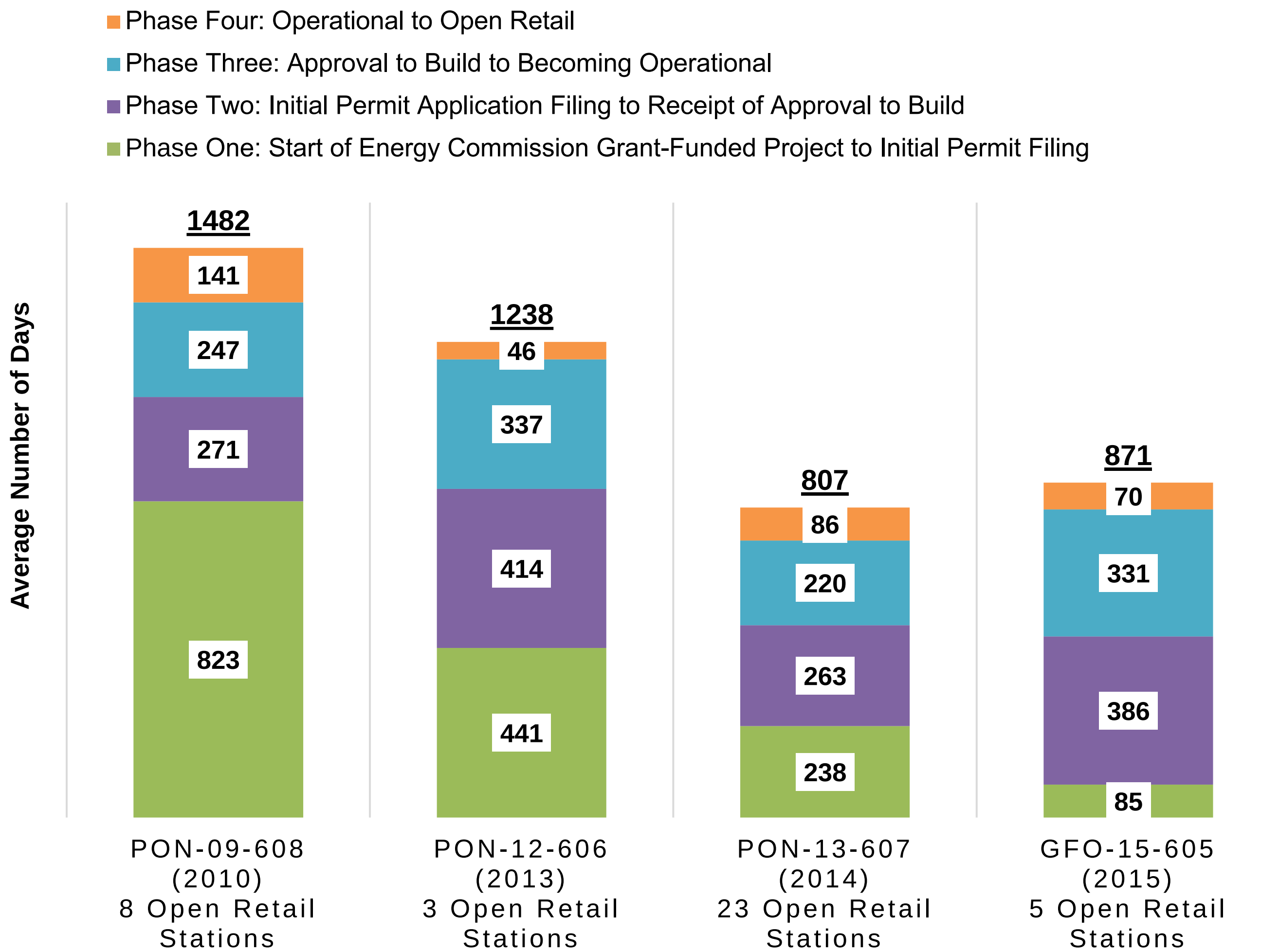
The factors described in previous joint reports continue to affect station development time, but a new factor was influential in 2019. The hydrogen supply disruption that began in June 2019 extended the time it took station developers to complete some of the development phases, particularly for stations funded under GFO-15-605. A station developer waited for hydrogen to conduct Phase Four tests for stations that were otherwise ready. The CEC staff identified the stations on Third Street and Harrison Street in San Francisco, and the station on University Avenue in Berkeley as needing fuel to complete the tests. For these stations, the station developer postponed the opening dates due to lack of hydrogen supply for testing and commissioning the stations, as well as serving customers once open. Priority for the limited hydrogen available was given to serving customers through existing open stations.[34]

In addition, the supply disruption caused some station developers with open retail stations to reallocate their resources to triage the situation, direct fuel where the demand was the greatest, and communicate with customers. This extra work at open retail stations decreased the resources available to make progress on their stations under development. In attempt to avoid similar problems in the future, GFO-19-602 requires stricter planning for reliable hydrogen supply, including more emphasis on solid agreements with supply chain providers.

Figure 11 shows the average duration of hydrogen refueling station development phases for the last four solicitations. Despite the unique challenges of 2019 that have extended the time to complete development phases for GFO-15-605 stations, station developers continue to make progress in reducing development time in Phase One and Phase Four. A few GFO-15-605 stations have encountered lengthy planning and permitting processes, in some cases relating to changes in station equipment design, installing new technologies, and in other cases to integrating broader site improvements (to the overall fueling station or convenience store) into the hydrogen refueling station permitting. Some stations also faced construction delays related to weather. These issues have extended the average time for Phase Two and Phase Three under GFO-15-605.

34 Email communication with Wayne Leighty of Shell Hydrogen on 10/30/2019. With permission.

**Figure 11: Average Number of Days Spent on Station Development**




Source: CEC

California Environmental Quality Act (CEQA) requirements may or may not influence the permitting time for a station. The CEC conducts an environmental review for all the Clean Transportation Program funded hydrogen refueling stations, either as the lead or as the responsible agency. In most cases, the CEC determined that the stations are categorically exempt from CEQA and filed a notice of exemption (NOE) for each project with the Governor's Office of Planning and Research State Clearinghouse.[35]

The CEC's CEQA findings are not typically binding on the cities in which stations are proposed, and sometimes an AHJ requires a station project to go through an initial study. These initial studies occurred in 3 percent of station projects thus far. Table 7 shows the CEQA exemptions used by the CEC and AHJs in CEQA determinations for hydrogen refueling stations.[36] Table 7 also shows the percentage of station projects in which the particular exemption has been applied.

35 Information on the OPR State Clearinghouse is available at http://opr.ca.gov/clearinghouse/ceqa/.

36 CEQA Guidelines information is available at http://opr.ca.gov/ceqa/.

**Table 7: CEQA Categorical Exemptions**

| California Code of Regulations (C.C.R.) | Applied to Station Projects (percentage) |
|---|---|
| 14 C.C.R. § 15061(b)(3) No possibility of significant effect on the environment ("common sense" exemption) | 2 percent |
| 14 C.C.R. § 15301 Existing Facilities | 91 percent |
| 14 C.C.R. § 15302 Replacement or Reconstruction | 2 percent |
| 14 C.C.R. § 15303 New Construction or Conversion of Small Structures | 88 percent |
| 14 C.C.R. § 15304 Minor Alterations to Land | 56 percent |

Source: CEC

Phase Four of the hydrogen refueling station development involves confirming the performance of the hydrogen refueling station and involves multiple state agencies and private businesses. California stations must be tested and certified that they deliver hydrogen with contaminant levels below the allowable standards, and that they dispense hydrogen mass accurately. Testing also helps ensure that stations follow the standard filling procedure that provides the customer a safe and full vehicle fill every time.

CARB operates the Hydrogen Station Equipment Performance (HyStEP) device to test hydrogen stations. HyStEP testing confirms that stations dispense hydrogen into the onboard FCEV hydrogen storage tanks per the hydrogen industry-developed protocol to ensure vehicle life expectancy. CARB tests the stations according to the CSA Group "Hydrogen Gas Vehicle and Fueling Installations 4.3, Test Methods for Hydrogen Fueling Parameter Evaluation," a reference standard used to validate that a station conforms to SAE International "J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles."

CARB staff is evaluating the need for a California regulation that would require hydrogen refueling stations to conform to the SAE International J2601. In November 2018, CARB held a scoping workshop with FCEV auto manufacturers, station providers, testing organizations, state agencies, and local agencies. Participants generally agreed that some centralized oversight is needed for testing, potentially including CARB-approved third party testers, for which CARB needs a modernized HyStEP. The SAE International J2601 fueling protocol is under revision to cover dispensing up to 50 kilograms into a single vehicle, which would fill the larger tanks of buses and trucks. Since the existing HyStEP only tests to 9-kilogram tanks, industry will need a different tester capable of performing larger tank tests.

The California Department of Food and Agriculture, Division of Measurement Standards (CDFA/DMS), conducts "type evaluations" for hydrogen dispensers through the California Type

Evaluation Program (CTEP).[37] CDFA/DMS performs these tests to ensure that hydrogen refueling stations conduct accurate, measurable retail sale of hydrogen.

Commercial testers evaluate and report hydrogen quality, and the CDFA/DMS conducts random spot checks according to California Code of Regulations Title 4, Division 9, Chapter 6, Article 8, Section 4181, which adopts SAE International J2719 for hydrogen quality. GFO-19-602 requires hydrogen quality checks at least every six months and any time a station becomes potentially exposed to contamination because of a retrofit or other adjustment.

The use of HyStEP for station testing and evaluation, combined with the activities undertaken by the PNNL HSP, contributes to hydrogen refueling station and hydrogen production plant safety evaluations.

The Hydrogen Safety Panel reviews safety plans under CEC Contract 600-17-006, Hydrogen Safety Panel Evaluation of Hydrogen Facilities, according to public guidelines.[38] The panel will potentially review the early designs of renewable hydrogen production plants and hydrogen refueling stations funded by GFO-19-602 under CEC Contract 600-15-014 and the Cooperative Research and Development Agreement (CRADA) with the U.S. Department of Energy discussed in Appendix C of this 2019 Joint Report.

The review includes safety plan assessments and compliance with the National Fire Protection Association (NFPA) 2 standards for the safe operation, handling, and use of hydrogen across installations and applications. In the event of a hydrogen release and incident, the panel would review the activity that led to the release or incident, and the subsequent response.

As the PNNL HSP transitions to the Center for Hydrogen Safety, founded under the auspices of the American Institute of Chemical Engineers (AICHE), the CEC staff will participate in crossover activities and strategic planning.[39]

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37 California Department of Food and Agriculture. Division of Measurement Standards: California Type Evaluation Program (CTEP). https://www.cdfa.ca.gov/dms/programs/ctep/ctep.html.

38 Pacific Northwest National Laboratory. September 2019. Safety Planning for Hydrogen and Fuel Cell Projects. PNNL-25279-2. https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-September2019.pdf.

39 AICHE. Center for Hydrogen Safety. https://www.aiche.org/CHS.

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

The CEC and CARB evaluate the vehicle projections and the need for fuel to determine the amount and timing of the needed growth of the hydrogen refueling network. Table 8 shows additional needed capacity for hydrogen fuel by 2025. In addition to today's network capacity, California will need more than another 10,000 kilograms per day of capacity to meet the projected demand for fuel in 2025. Nearly 8,000 kilograms of that need is from the Greater Los Angeles area, including Los Angeles and Orange Counties.

Table 8 uses 80 percent of station capacity in calculations to represent a sustainable level of fueling at each station, such that a station is not completely empty at the end of each day.[40]

**Table 8: Regional Projection for Fuel Demand**

| Region | 80% of Capacity (kg/day) | Projected FCEVs by 2025 | 80% of Capacity Needed by 2025 (kg/day) | 80% of Additional Needed Capacity for Projected Demand by 2025 (kg/day) |
|---|---|---|---|---|
| Greater Los Angeles | 8,700 | 24,000 | 16,800 | 8,100 |
| San Francisco Bay | 7,900 | 13,300 | 9,300 | 1,400 |
| Sacramento | 1,100 | 2,600 | 1,800 | 700 |
| San Diego | 1,200 | 1,800 | 1,300 | 100 |
| **Total** | 18,900 | 41,700 | 29,200 | 10,300 |

Source: CEC

Figures 12 through 15 compare CARB's estimated FCEV rollout shown in Figure 10, to the estimated, regional station deployment based solely on the funded station network of 63 stations. The yellow bars in Figures 12 through 15 show the range of CARB-estimated FCEVs from auto manufacturer surveys. The figures assume that stations will open according to station developers' timelines.

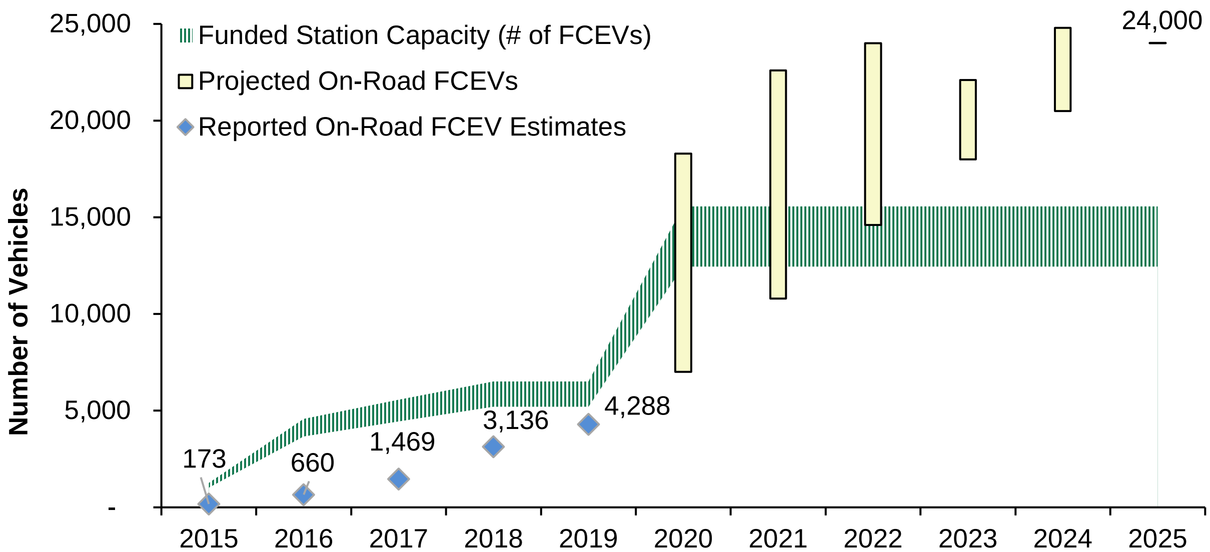
The analyses use 0.7 kilogram per day of hydrogen consumed per FCEV to convert station capacity into the estimated number of FCEVs supported. The green lines in the figure indicate the estimated number of FCEVs that could be supported by a region's stations. The width of the green line represents the difference between using 100 percent of the station nameplate capacity to determine the number of FCEVs supported (the upper bound) and using 80

40 Table 8 does not include connector and destination stations outside the four listed metropolitan regions.

percent (the lower bound). These green lines level off in 2020 because the currently funded stations under development are expected to become open retail in the 2020 time frame. These lines will increase when the CEC awards funding for additional stations and the development of those stations commences.

Figure 12 shows the need for fuel with a possible shortfall of hydrogen availability as early as 2020-21, and almost certainly by 2022, in the Greater Los Angeles Area without more stations being funded and built. By far, this region requires the largest growth in capacity. The auto manufacturers' production plan responses to the survey do not always grow from year to year in each region, as seen for 2023 in Figure 12, wherein the top of the yellow bar is lower than it is in 2022 and 2024. Any year with a possible decline from the previous year most likely reflects either reduced auto manufacturer confidence in FCEV rollout from the previous year, or fewer survey respondents providing information (Years 4–6 in the survey are optional, as described in the text for Figure 10).

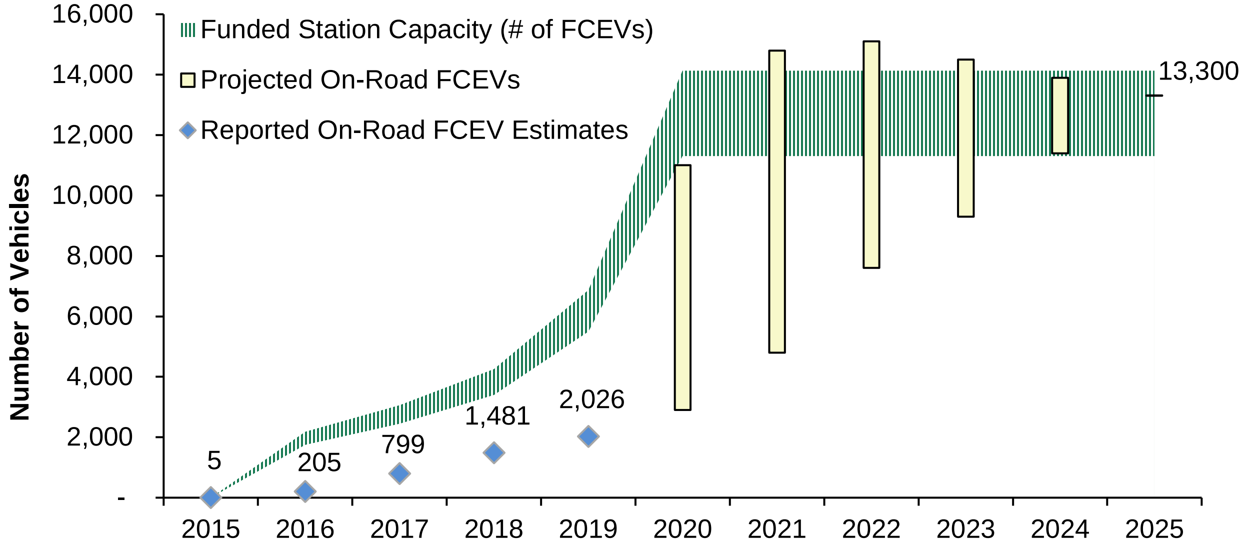
**Figure 12: Greater Los Angeles Area Station Capacity and Number of Vehicles**




Source: CEC

Figure 13 shows the funded network capacity in the San Francisco Bay Area likely satisfying FCEV fueling needs until sometime post-2021. The anticipated fueling availability in the Bay Area is significantly higher than reported last year. This year, 80 percent of funded capacity is nearly 7,900 kilograms per day, whereas last year it was 5,100 kilograms per day. This growth is largely due to station operators increasing the capacity of planned stations. After 2021, the launch of additional FCEVs would be limited without additional stations.

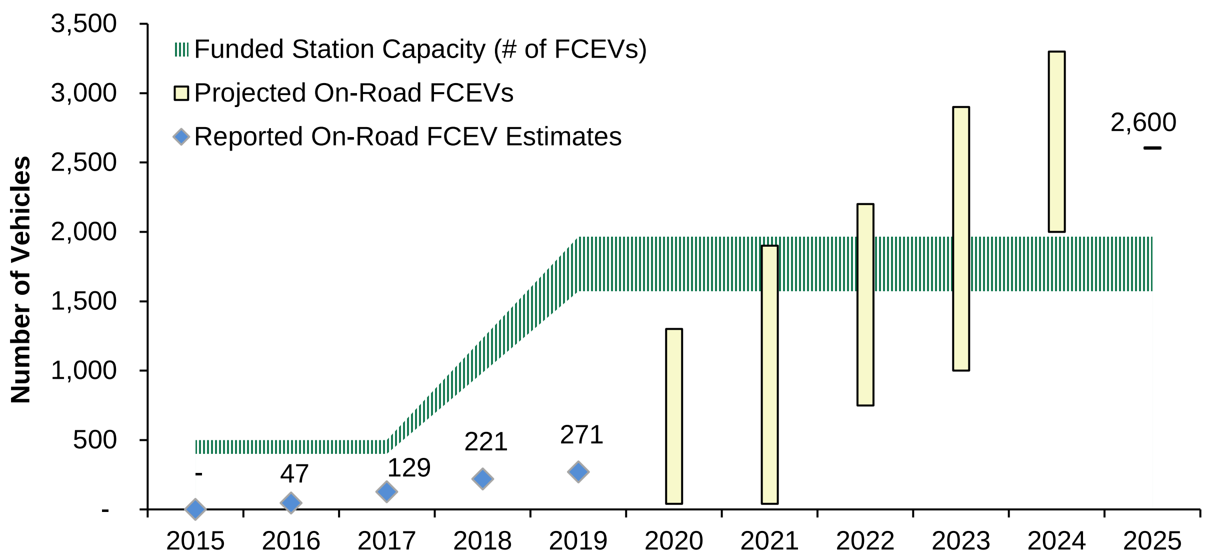
**Figure 13: San Francisco Bay Area Station Capacity and Number of Vehicles**




Source: CEC

Figure 14 shows that the current network capacity of the Sacramento region will likely satisfy demand until around 2021. All the funded stations in the Sacramento region are open, so station planning for this region is important so that new stations will be ready to develop with the next available funding, similar to other major state metropolitan areas. The 2025 estimate of 2,600 FCEVs is lower than the estimate made last year for 2024. Because these estimates are based on auto manufacturer survey, this pattern potentially reflects auto manufacturer uncertainty about the timing and volume of station rollout.

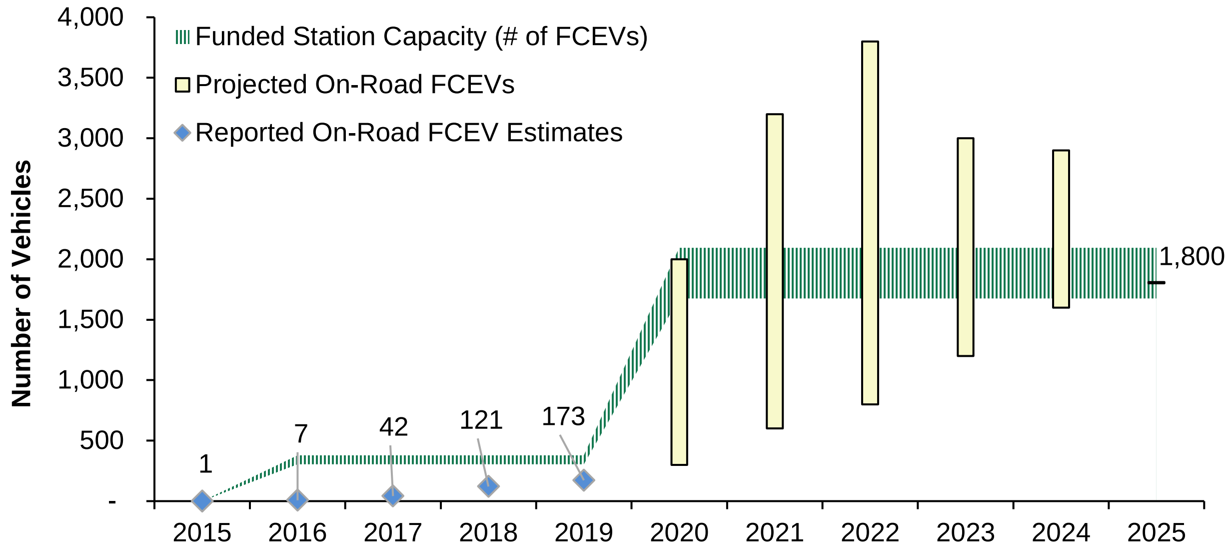
**Figure 14: Sacramento Area Station Capacity and Number of Vehicles**




Source: CEC

Figure 15 shows San Diego's network is operating near capacity now and will continue to do so in coming years, after another funded station opens. The estimated number of FCEVs declines after a peak in 2022, indicating that auto manufacturers are assessing that FCEV growth in this region will not be as robust as originally intended. Even though the one station yet to open will have more capacity than originally reported, given that the region has only two funded stations, industry expectations for this market may remain low until more stations are funded in the region.

**Figure 15: San Diego Area Station Capacity and Number of Vehicles**




Source: CEC

## Regional Readiness Plans

The Clean Transportation Program has funded readiness plans and implementation projects. Through these projects, regional, local, city, and county groups laid the groundwork to introduce and expand FCEVs, as well as other alternative fuel types, in their respective jurisdictions. The readiness plans often include education and outreach strategies to increase consumer awareness of FCEVs and, more broadly, explain benefits of and opportunities to use zero-emission vehicle technologies. Table 9 includes the names of such readiness plans and implementation projects, the entities that developed the plans, and the CEC agreement numbers that funded the projects.

**Table 9: Clean Transportation Program Funded Alternative Fuel Readiness Plans**

| Readiness Plan Project Title | Readiness Plan Developer(s) | CEC Funding Agreement(s) |
|---|---|---|
| *The Northwest California Alternative Fuels Readiness Project; North Coast and Upstate Fuel Cell Vehicle Readiness Project; North Coast ZEV Readiness Plan Implementation Phase 2* | Redwood Coast Energy Authority (RCEA) in partnership with the Schatz Energy Research Center and Humboldt, Del Norte, Trinity, Siskiyou, and Mendocino Counties | ARV-13-012, ARV-14-055, and ARV-16-012 |
| *Refuel San Diego* | San Diego Association of Governments (SANDAG), San Diego Regional Clean Cities Coalition, and the San Diego Air Pollution Control District | ARV-13-013 |
| *Alternative Fuel Ecosystem for the Monterey Bay Region* | Monterey Bay Unified Air Pollution Control District | ARV-13-016 |
| *Central Coast Alternative Fuel Vehicle Plan* | County of Santa Barbara | ARV-13-017 |
| *Alternative Fuel Readiness Plan for San Mateo County* | City/County Association of Governments of San Mateo County | ARV-13-018 |
| *City and County of San Francisco Alternative Fuel Vehicle Readiness Plan* | City and County of San Francisco | ARV-13-053 |
| *Hydrogen Readiness in Early Market Communities* | South Coast Air Quality Management District | ARV-13-056 |
| *Tri-Counties Hydrogen Readiness Plan* | Santa Barbara County Air Pollution Control District | ARV-14-038 |
| *FCEV and Hydrogen Fueling Station Development for San Francisco* | Department of the Environment - City and County of San Francisco | ARV-14-043 |
| *Central Coast Go-Zero: Zero Emission Vehicle Readiness Implementation in the Tri-Counties* | San Luis Obispo County Air Pollution Control District | ARV-16-015 |
| *San Bernardino Countywide ZEV Readiness and Implementation Plan* | San Bernardino Council of Governments | ARV-16-021 |
| *ZEV Readiness in the Sacramento Region* | Sacramento Metropolitan Air Quality Management District | ARV-16-023 |

Source: CEC

## Future Hydrogen Fuel Demand

With the increasing number of light-duty FCEVs on the road and with increasing fuel cell applications related to medium- and heavy-duty vehicles, hydrogen production will need to expand significantly to serve the transportation market in the near future.

The projected 48,000 light-duty FCEVs by 2025 will need as much as 33 metric tons of hydrogen daily.[41] According to the International Council on Clean Transportation,[42] Class 8 fuel cell electric trucks will require between 50 and 60 kilograms of hydrogen to achieve up to a 585-mile range, pulling a full load. Using these numbers, if 100,000 Class 8 fuel cell electric trucks entered the U.S. market, and if each truck refueled about every three days, they would use between 1,700 and 2,000 metric tons of hydrogen each day. While California would serve only a share of the national demand, this example demonstrates how dramatically fuel cell electric trucks would increase the hydrogen production volume needed to support ZEVs.

## GFO-19-602 Hydrogen Refueling Infrastructure

On December 26, 2019, the CEC released the Hydrogen Refueling Infrastructure grant funding opportunity, GFO-19-602.[43] This solicitation offers up to $115.7 million in grant funding, subject to future funding appropriations and future Clean Transportation Program Investment Plan allocations. The CEC staff expects to see station developers achieve economies of scale for equipment used in hydrogen refueling stations.

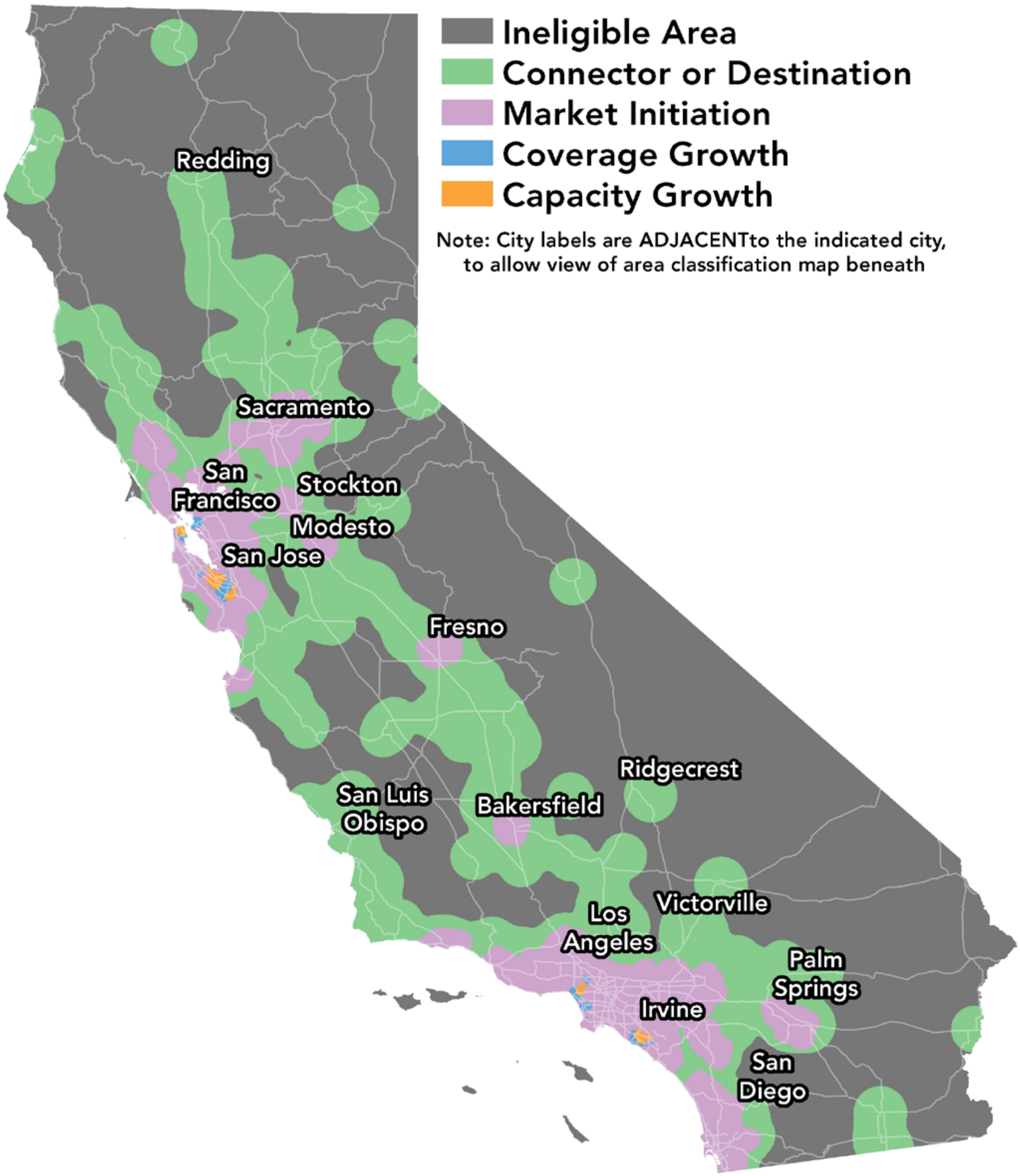
With GFO-19-602, the coverage of the hydrogen refueling network will increase. Applicants are required to propose stations within an area that is not an ineligible area in the Figure 16 map. CARB created this map based on CHIT.

41 Calculated assuming an average FCEV daily fuel consumption of 0.7 kilograms.

42 Hall, Dale and Nic Lutsey. 2019. *Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks*. International Council on Clean Transportation. https://theicct.org/publications/zero-emission-truck-infrastructure.

43 California Energy Commission. December 2019. GFO-19-602 – Hydrogen Refueling Infrastructure. https://www.energy.ca.gov/solicitations/2019-12/gfo-19-602-hydrogen-refueling-infrastructure.

**Figure 16: Station Area Classifications**



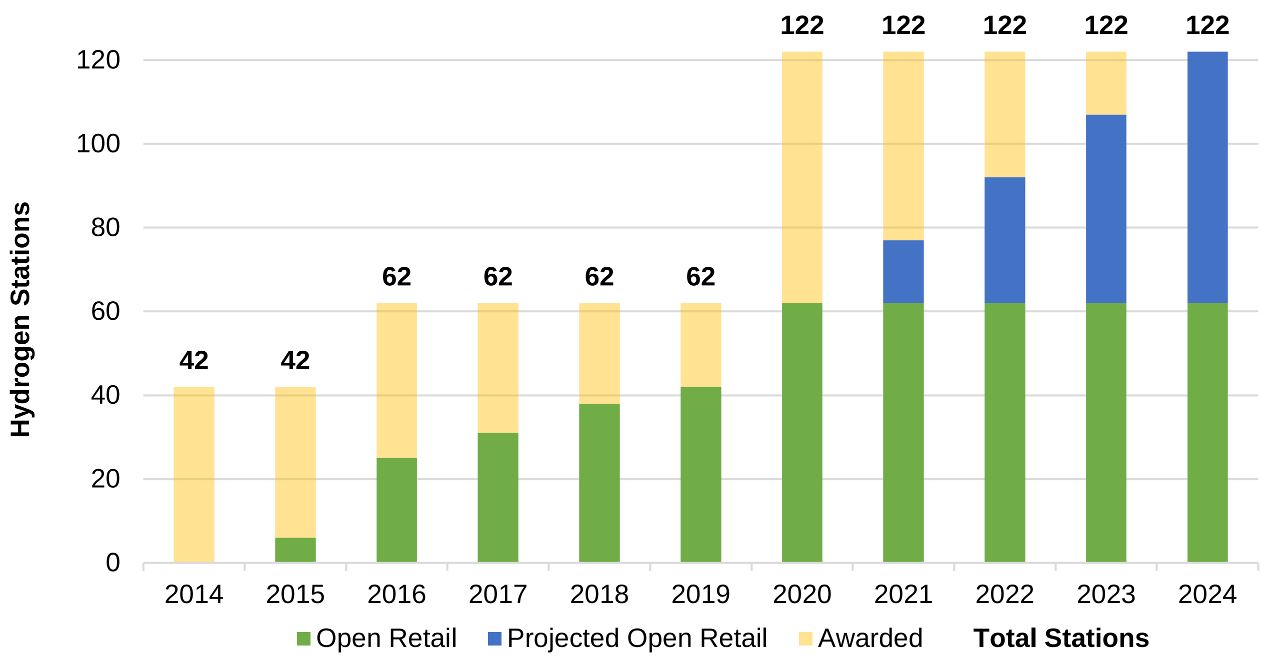

Source: CARB

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

The remaining cost and time required to establish a network of at least 100 publicly available hydrogen refueling stations are up to $115.7 million of Clean Transportation Program funding and four years. If stations become open retail within two years of funding being available, then California will exceed the goal of at least 100 publicly available stations by 2024, as shown in Figure 17.

With GFO-19-602, which requires grant recipients to provide match funding of at least 50 percent of the equipment cost, staff expects to fund, over the next four years, at least 60 stations. Given the potential revenue that station operators can earn through the HRI credits in the updated LCFS regulation,[44] CEC and CARB worked together to determine the appropriate match requirement for these future grants.

**Figure 17: Clean Transportation Program Funded Hydrogen Stations**




Source: CEC

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

The CEC staff anticipates hydrogen refueling station developers will achieve economies of scale, reduce the capital cost of stations per kilogram of capacity, and reduce the capital cost per station beyond achievements in cost reduction made by the most recently funded stations.[45] Figure 17 reflects a conservative estimate of the quantity of stations that the CEC expects to award under GFO-19-602.

For projected open retail stations, staff assumes an average of up to 15 stations funded by GFO-19-602 can become open annually, starting in 2021. Future stations are likely to have different configurations and some will potentially serve more than just light-duty FCEVs. GFO-19-602 provides funding for stations that fuel light-duty FCEVs, commercial fuel cell vehicle fleets, and fuel cell electric buses.

45 These stations were awarded under GFO-15-605, which contained incentive funding dates ranging from full funding if the developer opened the station within 20 months of the CEC business meeting, to maximum funding decreasing each month until reaching a baseline level of funding for developers that opened the station after 25 months of the CEC business meeting. The stations varied in their time to open. Overall, the stations increased their fueling capacity from 310 to 360 kilograms (for a 12-hour hour rated capacity) to 500 to 1,200 kilograms (for a 24-hour day) regardless of the receipt of full funding, or a decreased amount due to missed incentive funding dates.

# CHAPTER 7: Self-Sufficiency Evaluation of Hydrogen Refueling Stations

The *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development* provided an overview of the latest status of an effort underway by CARB and the CEC to assess the potential cost and timing of an approach to hydrogen fueling network financial self-sufficiency. Broadly, self-sufficiency of the network would indicate that no additional financial support programs specifically designed for hydrogen fueling station development would be needed to ensure longevity and good financial health of hydrogen fueling stations in California. This evaluation could be made at the individual station level or assessed networkwide.

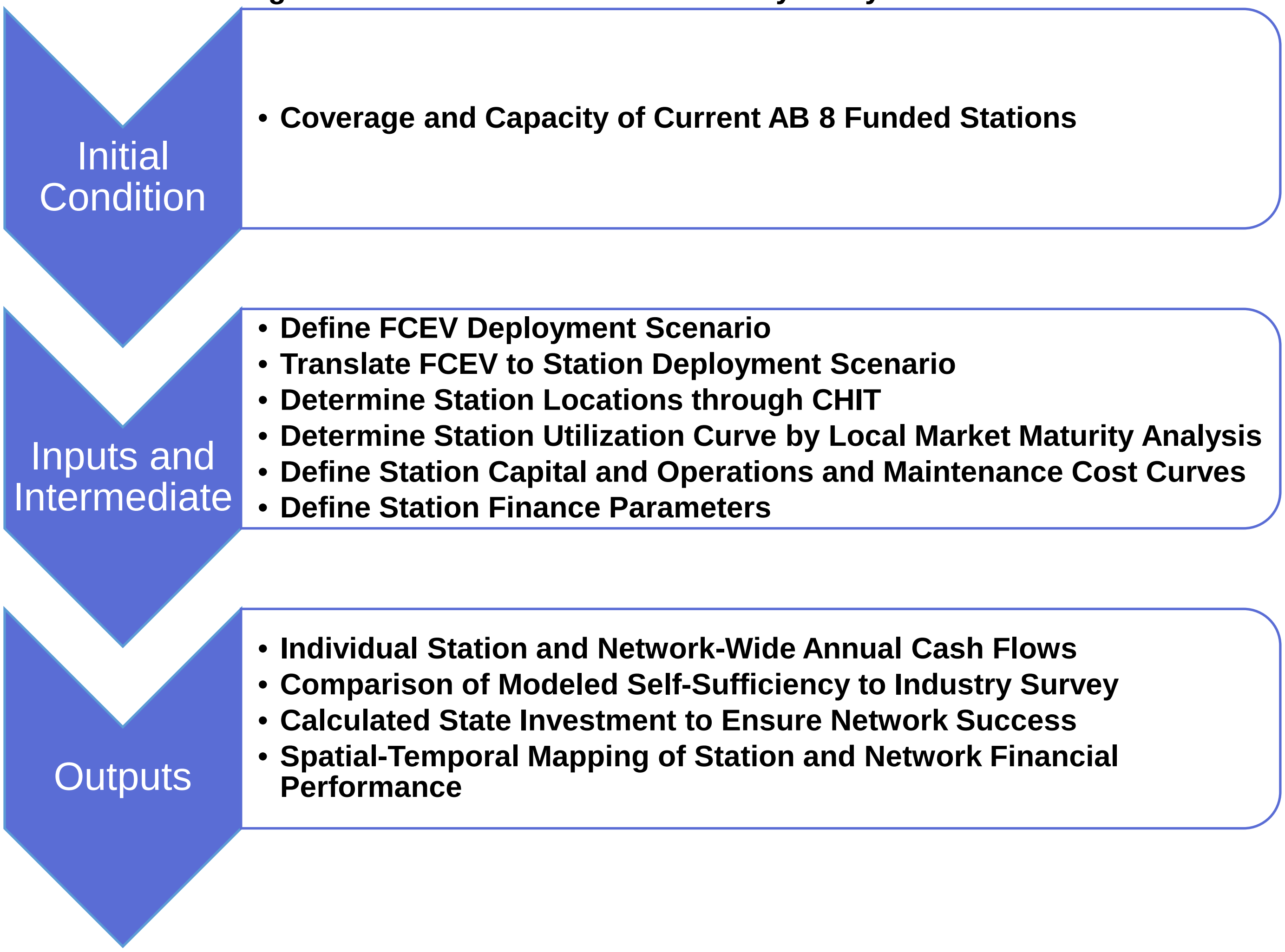
The question of self-sufficiency is complex and involves a large degree of uncertainty, especially as related to future trajectories of key financial parameters like the capital cost of station equipment, the competitive price for hydrogen sold to the consumer, and other considerations. For this reason, the analysis is not intended to be predictive; rather, the effort focuses on developing a flexible scenario analysis tool that enables assessment of cost and timing of self-sufficiency based on sets of user-defined assumptions and inputs.

Figure 18 provides an overview of the major steps in the self-sufficiency analysis. In general, the tool uses input data and pre-processed results from other resources (like the CHIT tool) to perform a cash flow analysis of all stations that would be built in California's network under prescribed vehicle deployment scenarios. Exploring the resultant cost and timing of potential financial support within a suite of scenarios is expected to provide insights for the overall conditions of self-sufficiency.

As reported in June and earlier AB 8 reports, CARB and the CEC began this analysis with a series of surveys and interviews conducted with various companies that participate in various aspects of California's hydrogen fueling network. Those interviews led to the development of the first draft assessment tool and many of the assumptions and input data that were used to develop a set of draft results. CARB shared these draft results with the same industry members that had participated in the survey. These industry members were invited to provide further input and review of the input and output data from these results voluntarily.

Over the past several months, CARB has taken the information gained from this second round of industry input and refined the scenario analysis tool. CARB has also received some requests and recommendations from industry for various scenarios that could be investigated with the tool; these scenarios do not necessarily require changes to input parameters, but would rather require additional synthesis of outputs from the tool and comparisons among particular scenarios evaluated by the tool. CARB and the CEC will consider and potentially assess these additional scenarios once the tool itself has been finalized.

**Figure 18: Overview of Self-Sufficiency Analysis Process**




Source: CARB

Major changes that have been made to the scenario analysis tool include the following:

1. Expanded options for methods to calculate average annual utilization (defined as the ratio of dispensed hydrogen to station capacity) at individual stations. Available options estimate station utilization based on age, local station network maturity (as determined by number of stations within each other's limits of coverage), and/or a projection of localized demand based on the selected statewide vehicle deployment trajectory.
2. Restructured calculation for hydrogen procurement and operation and maintenance cost. The preliminary draft version of the tool implemented a single variable cost estimate for the sum of these costs, though input parameters could determine the rate at which these costs were estimated to decline in the future. The revised version now calculates several individual contributions to these costs, some of which are fixed (the total cost for the year does not depend on the throughput of hydrogen), and some that are treated as variable (total annual costs do vary with the throughput of hydrogen).

a. Variable Operation and Maintenance Costs: Hydrogen procurement, variable electricity, credit card fees, sales tax

b. Fixed Operation and Maintenance Costs: Property tax, permits, hydrogen quality test, rent, fixed electricity, internet, insurance, fixed maintenance labor

c. A periodic major maintenance cost has also been added, which is a percentage of the installed cost of the station equipment when built

Hydrogen procurement cost is modeled to decline in future years, as was done for the full operation and maintenance cost previously shown for the preliminary draft calculations. In addition, the fixed maintenance labor in the revised model has also been designed to decline proportionally to the hydrogen procurement costs to emulate the potential to share labor costs among multiple hydrogen stations as network density increases.

3. Added the ability to define a target hydrogen sale price and a year within which this sale price would be first implemented. This capability enables the exploration of the costs that may be necessary to enable a hydrogen fuel market that competes with conventional transportation fuels on a cost-parity basis (providing equivalent miles of vehicle travel per dollar spent on fuel).

4. Expanded options for methods to calculate the reduction in installed cost for hydrogen fueling station equipment due to future technology progress and learning. The simple annual cost reduction method used in the preliminary draft results has been maintained and two new styles of calculation have been added, which determine cost reductions based on station deployment volume. One is a Moore's Law style (structured such that costs reduce by an input percentage for every doubling of the network), and the other follows the Hydrogen Station Cost Calculator function developed by NREL and described in prior AB 8 joint reports. Both new methods also have the ability to calculate cost reductions based on the full network deployment or to calculate separate cost reductions for each "class" of station, as determined by station capacity.

5. The ability to implement a speculative LCFS credit floor has been added. User input provides the dollar value of the credit floor and the year in which it would be implemented.

6. The minimum Internal Rate of Return used to calculate the additional funds needed to support a successful hydrogen refueling network can be set to decline as the network grows, which emulates the corresponding reduction of risk for investors into the industry.

CARB is validating these changes and considering draft results. CARB and the CEC may determine that one more round of industry review and feedback may be necessary to finalize validation of the results. Future reporting would then likely provide overviews of the assessments for several scenario evaluations, deep dives of results for select scenarios, and synthesis of commonalities and differences between scenarios. The agencies are working to complete this evaluation within one year.

# CHAPTER 8: Conclusions

In 2019, the deployment of FCEVs and hydrogen refueling stations continued in California. Today's hydrogen refueling station network, composed of 43 open retail stations (42 funded from the Clean Transportation Program and 1 funded privately), provides more than 11,800 kilograms of fueling capacity per day for the 6,826 FCEVs registered in California as of October 2019. The latest figure from private industry counts 7,883 FCEVs in the U.S. as of December 1, 2019. These U.S. sales figures are a close proxy for the number of FCEVs in California because there are few FCEVs in other states

Network coverage grew when four new stations opened, one in Sacramento, one in Oakland, and two in San Francisco. Nine open retail stations are in disadvantaged communities, and more than 23 percent of disadvantaged community residents live within a 15-minute drive of an open retail station.

Another 20 stations are in development. When all of these stations are open, the network will have a daily capacity of nearly 24,500 kilograms, 11 stations will be located in disadvantaged communities, and 35 percent of the disadvantaged community population will live within the 15-minute extent of coverage provided by the hydrogen refueling network.

However, California needs more stations to meet the AB 8 goal of at least 100 publicly available stations and the Governor Edmund G. Brown Jr. Executive Order B-48-18 goal of achieving 200 hydrogen stations by 2025. California also needs more stations to support the 48,000 FCEVs that industry projects by 2025. The Clean Transportation Program will support these needed stations through the recently released solicitation, GFO-19-602. Although industry involvement is expanding, station developers are relying on state funding to achieve economies of scale and reduce equipment costs, which are necessary for industry to achieve self-sufficiency.

The CEC structured GFO-19-602 to give station developers the opportunity to achieve the objectives of economies of scale and reduce equipment costs by providing funding allocations that span from 2020 to the end of the Clean Transportation Program. The CEC anticipates the up to $115.7 million in grant funding available in this solicitation will result in at least 60 additional stations. This expectation is based on stakeholder comments made in public workshops and discussions in meetings about economies of scale for hydrogen refueling equipment. The 60 additional stations would surpass the AB 8 goal of having at least 100 publicly available hydrogen refueling stations in California.

The CEC also continues to emphasize reduction in the time it takes to complete stations by adding critical milestones to ensure project readiness in GFO-19-602. CEC analysis indicates this approach is having some success, as station developers have significantly reduced the time to complete Phase One and Phase Four of recent projects. In addition, GFO-19-602 is reflective of the CEC's efforts to improve Clean Transportation Program investment in projects that result in tangible economic and environmental benefits to disadvantaged communities.

In 2020, the CEC will begin to assess if GFO-19-602 achieved the intended results in terms of station number, cost, time-to-build, and community benefits based on evaluation of station developer applications and grant awards. Hopefully, the solicitation will contribute to restoring momentum in FCEV and station deployment that slowed in the second half of 2019 because of a hydrogen supply disruption. Despite this setback, stakeholders are working to strengthen the hydrogen supply chain and the future for hydrogen transport looks bright as more medium- and heavy-duty fuel cell vehicles complete demonstrations and continue into commercial launch. The CEC and CARB support hydrogen projects for many types of heavier vehicles, as described in Appendix C and Appendix D, and these various projects should both help and be helped by the growth in light-duty FCEVs and the stations serving them.

# GLOSSARY

California Environmental Quality Act (CEQA)—a statute that requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate (address or reduce) those impacts, if feasible.

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

California Type Evaluation Program (CTEP)—all commercial weighing and measuring devices must be evaluated, tested, and approved by the Department of Food and Agriculture before use in California. This process is known as "type evaluation."

Chevron profile—the hourly variation in gasoline sales that reflects the influence of commuter patterns on fueling.[46]

Curtailment—reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis.

Disadvantaged Community—a community specifically targeted for investment of proceeds from the state's Cap-and-Trade Program. These investments are aimed at improving public health, quality of life, and economic opportunity in California's most burdened communities while reducing pollution that causes climate change. Disadvantaged communities are defined in CalEnviroScreen. https://oehha.ca.gov/calenviroscreen.

Fuel cell electric bus—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—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

46 Chen, Tan-Ping. Final Report: Hydrogen Delivery Infrastructure Options Analysis. Nexant. DOE Award Number: DE-FG36-05GO15032. http://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf. Nexant, Inc., Air Liquide, Argonne National Laboratory, Chevron Technology Venture, Gas Technology Institute, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and TIAX LLC. May 2008. H2A Hydrogen Delivery Infrastructure Analysis Models and Conventional Pathway Options Analysis Results, Interim Report. DE-FG36-05GO15032. https://www.energy.gov/sites/prod/files/2014/03/f9/nexant_h2a.pdf.

verify station capacity for the LCFS HRI program, and the CEC uses it to verify station capacity under GFO-19-602.

Hydrogen Station Equipment Performance (HyStEP) device—a device used by a certification agency to measure the performance of hydrogen dispensers with respect to the required fueling protocol standard. Specifically, the device has been designed to carry out the test methods of CSA HGV 4.3 to measure that stations follow the fueling protocols standard SAE International J2601-2014 including IrDA communications per SAE International J2799.

Levelized cost—the present value of the total cost of building and operating over an assumed lifetime.

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

Power-to-gas—is the conversion of surplus renewable energy into hydrogen gas by rapid response electrolysis and the subsequent injection into the gas distribution network.

Renewable Energy Certificates (RECs)—tradeable, non-tangible energy commodities that represent proof that 1 megawatt-hour of electricity was generated from an eligible renewable energy resource.

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

San Diego Area—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.

Spatially and Temporally Resolved Energy and Environmental Tool (STREET) Model—a model that determines the number of strategically located hydrogen refueling stations needed within a geographic area to enable the introduction of commercial volumes of fuel cell electric vehicles, and determine the geographic distribution of the required stations while assessing the environmental impacts.

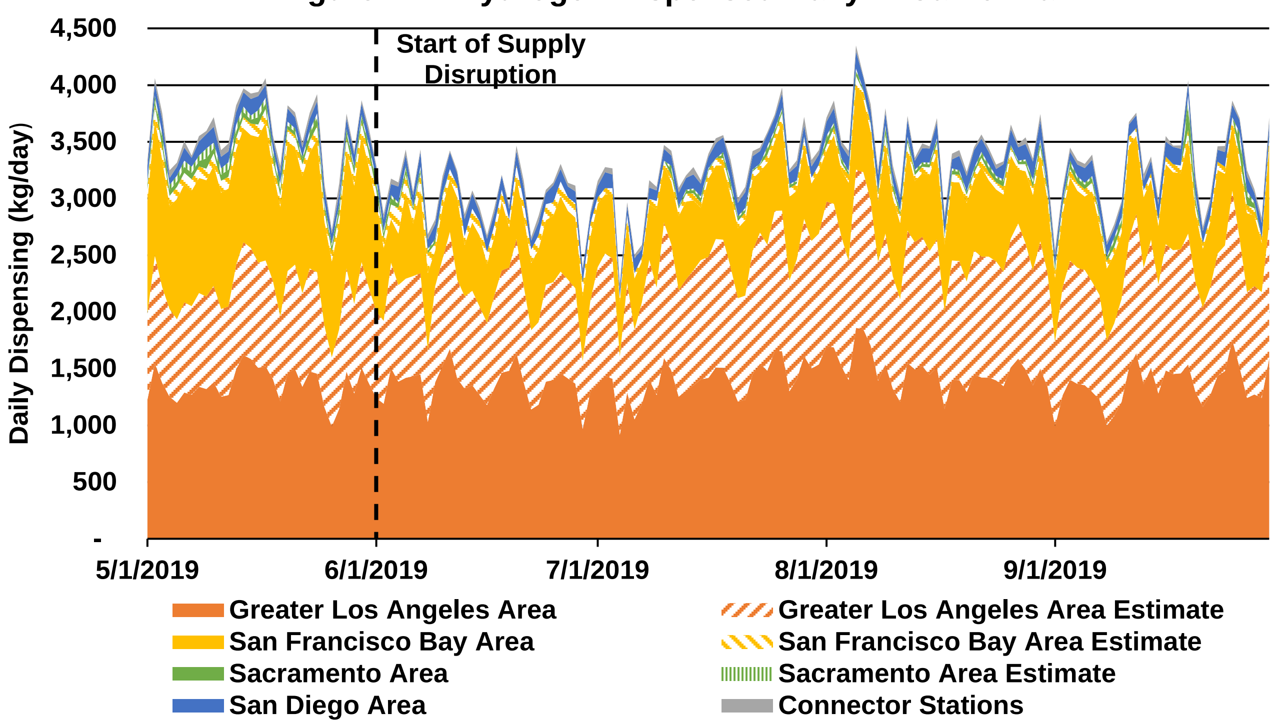
Zero-emission vehicle (ZEV)—a vehicle that emits no exhaust gas from the onboard source of power.

# APPENDIX A: Hydrogen Supply

A hydrogen supply disruption, caused by downtime at the Santa Clara transfill facility between June 1 and October 4, 2019, decreased the amount of hydrogen available to FCEV drivers. According to a press release by Air Products on November 1, 2019, "our Santa Clara system has returned to normal operation and our delivery capacity has reached pre-incident levels."[47] Figure A-1 shows the actual hydrogen dispensed in California between May 2019 and September 2019, before and during the downtime at the Santa Clara transfill facility. The decrease in hydrogen dispensed was nearly 300 kilograms per day. However, this decrease is not readily apparent in Figure A-1, for it is relatively small when looking at fueling for the entire state.

In Figure A-1, CEC staff added an "estimate," which is the dispensing amount that the CEC estimated for the stations that no longer report dispensing data. (Data reporting is required for a specified term in each grant agreement, and the terms for some stations have ended.) CEC staff assumed that each nonreporting station dispensed the average amount of hydrogen dispensed per reporting station within the respective region (either the Greater Los Angeles Area, San Francisco Bay Area, or Sacramento area).

**Figure A-1: Hydrogen Dispensed Daily in California**

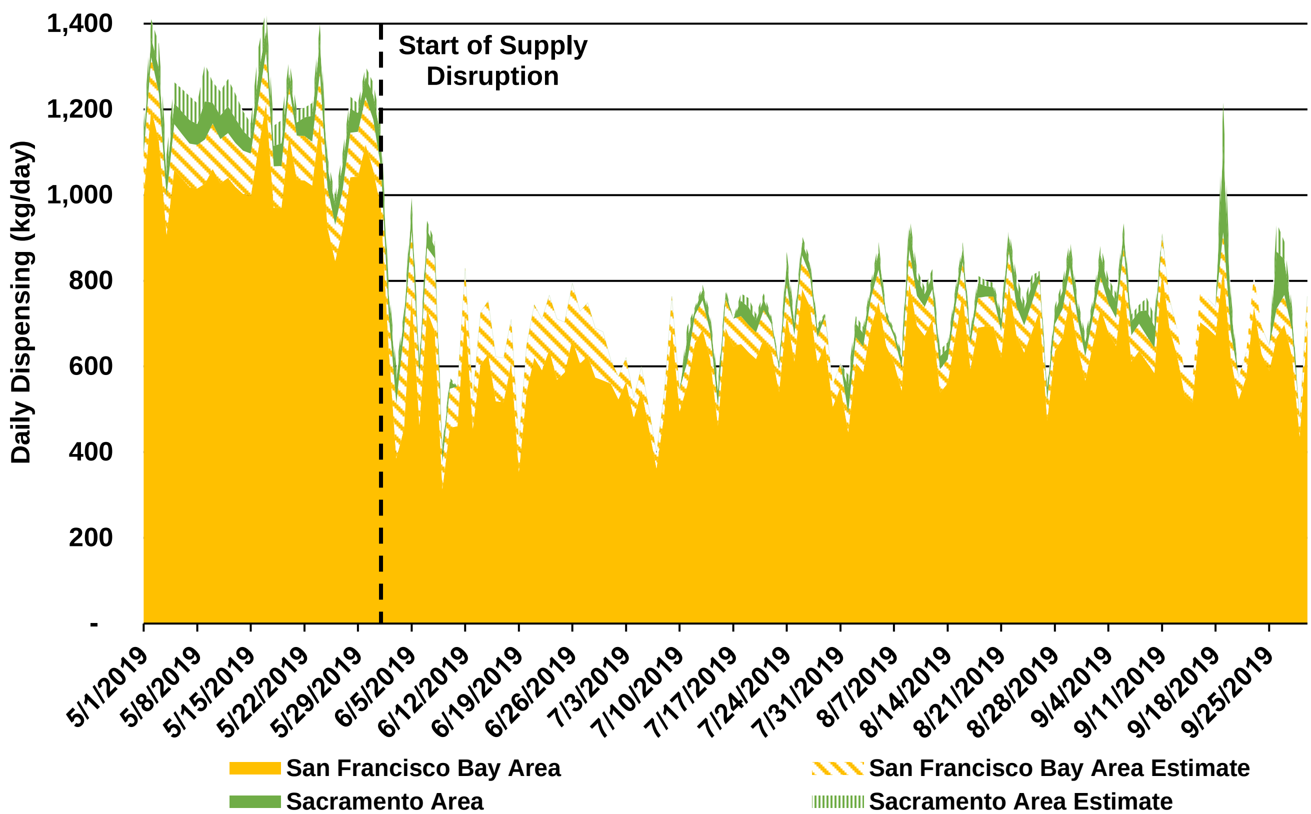



Source: CEC

47 Air Products. November 1, 2019. Air Products News: California Hydrogen Fueling Update. http://www.airproducts.com/APNews.aspx.

Figure A-2 shows the actual hydrogen dispensed in Northern California between May 2019 and September 2019, before and during the downtime at the Santa Clara transfill plant. When viewing fueling in Northern California only, the effect of the supply disruption is more apparent than when looking at the entire state. The decrease in hydrogen dispensed in Northern California was nearly 600 kilograms per day. Figure A-2 also has an "estimate" added for the stations that no longer report dispensing data because the mandatory reporting period has ended.

**Figure A-2: Hydrogen Dispensed Daily in Northern California**




Source: CEC

The supply disruption also negatively affected FCEV drivers and their confidence in hydrogen's future as a transportation fuel. FCEV drivers endured over four months with limited fuel and some auto dealerships decided to pause their FCEV deliveries until conditions improved, while others steered potential drivers away from choosing an FCEV as their next vehicle. One auto manufacturer stated, "They [the dealers] are making prudent decisions based on station outages and an abundance of caution to protect customers, our brand image, and dealership reputation."[48]

The industry response was swift and positive to address the supply disruption. The following are a few of the actions and activities undertaken by industry stakeholders:

- Auto manufacturers reimbursed their FCEV customers for rental car expenses and ride share and taxi expenses. In some cases, the cost of gasoline for private and rental cars

48 Phone communication with Stephen Ellis of American Honda Motor Company on 11/22/2019. With permission.

was covered.[49] Because many FCEV leases include a certain number of days of free car rental, auto manufacturers did not count these rental car days against the free benefit.[50]

- Station operators collaborated with each other and with auto manufacturers to direct available fuel to the stations that could serve the regional market needs most effectively during the disruption.[51]
- Some station developers chose to use all available hydrogen fuel to serve current customers, rather than divert some of that fuel to test and commission new stations to become open retail. Because of this choice, these developers missed deadlines for finishing new stations that they had to meet to receive full CEC grant funding.[52]
- Some station operators diverted the hydrogen supply that was available in Southern California to stations in Northern California experiencing the greatest unmet demand.
- One station operator incurred increased cost for their hydrogen supply, reporting as much as double the transportation costs for the fuel from source to station.[53]
- One station operator decoupled from their original supplier and provided their own fuel.[54]
- One station operator used the tube trailers they use as on-site storage in Southern California to deliver hydrogen to Northern California.[55]
- One station operator hired several "ambassadors," including a local college student, to help drivers fuel and answer questions at the Mountain View Station.[56]

The supply disruption exposed supply chain issues that stakeholders are now addressing. While it was an unfortunate setback, industry and government are implementing changes to avoid similar issues in the future, which will make the industry stronger.[57]

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49 Email communication with Matt McClory of Toyota Motor North America on 10/31/2019 and phone communication with Stephen Ellis of American Honda Motor Company on 11/22/2019. With permission.

50 Email communication with Gilbert Castillo of Hyundai Motor America on 11/5/2019 and phone communication with Stephen Ellis of American Honda Motor Company on 11/22/2019. With permission.

51 Email communication with Joseph Cappello of Iwatani and Wayne Leighty of Shell on 10/22/2019 and 10/30/2019, respectively. With permission.

52 Email communication with Wayne Leighty of Shell Hydrogen on 10/30/2019. With permission.

53 Email communication with Aaron Harris of Air Liquide on 10/24/2019. With permission.

54 Ibid.

55 Email communication with Edward Heydorn of Air Products on 10/28/2019. With permission.

56 Email communication with Joseph Cappello of Iwatani on 10/22/2019. With permission.

57 Email communication with Tim Brown of FirstElement Fuel on 10/30/2019. With permission.

## Announcements for More Hydrogen Supply

The industry is investing to make more hydrogen available to hydrogen refueling stations. A summary of recent press releases that identify planned hydrogen supplier investments follows:

- In November 2018, Air Liquide announced a $150 million planned investment in a 30 ton-per-day liquid hydrogen production plant.[58] The planned plant will produce enough hydrogen capacity to fill 35,000 light-duty FCEVs per day, or 10,000 FCEV trucks with fueling tanks of 30 kilograms. The plant will be located in North Las Vegas, Nevada.[59] Air Liquide will dedicate the hydrogen produced at this plant to hydrogen transport and mobility uses, particularly to the public hydrogen refueling stations in California.
- In January 2019, Air Products announced a second liquid hydrogen production plant in California. Air Products expects the plant to open in 2021.[60]
- In April 2019, Praxair expressed interest in serving a greater portion of the FCEV market than it presently does through its hydrogen production facility in Ontario, California.[61]
- In November 2019, Iwatani Corporation of America and ITM Power announced a collaboration to deploy multi-MW electrolyzers to produce renewable hydrogen as part of their shared interest in the California hydrogen refueling station market.[62]

Figure A-3 shows the locations of renewable hydrogen production plants funded by the Clean Transportation Program,[63] and a central fill plant that uses steam methane reformation, funded under the Clean Transportation Program.

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58 Air Liquide. November 26, 2018. "Air Liquide to build first world scale liquid hydrogen production plant dedicated to the supply of Hydrogen energy markets." https://en.media.airliquide.com/news/air-liquide-to-build-first-world-scale-liquid-hydrogen-production-plant-dedicated-to-the-supply-of-hydrogen-energy-markets-1cde-56033.html.

59 Air Liquide. October 8, 2019. "Air Liquide committed to producing renewable hydrogen for the West Coast mobility market with new liquid hydrogen plant." https://www.airliquide.com/united-states-america/air-liquide-committed-producing-renewable-hydrogen-west-coast-mobility-market.

60 Air Products. January 7, 2019. News Release – Air Products to Build Second Liquid Hydrogen Production Facility in California. http://www.airproducts.com/Company/news-center/2019/01/0107-air-products-to-build-second-liquid-hydrogen-productions-facility-in-california.aspx.

61 Email communication with Al Burgunder of Praxair on 10/30/2019. With permission.

62 ITM Power. November 19, 2019. ITM Power and Iwatani Corporation of America Establish U.S. Collaboration Agreement. https://www.itm-power.com/news/itm-power-and-iwatani-corporation-of-america-establish-us-collaboration-agreement.

63 California Energy Commission. Grant Funding Opportunity (GFO-17-602). Renewable Hydrogen Transportation Fuel Production Facilities and Systems. https://energyarchive.ca.gov/contracts/transportation.html.

**Figure A-3: Clean Transportation Program Funded Hydrogen Production Plants**


Source: CEC

## The Hydrogen Fuel Supply Chain

A resilient and reliable hydrogen fuel supply chain is essential to dependable refueling station operation and FCEV customer satisfaction. Diversifying fuel sources is one aspect of having a resilient supply chain and the CEC encourages station operators to have both primary and back-up supply sources. GFO-19-602 requires stations to have a second supply arrangement as backup.

Currently, most hydrogen delivered to hydrogen refueling stations is produced at the same production plant, which is why the supply announcements mentioned earlier in this section are of particular importance. Also important to a resilient hydrogen fuel supply chain is strengthening the distribution system, and the related logistics management, that brings hydrogen to stations. California uses predominantly tube trailer delivery and has one station with pipeline delivery.

The majority of the open retail stations in California store their hydrogen supply in gaseous form. There are limited distribution points (in other words, transfill plants) and tube trailer trucks to deliver gaseous hydrogen to stations, which is another potential weakness in the current system. Table A-1 shows today's open stations with liquid storage and those in development, which will enable delivery of hydrogen to stations using liquid trailers, a more robust system that transports more hydrogen fuel per delivery. Although the number of gaseous stations is almost triple that of liquid stations in the funded station network, the capacity stored in liquid form will exceed the amount stored in gaseous form when all funded stations are open. Liquid hydrogen does not need to go through a transfill plant, which is why the Santa Clara transfill plant downtime in 2019 did not affect the open retail liquid hydrogen stations. Having a more balanced mix of gaseous and liquid stations will help with supply chain resiliency and the overall resiliency of the hydrogen refueling station network in California.

**Table A-1: Liquid and Gaseous Hydrogen Refueling Stations in California**

| | Number of Stations | Capacity (kg/day) |
|---|---|---|
| **Open Retail Stations (Liquid)** | 5 | 2,208 |
| **Planned Stations (Liquid)** | 11 | 10,316 |
| **Total (Liquid)** | **16** | **12,524** |
| | | |
| **Open Retail Stations (Gaseous)** | 38 | 9,604 |
| **Planned Stations (Gaseous)** | 9 | 2,299 |
| **Total (Gaseous)** | **47** | **11,903** |

Source: CEC

Additionally, improvements are expected in the gaseous hydrogen distribution system. The economics for gaseous hydrogen transportation for regional distribution are improving with newer carbon-fiber tube trailers coming to market that will be able to deliver more than 1,100 kilograms in one truck, about doubling the capability of the tube trailers in use now.[64] These improved economics should lead to more investment in tube trailer infrastructure.

64 The National Academies vimeo website. Hydrogen Fueling Infrastructure. https://vimeo.com/355388282.

## Renewable Hydrogen

Presently, the amount of renewable hydrogen dispensed in California's network of hydrogen refueling stations is nearly 36 percent renewable. As stipulated in many CEC hydrogen solicitations and grant agreements and per the intent of Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006),[65] the California network of hydrogen refueling stations meets and exceeds the required 33 percent renewable hydrogen standard for dispensed hydrogen.

The fulfillment of the renewable hydrogen requirement can be either in the form of Renewable Energy Certificates (RECs) or from the dispensing of renewable hydrogen produced directly from renewable sources.[66] With limited sources and infrastructure available to secure hydrogen fuel from direct renewable sources, however, most of the fulfillment comes from the procurement of RECs.

As more renewably sourced hydrogen becomes available with the completion of 100 percent renewable production facilities funded by the Clean Transportation Program (GFO-17-602, Renewable Hydrogen Transportation Fuel Production Facilities and Systems) as shown in Figure A-3, there may be a business case to purchase and sell renewably sourced hydrogen directly from wind and solar projects.

## Hydrogen Production by Electrolysis

According to the U.S. DOE, as of 2017, annual hydrogen demand in the United States was about 8.8 million metric tons, which is mostly consumed by refineries and ammonia production. U.S. DOE projected that by 2030 hydrogen demand will jump to 25.6 million metric tons with demand coming from refineries, ammonia production, synthetic fuel production, and transportation. U.S. DOE expects nearly 1.6 percent (400,000 metric tons) of all hydrogen produced in the United States to be used for transportation in 2030.[67]

Hydrogen production from electrolyzers, which uses electricity to split water into hydrogen and oxygen, can especially be beneficial when the technology is coupled with electrical power produced from renewables, such as wind and solar. Electrolyzers can mitigate oversupply of electricity on the electrical grid (which can happen mostly during the midday periods, when renewable energy generation is high and demand low) by absorbing excess electricity to produce hydrogen that can be used for FCEVs. In the early evening, electric power demand begins to rapidly increase typically at the same time that renewable generation declines. This poses another challenge in ensuring a supply/demand balance on the grid, as new energy resources need to be tapped quickly. Fuel cells can help meet this need by providing electricity to the electrical grid by converting the hydrogen generated earlier in the day (or on previous

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65 California Legislative Information. Senate Bill 1505 Fuel: hydrogen alternative fuel (Lowenthal, Chapter 877, Statutes of 2006). https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=200520060SB1505.

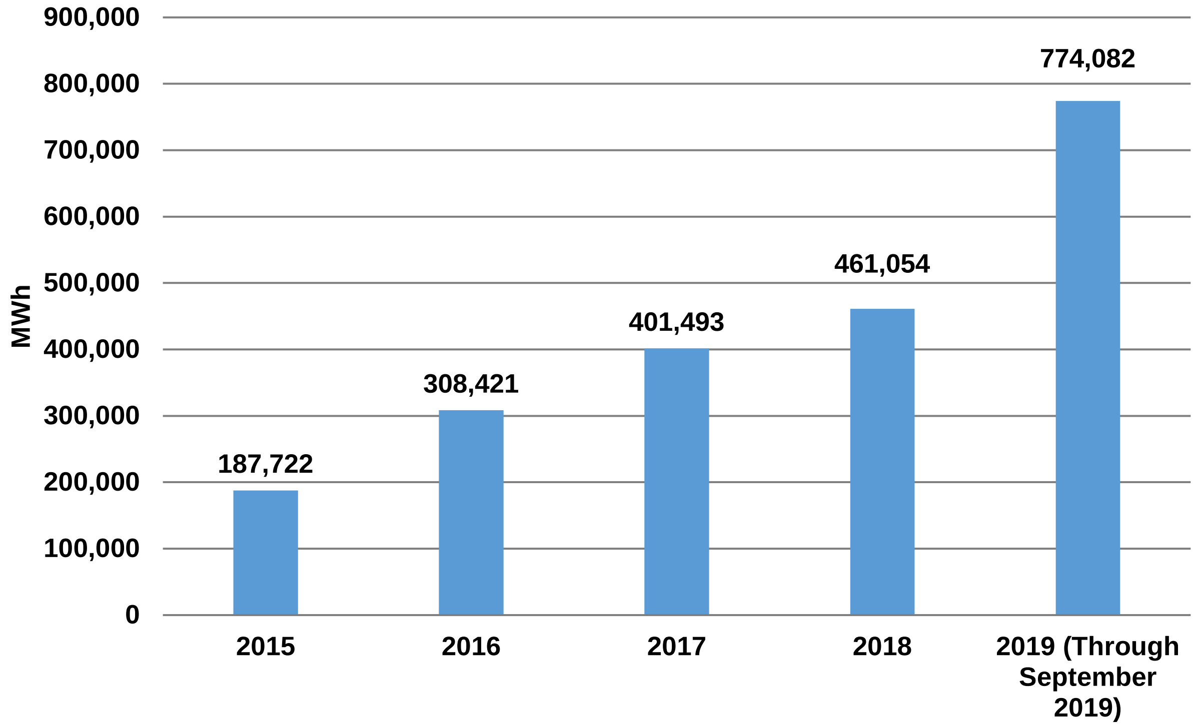
66 California Energy Commission. GFO-15-605 Solicitation Manual, Section VII. Renewable Hydrogen Requirements, pp 45-47. https://www.energy.ca.gov/solicitations/2016-04/gfo-15-605-light-duty-vehicle-hydrogen-refueling-infrastructure.

67 Satyapal, Sunita. June 13, 2018. Hydrogen and Fuel Cell Program Overview. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. https://www.hydrogen.energy.gov/pdfs/review18/01_satyapal_plenary_2018_amr.pdf.

days, weeks, or even months) back into electricity. The combination of midday excess generation and early evening demand ramp results in what is commonly known as the “duck curve.” In this way, hydrogen can act as a form of renewable energy storage that contributes to balancing the grid during challenging periods while also offering the opportunity to generate zero-emission fuel.

Figure A-4 shows actual electricity curtailment reported from solar and wind energy sources on the California Independent System Operator (CAISO) grid from 2015 to September 2019. The amount nearly quadruples over the five years. From 2018 to 2019, the amount doubled.

**Figure A-4: Curtailed Solar and Wind Electricity in California**

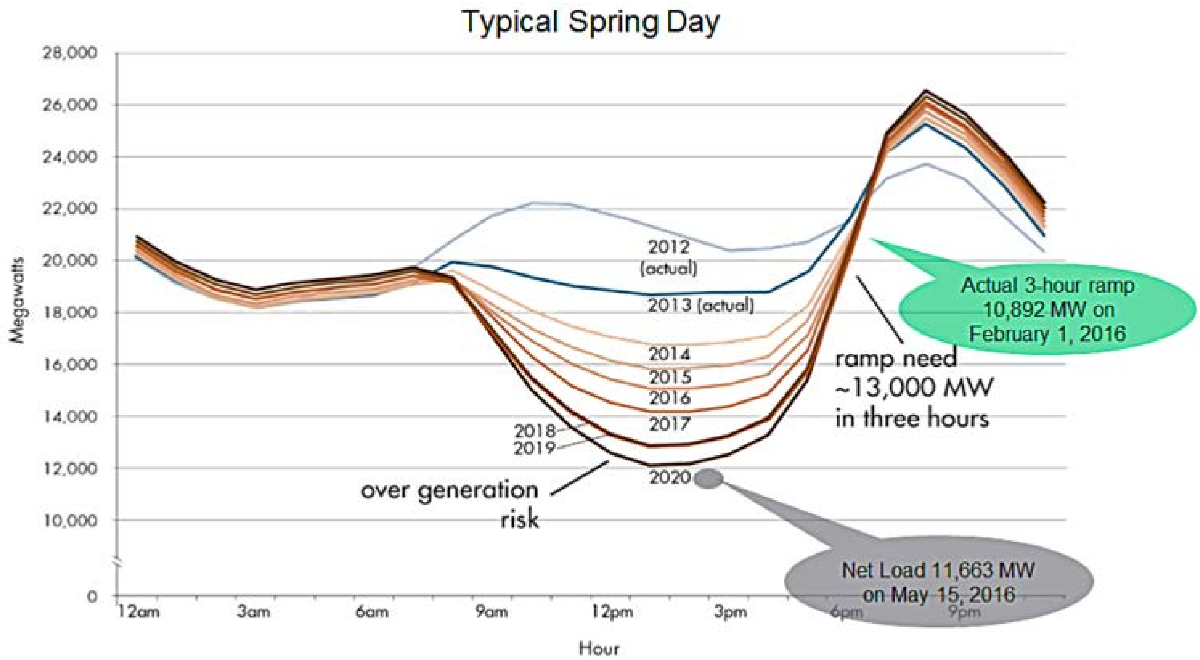



Source: CEC. Data obtained from CAISO.[68]

The CAISO projects that this trend is likely to continue into the future as shown in Figure A-5, which shows the “duck curve.” Figure A-5 shows the increasing potential for renewable energy curtailment as more of these resources are used on the electrical grid. All this leads to a growing potential for hydrogen refueling station operators to use greater amounts of curtailed solar and wind electricity in their stations in future years. GFO-19-602 encourages applicants to submit more competitive applications by explaining their plans to use curtailed solar and wind electricity in their hydrogen refueling station projects.

68 California ISO. Managing Oversupply.
http://www.caiso.com/informed/Pages/ManagingOversupply.aspx#dailyCurtailment.

**Figure A-5: Balancing Demand and Supply on California's Electrical Grid**




Source: CAISO[69]

According to the Union of Concerned Scientists, there are two main reasons behind renewable energy curtailment: system-wide oversupply and local transmission constraints. Oversupply occurs when there is not enough demand for all the renewable electricity that is available. Curtailment related to local transmission constraints occurs when there is insufficient transmission infrastructure to deliver that electricity to a place where it could be used. According to the Union of Concerned Scientists, without the additional transmission infrastructure, renewable electricity produced in some local areas of California will end up being curtailed because the electricity cannot be moved to places where it can be used. In 2018, about three-fifths of all curtailment was due to local transmission constraints.[70]

For every 100,000 MWh of usable electricity, about 1,700 metric tons of hydrogen can be produced assuming it takes 58 kWh to produce one kilogram of hydrogen. This calculation represents the maximum technical potential, given state-of-the-art electrolyzer technology. Estimating the real-world achievable hydrogen production potential from curtailed renewable electricity requires additional considerations. These include the electricity consumption needed to compress, store, and distribute the hydrogen (which may be similarly sourced from the curtailed renewable resources), local electrical grid constraints, individual project economics (especially matching volume and timing of locally-available electricity to individual project investment and profit potential), and market competition (such as battery energy storage, which can be implemented similarly to address renewable energy curtailment). These considerations require much more detailed analysis than can be presented here and appears

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69 California ISO. Fast Facts: What the duck curve tells us about managing a green grid. https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

70 Union of Concerned Scientists. Renewable Energy Curtailment 101: The Problem That's Actually Not a Problem At All. https://blog.ucsusa.org/mark-specht/renewable-energy-curtailment-101.

to currently represent a gap in the available research and technical literature. Still, with the expectation that curtailed renewable energy will only become an increasingly prominent concern for the reliable operation of the electrical grid, the potential for hydrogen to be implemented as a solution should similarly grow with time.

While it is currently difficult to estimate the full statewide potential for annual hydrogen production volume from curtailed renewable energy, there has been some investigation into the potential business case for pursuing this technology. In 2016, researchers at NREL published their analysis of the business case for these systems and found the potential to reduce the cost of renewable hydrogen by $2.50 per kilogram by enabling flexible electrolyzer operation (in response to supply and demand balance on the grid).[71] This work is also being updated through a study supported by the U.S. DOE, CARB, GO-Biz, and PG&E to explore more options for specific locations in California through a more detailed analysis of interactions with the grid and expanded system configuration options. Preliminary results demonstrate integrated renewable electrolysis can "present a valuable asset to the operation of the overall energy system, especially for their ability to act as a highly flexible load."[72] The California Hydrogen Business Council has also published a white paper on the topic, in which they found that hydrogen produced by this method could be cost-competitive with conventional vehicle fuels, even without assuming a price premium for conventional fuels in the future.[73]

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71 Eichman, Josh and Francisco Flores-Espino. December 2016. *California Power-to-Gas and Power-to-Hydrogen Near-Term Business Case Evaluation*. National Renewable Energy Laboratory. Technical Report NREL/TP-5400-67384. https://www.nrel.gov/docs/fy17osti/67384.pdf.

72 California Air Resources Board. July 2019. *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. Page 17. https://ww2.arb.ca.gov/sites/default/files/2019-07/AB8_report_2019_Final.pdf.

73 California Hydrogen Business Council. October 2015. *Power-to-Gas: The Case for Hydrogen White Paper.* https://www.californiahydrogen.org/wp-content/uploads/2018/01/CHBC-Hydrogen-Energy-Storage-White-Paper-FINAL.pdf.

# APPENDIX B:
# Fueling Trends

This appendix presents fueling trends from open retail stations. The CEC obtains quarterly data from station operators, and CEC and NREL staff compile and analyze the data. In most cases, station operators report dispensing data to the CEC through grant agreements. Some station operators stopped reporting data once their grant agreement ended, in which case CEC staff calculated the average dispensing per station for each region (Greater Los Angeles Area, San Francisco Bay Area, San Diego Area, and Sacramento Area) and assumed that calculated average was the amount dispensed for any station in that region that did not report.

Table B-1 shows stations with the most dispensed hydrogen in a day. Station operators can dispense more hydrogen than the reported nameplate capacity of the station by having hydrogen delivered multiple times to the station in one day. By doing this, the capacities of the hydrogen storage tanks effectively are increased through replenishment by the delivery trucks.

**Table B-1: Stations With the Most Dispensed Hydrogen in One Day in Q3 2019**

| Station | Reported Nameplate Capacity (kg/day) | Most Dispensed Hydrogen in One Day (kg/day) | Date |
|---|---|---|---|
| UC Irvine | 180 | 384 | 9/4/2019 |
| Torrance | 200 | 350 | 9/13/2019 |
| Costa Mesa | 180 | 320 | 8/6/2019 |
| Anaheim | 180 | 320 | 8/5/2019 |
| Mountain View | 350 | 310 | 8/8/2019 |
| Lake Forest | 180 | 300 | 8/5/2019 |
| San Ramon | 350 | 280 | 9/19/2019 |

Source: CEC

## Quarterly Trends

Figure B-1 shows the statewide network use by region, comparing actual hydrogen dispensing to the amount of hydrogen that could have been dispensed by the regional open retail station network each day according to its fueling capacity. The San Diego area experienced the highest rate of utilization growth from the fourth quarter of 2018 to the third quarter of 2019. Station utilization decreased in Northern California this year because of the hydrogen supply disruption discussed in Appendix A, and because a few new, relatively large stations opened in Sacramento and the San Francisco Bay Area. The new stations increased the fueling capacity in these regions substantially, outpacing the growth in fuel demand from FCEVs. While station utilization has grown continuously by quarter in Southern California, the overall statewide network utilization rate fell in quarter 3 of 2019, influenced by the factors mentioned for Northern California.

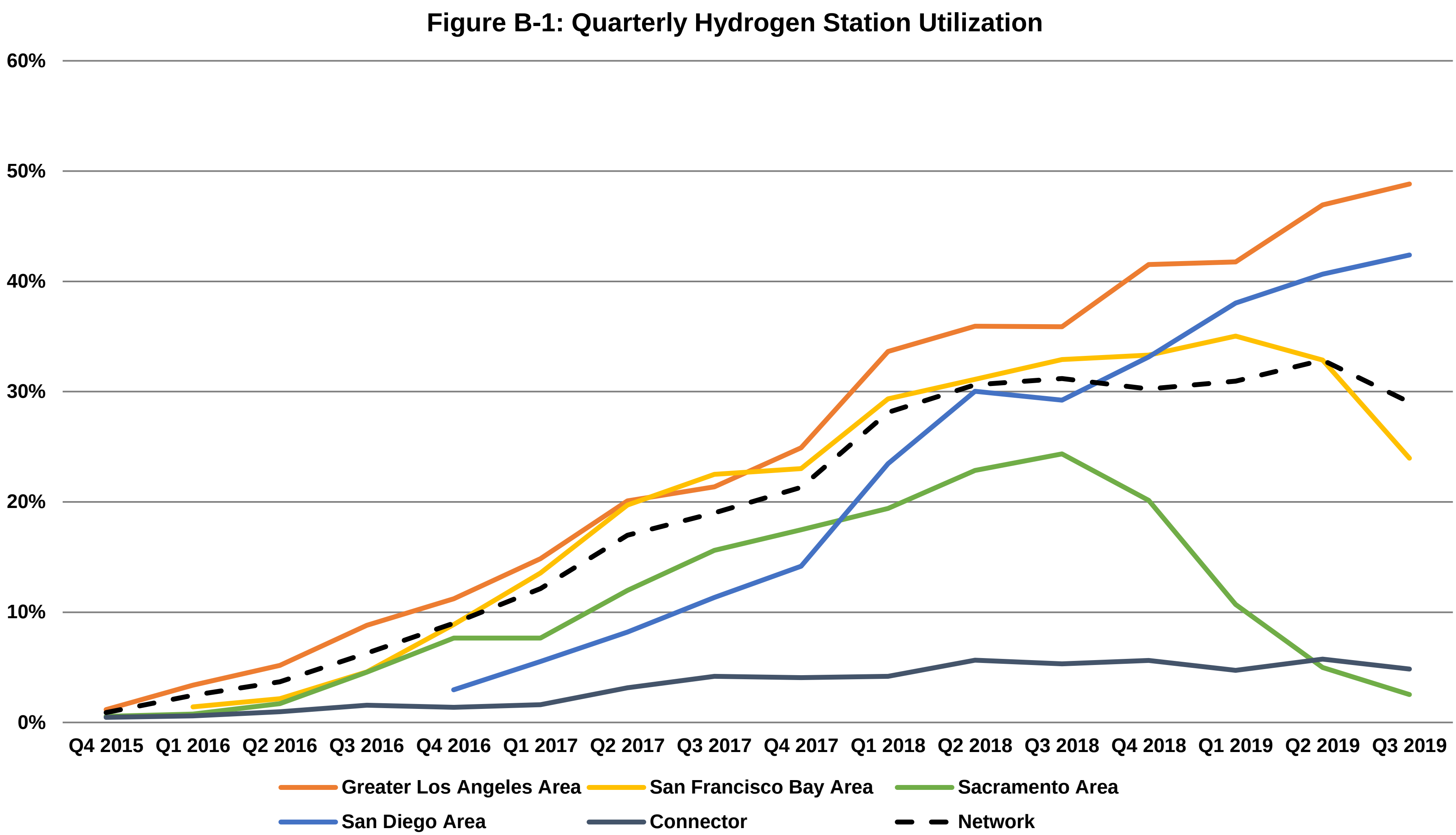


Figure B-1: Quarterly Hydrogen Station Utilization
60%
50%
40%
30%
20%
10%
0%
Q4 2015
Q1 2016
Q2 2016
Q3 2016
Q4 2016
Q1 2017
Q2 2017
Q3 2017
Q4 2017
Q1 2018
Q2 2018
Q3 2018
Q4 2018
Q1 2019
Q2 2019
Q3 2019
Greater Los Angeles Area
San Francisco Bay Area
Sacramento Area
San Diego Area
Connector
Network

Source: CEC

Figure B-2 summarizes the utilization for stations that are required to report the amount dispensed through an operation and maintenance agreement. The chart shows quarterly average kilograms dispensed relative to the capacity of the station (dispensed kilograms/capacity kilograms). The figure shows station count by quarterly average utilization in 10 percent increments with a cap of 100 percent. The 2018 Joint Report presented that two stations had greater than 90 percent utilization on average as of the third quarter of 2018. One year later, in the third quarter of 2019, one station had greater than 90 percent utilization on average. The average utilization rate is specified in the row of black boxes at the bottom of the figure.

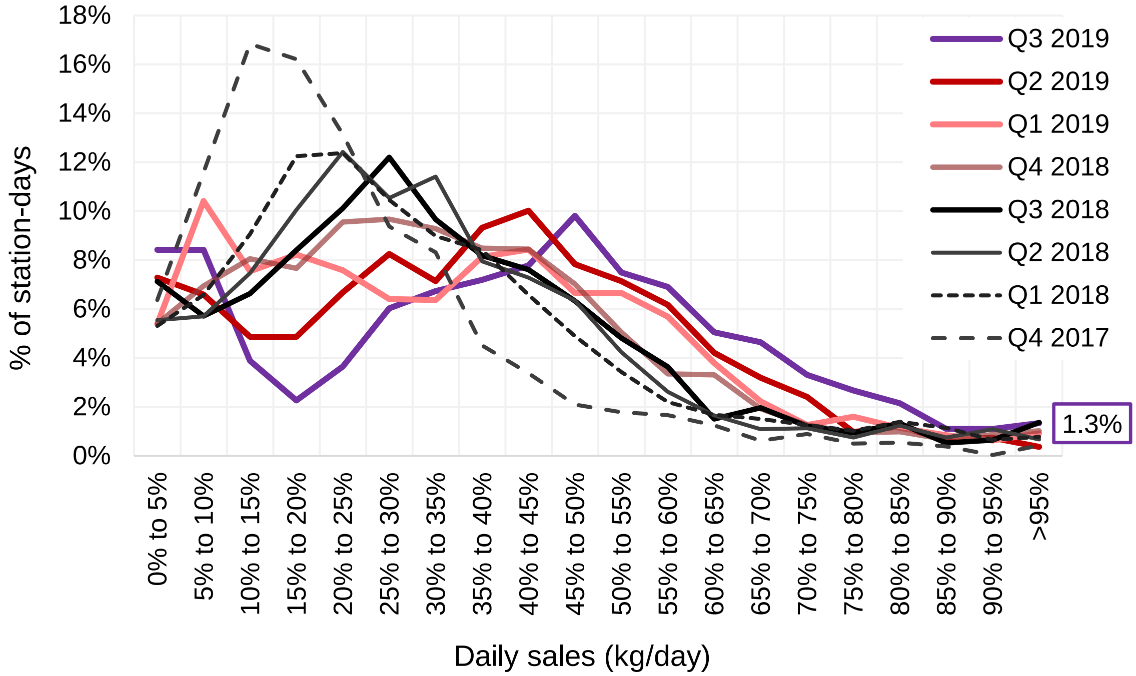
**Figure B-2: Number of Stations by Level of Utilization and Quarter**

| Utilization | Q4 17 | Q1 18 | Q2 18 | Q3 18 | Q4 18 | Q1 19 | Q2 19 | Q3 19 |
|---|---|---|---|---|---|---|---|---|
| 0% to 10% | 3 | 4 | 3 | 3 | 7 | 5 | 5 | 5 |
| 10% to 20% | 11 | 8 | 6 | 5 | 2 | 1 | 1 | |
| 20% to 30% | 8 | 5 | 9 | 6 | 5 | 5 | 7 | 4 |
| 30% to 40% | 4 | 6 | 5 | 7 | 5 | 4 | 4 | 1 |
| 40% to 50% | 1 | 4 | 5 | 4 | 5 | 4 | 3 | 4 |
| 50% to 60% | | | 1 | 3 | 3 | 4 | 4 | 3 |
| 60% to 70% | 1 | | | | 1 | 1 | 1 | 2 |
| 70% to 80% | 1 | 2 | 1 | 1 | | | 1 | 2 |
| 80% to 90% | | | 1 | | | 1 | | |
| 90% to 100% | | 1 | 1 | 2 | 2 | 1 | 1 | 1 |
| Reporting station count | 29 | 30 | 32 | 31 | 30 | 26 | 27 | 22 |
| Average utilization % | 22% | 28% | 31% | 32% | 35% | 34% | 34% | 34% |

Source: NREL

Figure B-3 shows the distribution of daily utilization across the network according to the number of days that each station operated within the indicated utilization ranges. In the third quarter of 2019, 1.3 percent of the station-days were spent at or above 95 percent of the capacity of the stations.

**Figure B-3: Percentage of Station-Days by Utilization Rate**




Source: NREL

One of the stations achieving more than 100 percent utilization shown in Figure B-3 is the UC Irvine station.[74] The station has the greatest throughput and was the most used station in California in 2019. Through the third quarter of 2019, the station experienced 51 days of more than 300 kilograms dispensed in one day. In September 2019, the station also experienced the highest monthly throughput of more than 8,200 kilograms dispensed. On October 10, 2019, the station dispensed nearly 400 kilograms, the new record for highest amount of hydrogen dispensed in a single day at a single station. This station fills one fuel cell electric bus daily. The filling occurs between 10 p.m. and 2 a.m., when light-duty FCEVs are unlikely to use the station.

Figure B-4 shows the percentage of the hourly amount of fuel dispensed in the California network from the fourth quarter of 2018 through the third quarter of 2019 compared with the Chevron Friday profile.[75] The Chevron Friday profile shows the hourly variation in refueling station demand for gasoline stations. The hydrogen fueling profile follows the gasoline fueling closely. However, because the California network of open hydrogen stations is 43 compared with 387 gasoline stations included in the Chevron Friday profile, having one station down for maintenance has a greater effect on the overall hydrogen station network than it would on the

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74 UCI plans to increase the daily capacity of the station from 180 kilograms per day to 800 kilograms per day by changing from gaseous hydrogen to liquid hydrogen and adding a second hydrogen dispenser for simultaneous refueling of two FCEVs. The upgrade funded by the Clean Transportation Program will have four fueling positions.

75 The *Chevron profile* is a profile developed based on fuel dispensing data from gas stations provided by Chevron. Source: Chen, Tan-Ping. *Final Report: Hydrogen Delivery Infrastructure Options Analysis*. Nexant. DOE Award Number: DE-FG36-05GO15032. http://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf.

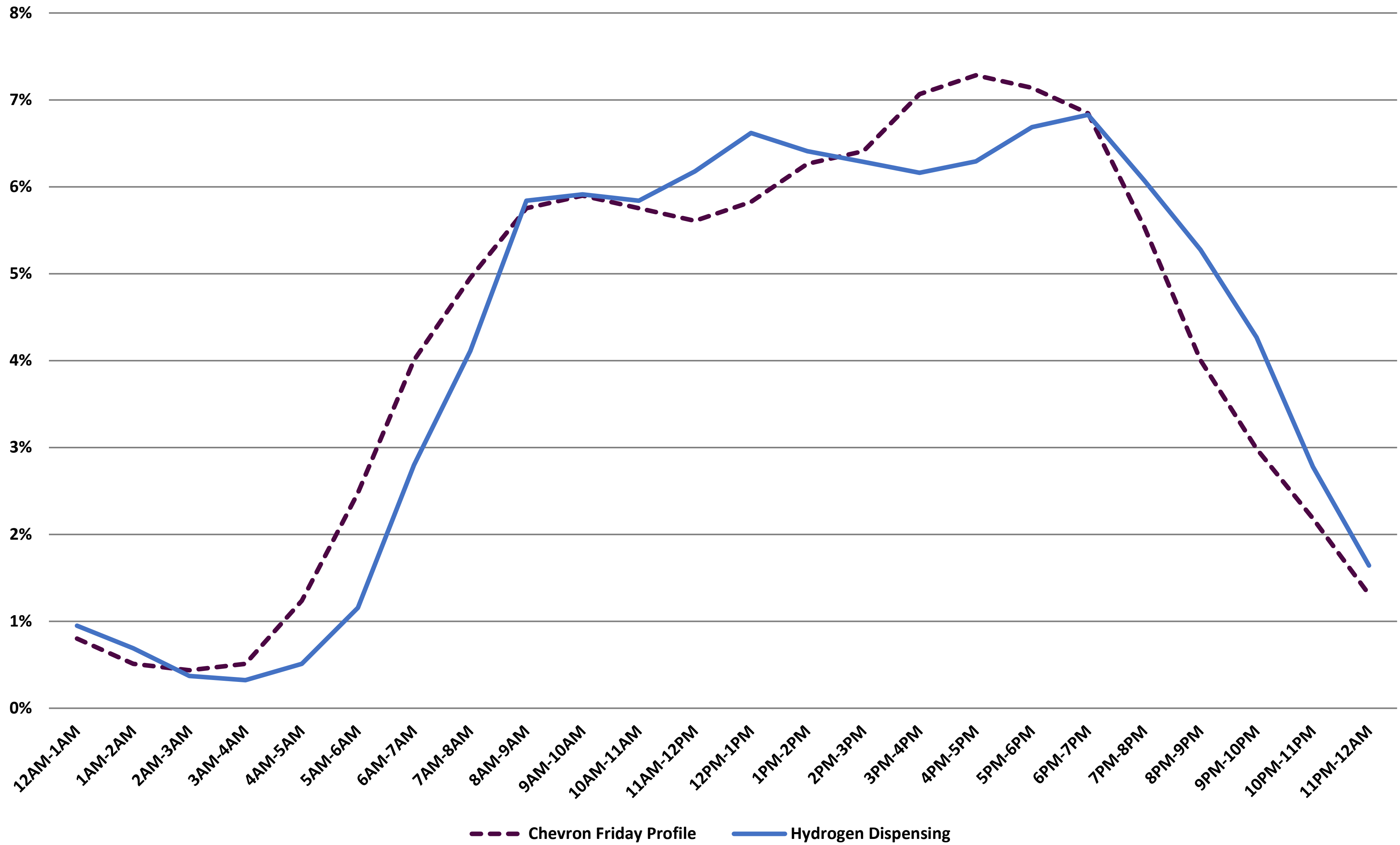
larger gasoline station network. In addition, FCEV drivers sometimes do not fuel at the times that they would normally depending on fuel availability. This situation may be one reason that the hydrogen dispensing profile differs a little from the Chevron Friday profile.

As shown in Figure B-4, the highest amount of hydrogen dispensing occurred between 6 p.m. and 7 p.m. and the lowest amount of dispensing occurred between 3 a.m. and 4 a.m. These are the same peak hours in fueling as in the 2018 Joint Report data from the previous year.

Figures B-5 through B-8 show regional analyses of average dispensing by time of day based on data from the fourth quarter of 2018 through the third quarter of 2019. The historical trend is that the fueling profile for hydrogen stations more closely resembles the Chevron Friday profile in areas with more hydrogen stations, such as the Greater Los Angeles Area and San Francisco Bay Area. The fueling profile in the Sacramento Area varies the most from the Chevron Friday profile.

Figure B-9 shows the percentage of fuel dispensed by day of the week from the fourth quarter of 2018 through the third quarter of 2019. The data show that most fueling occurs during the weekdays, with a smaller percentage of fuel dispensed over the weekends. This pattern is reversed for connector and destination stations, likely reflecting recreational trips taken on weekends.

## Figure B-4: Network Utilization Percentage by Time of Day




Source: CEC

**Figure B-5: Greater Los Angeles Area Fueling by Time of Day**

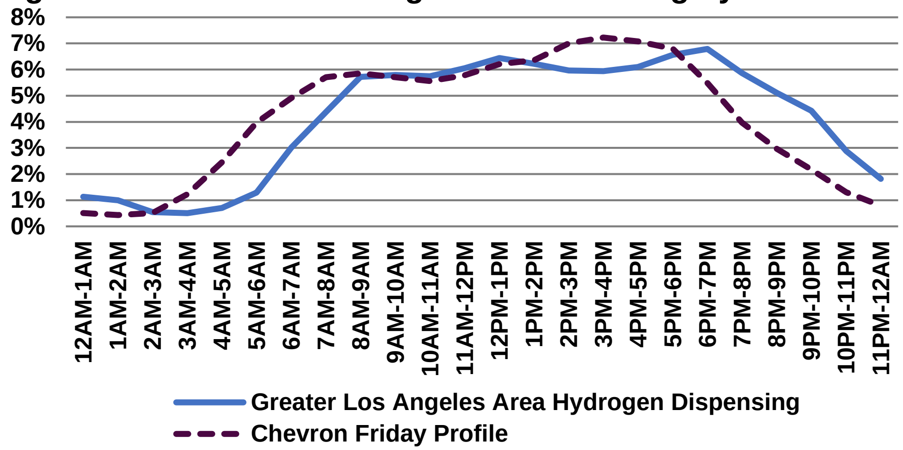



**Figure B-6: San Francisco Bay Area Fueling by Time of Day**

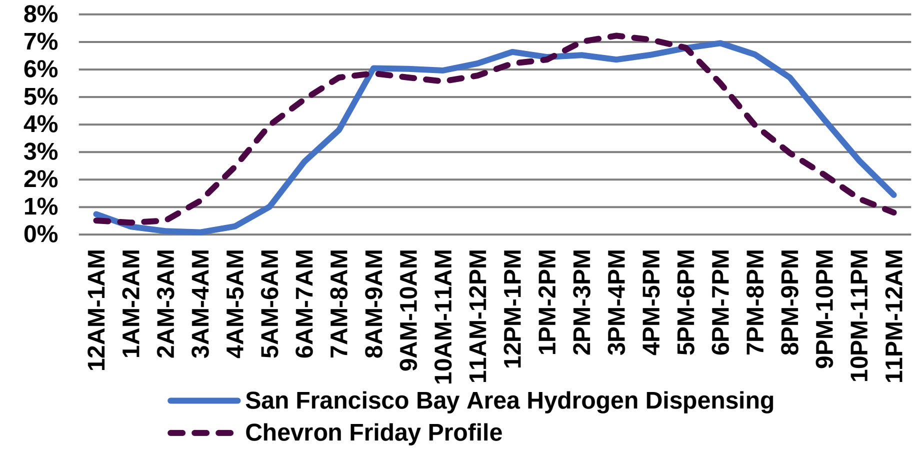



**Figure B-7: San Diego Area Fueling by Time of Day**

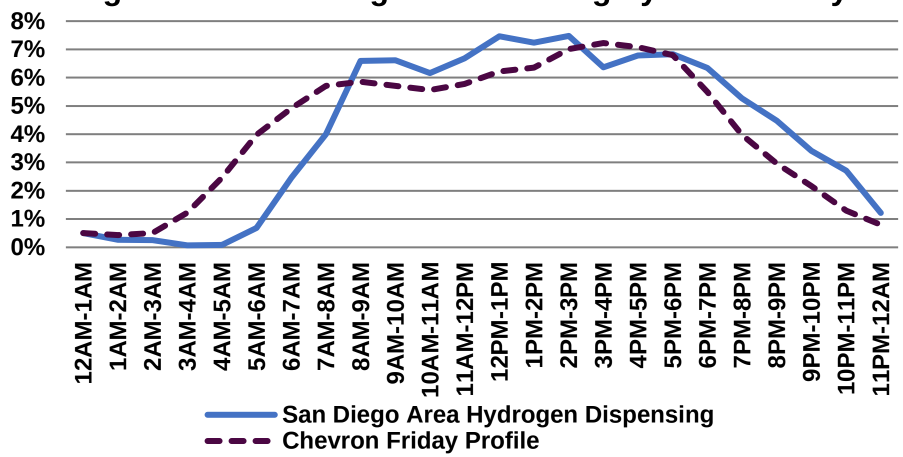
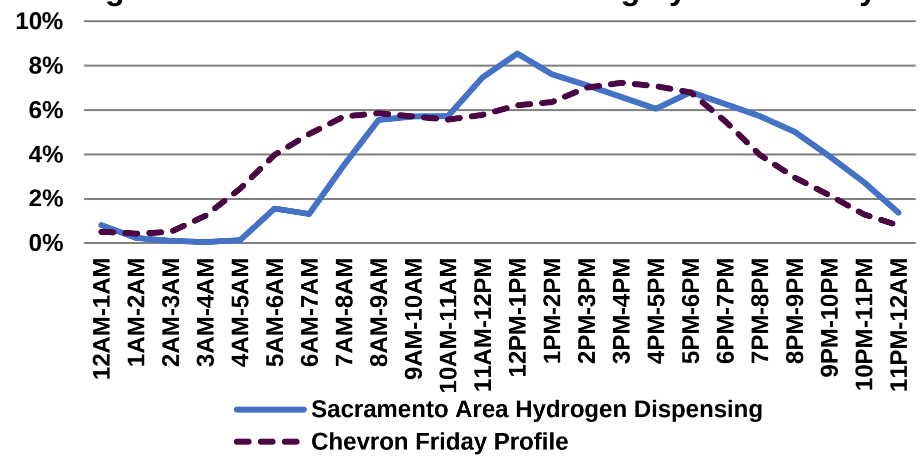
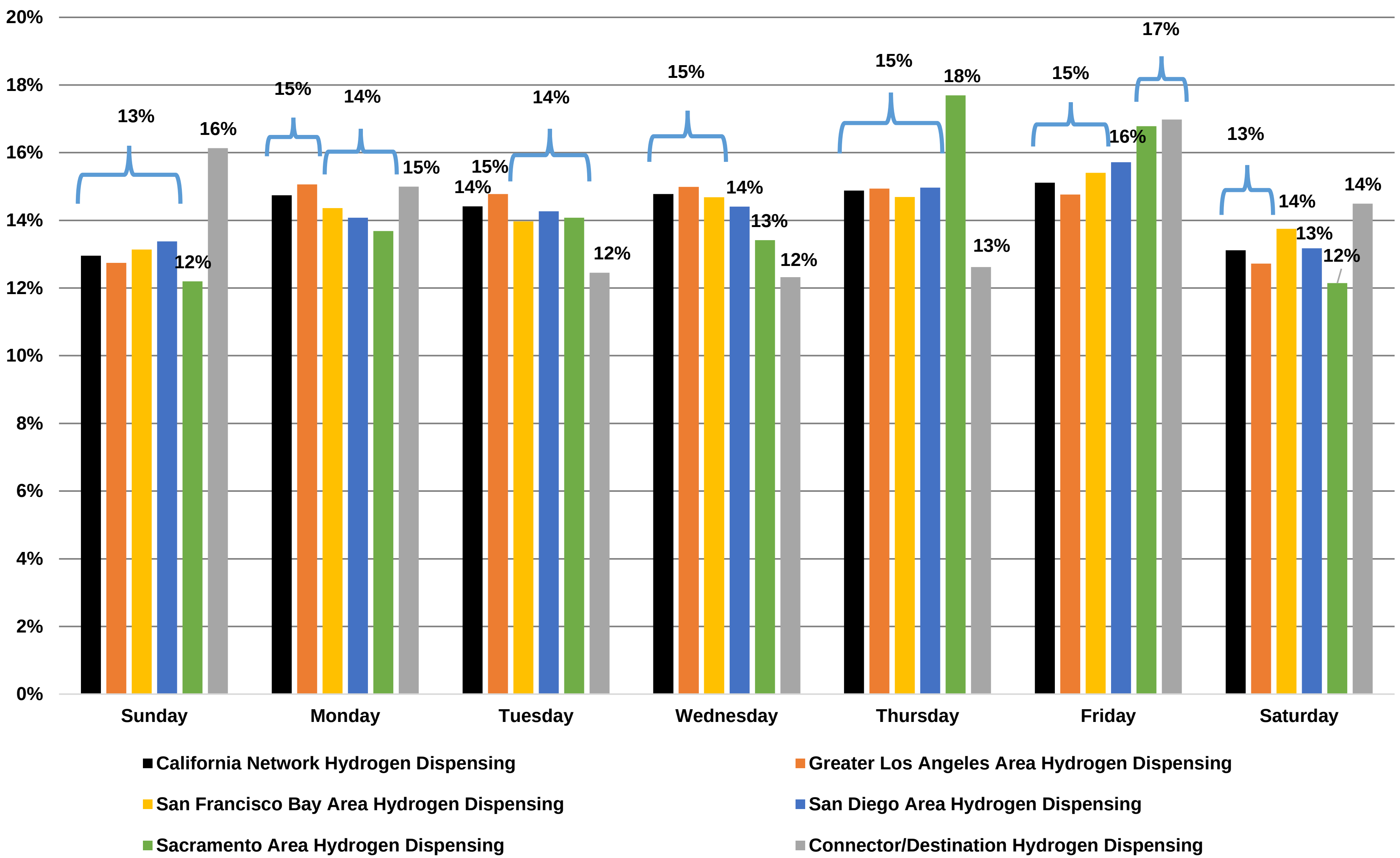



**Figure B-8: Sacramento Area Fueling by Time of Day**




Source: CEC

### Figure B-9: Percentage of Fuel Dispensed by Day of Week




Source: CEC

# APPENDIX C: H2@Scale Cooperative Research and Development Agreements

During 2019, CEC and CARB staff continued working on two H2@Scale Cooperative Research and Development Agreements (CRADA). The focus is hydrogen safety and infrastructure research.

## PNNL H2@Scale CRADA

The U.S. Department of Energy (U.S. DOE) awarded the CEC Clean Transportation Program a three-year safety project under its H2@Scale CRADA in 2017.[76] The Clean Transportation Program contributed $60,000 to the project. Under the CEC contract 600-17-006, the PNNL HSP continues to provide safety plan reviews according to their public guidelines[77] and potentially early design reviews of two renewable hydrogen production facilities funded under GFO-17-602, Renewable Hydrogen Transportation Fuel Production Facilities and Systems.

Work in 2019 included discussions with the two renewable hydrogen plant developers on their design, hydrogen equipment setback distances, safety protocol and procedures, and vulnerability assessments. Alignment with the U.S. DOE safety guidelines is critical to safe handling of high pressure and cryogenic hydrogen used in California's hydrogen refueling stations.

This year, the PNNL HSP provided CEC staff technical guidance on the Clean Transportation Program "Hydrogen Draft Solicitation Concepts for Hydrogen Refueling"[78] and the most recent solicitation, GFO-19-602,[79] on safety evaluations and requirements for future grant recipients to participate in early design reviews. The PNNL HSP will also conduct safety plan reviews of hydrogen refueling stations and hydrogen production plants funded in future Clean Transportation Program solicitations.

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76 National Renewable Energy Laboratory. H2@Scale Laboratory CRADA Call. https://www.nrel.gov/hydrogen/h2-at-scale-crada-call.html.

77 Pacific Northwest National Laboratory. September 2019. Safety Planning for Hydrogen and Fuel Cell Projects. PNNL-25279-2. https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-September2019.pdf.

78 California Energy Commission. January 23, 2019. Hydrogen Draft Solicitation Concepts. Subject Area – Light-Duty Hydrogen Refueling Infrastructure. https://efiling.energy.ca.gov/GetDocument.aspx?tn=226356&DocumentContentId=57125. Additional solicitation materials are available at California Energy Commission. Solicitations for Transportation Area Programs. https://energyarchive.ca.gov/contracts/transportation.html.

79 California Energy Commission. December 2019. GFO-19-602 – Hydrogen Refueling Infrastructure. https://www.energy.ca.gov/solicitations/2019-12/gfo-19-602-hydrogen-refueling-infrastructure.

## California Hydrogen Infrastructure Research Consortium CRADA

In 2019, the CEC, CARB, South Coast Air Quality Management District (SCAQMD), and the Governor's Office of Business and Economic Development (GO-Biz) continued to participate in the California Hydrogen Infrastructure Research Consortium CRADA with NREL. The U.S. DOE contributed $540,000 to this project, while the Clean Transportation Program provided $100,000, matched by CARB and SCAQMD, and GO-Biz provided in-kind resources.

The overall project objective is to have NREL and other H2@Scale national laboratory experts address near-term challenges for California hydrogen infrastructure development, deployment, and operation. Specifically, the CRADA includes the following tasks:[80]

**Data Collection and Analysis:** The purpose of this task is to perform analysis and aggregation of station performance, operation, and maintenance data. This task builds on years of collaboration between NREL, California agencies, and hydrogen refueling station operators to collect and analyze station data so that all public and private stakeholders investing in the stations can understand their costs, reliability, and fueling performance. NREL continues to prepare composite data products that report on key metrics and make them available online.[81] In this task, the Consortium is re-evaluating top priority metrics, considering monthly updates in addition to quarterly reporting, and identifying improvements to the online interface and report graphics. NREL is updating its data collection template accordingly to reflect the recommended changes.

**Medium-Duty/Heavy-Duty Fueling Data:** This task's objectives are to gather information on the benefits and opportunities of electrification via hydrogen in the medium- and heavy-duty sectors and report findings in a useable and accessible format for fueling–method decision makers. By compiling fueling performance information, this task also aims to provide useful information for stakeholders involved in fueling system design and protocol development for medium- and heavy-duty fuel cell trucks. The NREL team completed a summary of available information in May of this year and completed its analysis in August. NREL has drafted a report with the working title, *Why Hydrogen is Gaining Momentum in the Electrification of the Medium and Heavy-Duty Freight Market*, for publication once reviewed by the Consortium. The report will discuss class 4-6 medium-duty vehicles such as box trucks, school buses, and beverage trucks, and class 7-8 heavy-duty trucks such as transit buses, garbage trucks, drayage trucks, and semi sleeper trucks.

**H2 Contaminant Detector:** This task's goals are to complete near real-time compliance verification of some contaminants to the SAE International J2719 hydrogen purity specification requirements of two in-line hydrogen contaminant detectors (HCDs) prior to validation at retail

80 Kurtz, Jennifer, Sam Sprik, Mike Peters, Bill Buttner, Shaun Onorato. April 2019. California Hydrogen Research Consortium, Project ID H2041. Presentation given at the U.S. DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/73801.pdf.

81 NREL. Hydrogen & Fuel Cells – Hydrogen Fueling Infrastructure Analysis. https://www.nrel.gov/hydrogen/hydrogen-infrastructure-analysis.html.

hydrogen stations. After considering various selection criteria, the Consortium chose to evaluate two sensors, one a commercially available Fourier-transform infrared spectroscopy sensor, and one a prototype electrochemical sensor provided by the Los Alamos National Laboratory. NREL ordered and received the selected HCDs and has developed a test plan for validating them. NREL first will conduct benchtop tests before testing the HCDs outdoors at the NREL hydrogen refueling station using an NREL-designed and built HCD-Interface that will serve as a pressure reducer and flow controller. The Consortium anticipates publishing results of the HCD testing in 2020.

**Nozzle Freeze-Lock Evaluation:** The purpose of this task is to create an environmentally controlled experiment to identify conditions leading to hydrogen dispenser nozzle freeze-lock and to verify solutions to this problem. NREL finalized the test plan for a three-phase experiment in early 2019 and shared the baseline freeze-lock occurrence analysis results of the phase one tests with the Consortium members in June 2019. Thus far, NREL has reliably generated the temperature and dew point conditions needed for the tests in most cases, and has found that freeze-lock occurrence is more likely in more humid and hotter conditions (as expected). More data points are required to determine freeze-lock trends, especially at lower temperatures. NREL is progressing to phase two testing using a redefined test matrix of temperature and dew points to better understand conditions in which freeze-lock occurs. Phase three will evaluate new/existing nozzles under freeze-lock conditions using the comprehensive text matrix developed through the earlier phases. NREL is writing a technical report that documents the results from each phase of testing.

**California Hydrogen Integration:** This task's objective is to inform California decision/policy makers about the benefits and gaps of integrating hydrogen into energy management plans as a strategy for achieving carbon-free energy systems. NREL has completed a literature review of existing hydrogen grid integration and energy storage projects, including related experiments conducted at various national laboratories. NREL is analyzing electrolyzers in comparison to other production and storage technologies, evaluating the value of electrolyzers towards resolving the "duck curve"[82] and reducing curtailment of renewable energy, and studying affordable pathways for hydrogen integration and transportability. This task will result in a technical report.

82 California Energy Commission. Tracking Progress – Resource Flexibility. https://ww2.energy.ca.gov/renewables/tracking_progress/documents/resource_flexibility.pdf.

# APPENDIX D: Hydrogen and Fuel Cell Projects

Since its inception, the Clean Transportation Program has funded various hydrogen related projects in addition to light-duty hydrogen refueling stations using Clean Transportation Program funding. Combined with the projects funded by the CARB Climate Change Investments Program and the South Coast Air Quality Management District, the CEC estimates that the renewable hydrogen produced from the projects totals over 3,000 kilograms per day and the fuel demand expected from the vehicle projects totals over 1,400 kilograms per day.

## Projects Funded by Clean Transportation Program

Table D-1 shows fuel cell commercial vehicle projects, fuel cell transit bus projects, and other related projects that the Clean Transportation Program funded, in chronological order.

**Table D-1: Fuel Cell Commercial Vehicle and Transit Bus Projects**

| Year and Project | Description |
|---|---|
| 2009: Southern California Fill System, Stations, and Delivery Trailers | Hydrogen production plant with 4,000 kg/day capacity, twelve delivery trailers, and eight hydrogen refueling stations (AB 118 funding). The plant uses steam methane reformation and produces 33 percent renewable hydrogen. |
| 2010: Purpose Built Hydrogen Fuel Cell Light Duty and Bus Refueling Station in Emeryville | The Emeryville station was built with a 510 kilowatt (kW) solar photovoltaic system to provide 100 percent renewable electricity to an electrolyzer that is capable of producing up to 65 kilograms daily of renewable hydrogen. This station was upgraded in 2018 and no longer includes the electrolyzer. This station now dispenses hydrogen with 33 percent renewable content. |
| 2010: Hydrogen Fuel Cell Bus Refueling Station in the Alameda-Contra Costa Transit District (AC Transit) | Hydrogen refueling station at AC Transit's Seminary Division 4 facility in Oakland, CA was funded by the Clean Transportation Program, CARB, the Federal Transit Administration, Valley Transportation Authority, San Mateo County Transit District, Golden Gate Transit, PG&E, and AC Transit. The station serves fuel cell buses that operate in the San Francisco Bay Area. AC Transit has 24 fuel cell buses in their fleet. |

| Year and Project | Description |
|---|---|
| 2013: Battery Dominant Fuel Cell Hybrid Bus Project | The project funded a 40-foot heavy-duty transit bus. The project reduced the size of the onboard fuel cell engine, the most expensive component on the bus, thereby reducing the overall price of the bus by 70 percent. Other funders included the Federal Transit Administration, SunLine Transit, and other private parties. SunLine has operated the bus since November 16, 2018, and has accumulated 300 to 400 miles per week on routes in service. The bus is expected to reduce greenhouse gas emissions by about 90 metric tons per year. |
| 2013: UC Irvine Light Duty Station that Fills Buses | The UC Irvine hydrogen station is used by light-duty FCEV drivers and two fuel cell buses operated by the UCI Anteater Express and the Orange County Transit Authority (OCTA). |
| 2014: Fuel Cell Hybrid Electric Walk-In Van Deployment Project | The project was to develop, validate, and deploy fuel cell hybrid electric walk-in delivery vans. The U.S. Department of Energy also awarded this project a federal grant. Project partners included the University of Texas Center for Electromechanics, Electric Vehicles International, Hydrogenics, Valence Technology, and United Parcel Service (UPS). |
| 2016: Innovative Mobility Service Demonstrations with ZEVs | Funded under GFO-16-605 Innovative Mobility Service Demonstrations with Zero-Emission Vehicles, the StratosFuel, Inc. project funds a car sharing service called StratosShare using a fleet of Toyota™ Mirai. |
| 2018: Renewable Hydrogen Production Plant in Moreno Valley in Riverside County | The plant will produce 100 percent renewable hydrogen. The CEC funded 2,000 kg/day of the plant’s total capacity of 5,000 kg/day. |
| 2018: Renewable Hydrogen Production Plant in unincorporated Kings County near Coalinga | The plant, which will produce 1,000 kg/day of 100 percent renewable hydrogen, is expected to be funded by the Clean Transportation Program. |
| 2018: Renewable Hydrogen Fueling at Scale for Freight | Equilon Enterprises LLC (d.b.a. Shell Oil Products US) partnered with Toyota Motor North America to produce a heavy-duty hydrogen fueling project for the Port of Long Beach. The project will develop a hydrogen fueling station servicing Class 8 fuel cell drayage trucks by sourcing hydrogen from 100 percent renewable biogas. The station will fill light- and medium duty passenger vehicles and commercial trucks. |

| Year and Project | Description |
|---|---|
| 2018: Roadmap for the Deployment and Buildout of Renewable Hydrogen Generation Plants | The CEC funded a renewable hydrogen roadmap from 2019 to 2050, which includes the potential strategies for renewable hydrogen production and the economic and environmental benefits of using hydrogen. Technical experts at the Advanced Power and Energy Program at the University of California, Irvine, are developing the roadmap. |
| 2020: Advanced Hydrogen Refueling Hub Station | The CEC is in the process of releasing a Request for Information on advanced hydrogen refueling hub stations, their requirements, their cost, and their viability. |

Source: CEC

## StratosShare Launch

On September 19, 2019, the StratosShare carsharing project, funded under GFO-16-605, Innovative Mobility Service Demonstrations with ZEVs, had a ribbon-cutting event at the UC Riverside Center for Environmental Research and Technology (CE-CERT).

CEC Commissioner Patty Monahan spoke at the event and held the scissors for the ribbon cutting. Figure D-1 pictures (left to right) James Kast, Toyota Motor North America; Matthew Barth, UC Riverside CE-CERT; Patty Monahan; Jonathan Palacios-Avila, StratosFuel/StratosShare; Brittany Avila, StratosFuel/StratosShare; John Valdivia, Mayor of San Bernardino; and Todd Warden, South Coast Air Quality Management District.

**Figure D-1: CEC Commissioner Patty Monahan at the StratosShare Launch Event**


Source: CEC

## Projects Funded by CARB California Climate Investments

Table D-2 lists hydrogen and fuel cell projects in the medium- and heavy-duty sectors funded by the CARB California Climate Investments (CCI) Program.[83] The CCI Program funded 30 buses, 15 Class 8 trucks, 3 yard trucks, 1 electric top loader, 19 delivery vans, and 1 passenger ferry.

The table also shows an estimate of daily hydrogen consumption, which totals 1,250 kilograms per day, for the projects in the table. The CEC estimated this amount based on typical fuel usage of the vehicles. Actual amount is very likely to differ.

**Table D-2: CCI Projects and Estimated Daily Use of Hydrogen**

| Project funded through CCI | Description | Hydrogen Supply | Estimated H2 Consumption (kg/day)[84] |
|---|---|---|---|
| SunLine Fuel Cell Buses and Hydrogen Onsite Generation Refueling Station Pilot Commercial Deployment | • 5 fuel cell buses<br>• Upgraded hydrogen refueling station | On-site electrolysis | 250 |
| Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project | • 5 fuel cell buses at SunLine Transit | On-site electrolysis | 250 |
| Fuel Cell Electric Bus Commercialization Consortium | • 20 fuel cell buses at Orange County Transit Authority and AC Transit<br>• Upgraded hydrogen refueling stations at AC Transit Emeryville and Oakland<br>• Hydrogen station at OCTA's Santa Ana Base | Delivered liquid | 350 |
| 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 | Delivered gas | 60 |
| Zero-Emission for California Ports Yard Trucks | • 2 yard trucks at the Port of Los Angeles | Delivered gas | 10[85] |

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

84 Estimated consumption, actual consumption may vary.

85 Consumption potential of 20 kilograms.

| Project funded through CCI | Description | Hydrogen Supply | Estimated H2 Consumption (kg/day)[84] |
|---|---|---|---|
| Fuel Cell Hybrid Electric Top Loader | • 1 electric top loader at the Port of Los Angeles | Delivered gas | 20 |
| Fuel Cell Hybrid Electric and Next Generation Fuel Cell Delivery Van Deployment | • 19 fuel cell electric delivery vans in Ontario | Delivered gas | 80 |
| Zero-Emission Hydrogen Ferry Demonstration | • 1 hydrogen fuel cell ferry in the San Francisco Bay | Delivered gas | 60 |
| Port of Los Angeles “Shore to Shore” | • 10 hydrogen fuel cell Class 8 on-road trucks in the Port of Los Angeles | Delivered gas | 160 |
| The Commercialization of Port of Long Beach Off-Road Technology Demonstration | • 1 yard truck at the Port of Long Beach | Delivered gas | 10 |
| | | **Total Daily Hydrogen Consumption** | **1,250** |

*Assumes fuel consumption on SunLine’s HVIP-funded buses will be the same as that of the five buses funded in SunLine’s pilot project.

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

## Zero Emission Cargo Transport II (ZECT II)

ZECT II is funded by the U.S. DOE in partnership with the SCAQMD, CEC, Port of Los Angeles, Port of Long Beach, Los Angeles Department of Water and Power, and SoCal Gas, consisting of demonstration, data collection, and analysis of seven alternative fuel trucks on five different vehicle architectures to accelerate the introduction and penetration of zero and near-zero-emission fuel cell and hybrid technologies in the cargo transport sector. The project includes six fuel cell trucks that will use hydrogen as fuel. Table D-3 lists the ZECT II project vehicles and their expected fuel demand if operating at full schedules.

The Center for Transportation and the Environment (CTE), BAE Systems, and Kenworth are developing one of the vehicles. It is a battery electric truck with a hydrogen fuel cell range extender. This truck will operate in electric mode at all times and all speeds until the battery energy system reaches a low operating state of charge, at which point the hydrogen range extender will be activated to supplement power.

TransPower is developing two battery electric trucks with hydrogen fuel cell range extenders that will use a small fuel cell and stored hydrogen. Both TransPower trucks will be equipped with a 60 kW fuel cell.

U.S. Hybrid is developing two battery electric trucks with an on-board hydrogen fuel cell generator. Each truck will have 20 kilograms of hydrogen storage at 350 bar pressure, with an estimated fueling time under 10 minutes.

Hydrogenics is developing and demonstrating a fuel cell range extended Class 8 truck. The truck has an expected range of 150-200 miles on 20 kilograms of hydrogen, with the truck demonstration expected to use two tanks of fuel per day.

The daily hydrogen demand from all of these ZECT II projects, if all the trucks are operated at their full potential, is nearly 170 kilograms.

**Table D-3: Expected ZECT II Project Fuel Demand**

| Project Vehicles | Estimated H2 Consumption (kg/day) |
|---|---|
| Kenworth Truck (CTE) | 50 |
| Two TransPower Trucks | 38 |
| Two U.S. Hybrid Trucks | 40 |
| Hydrogenics Truck | 40 |
| **Potential Daily Hydrogen Consumption** | **168** |

Source: CTE

# APPENDIX E:
# List of Hydrogen Refueling Stations in California

Table E-1 lists 42 open retail hydrogen refueling stations, with photos, funded by the Clean Transportation Program (the privately-funded open retail station in Newport Beach is not listed). The CEC staff took the photo if no photo credit is listed.

**Table E-1: Clean Transportation Program Funded Open Retail Stations**

| Station Information | Station | Station | Station |
|---|---|---|---|
| **Photograph** |  Photo Credit: Air Liquide |  |  Photo Credit: California Fuel Cell Partnership |
| **Name** | Anaheim | Campbell | Citrus Heights |
| **Address** | 3731 East La Palma Avenue | 2855 Winchester Boulevard | 6141 Greenback Lane |
| **Open Retail Date** | 11/29/2016 | 6/9/2016 | 12/18/2018 |
| **Solicitation** | PON-12-606 | PON-13-607 | GFO-15-605 |
| **Photograph** |  Photo Credit: FirstElement Fuel |   |  |
| **Name** | Coalinga | Costa Mesa | Del Mar (San Diego) |
| **Address** | 24505 West Dorris Avenue | 2050 Harbor Boulevard | 3060 Carmel Valley Road |
| **Open Retail Date** | 12/11/2015 | 1/21/2016 | 12/2/2016 |
| **Solicitation** | PON-13-607 | PON-13-607 | PON-13-607 |

Source: CEC, photo credit: CEC unless otherwise stated

| Station Information | Station | Station | Station |
|---|---|---|---|
| **Photograph** |  |  Photo Credit: Linde |  Photo Credit: Air Products and Chemicals, Inc. |
| **Name** | Diamond Bar | Emeryville[86] | Fairfax (Los Angeles) |
| **Address** | 21865 East Copley Drive | 1172 45th Street | 7751 Beverly Boulevard |
| **Open Retail Date** | 8/18/2015 | 11/19/2018 | 5/2/2016 |
| **Solicitation** | PON-09-608 | PON-13-607 | PON-09-608 |
| **Photograph** |  Photo Credit: FirstElement Fuel |  |  |
| **Name** | Fremont | Hayward | Hollywood (Los Angeles) |
| **Address** | 41700 Grimmer Boulevard | 391 West A Street | 5700 Hollywood Boulevard |
| **Open Retail Date** | 9/7/2017 | 4/27/2016 | 11/10/2016 |
| **Solicitation** | PON-13-607 | PON-13-607 | PON-13-607 |

Source: CEC, photo credit: CEC unless otherwise stated

86 Messer Group and CVC Capital Partners Fund VII acquired Linde's gases business in North America on March 1, 2019. The Emeryville station, which Linde developed and operated, now is recognized as a Messer station.

| Station Information | Station | Station | Station |
|---|---|---|---|
| **Photograph** |  |  Photo Credit: FirstElement Fuel |  Photo Credit: Air Products and Chemicals, Inc. |
| **Name** | La Cañada Flintridge | Lake Forest | Lawndale |
| **Address** | 550 Foothill Boulevard | 20731 Lake Forest Drive | 15606 Inglewood Avenue |
| **Open Retail Date** | 1/25/2016 | 3/18/2016 | 6/22/2017 |
| **Solicitation** | PON-13-607 | PON-13-607 | PON-09-608 |
| **Photograph** |  Photo Credit: Air Liquide |  |  Photo Credit: FirstElement Fuel |
| **Name** | LAX (Los Angeles) | Long Beach | Mill Valley |
| **Address** | 10400 Aviation Boulevard | 3401 Long Beach Boulevard | 570 Redwood Highway |
| **Open Retail Date** | 12/21/2018 | 2/22/2016 | 6/16/2016 |
| **Solicitation** | SCAQMD Contract | PON-13-607 | PON-13-607 |

Source: CEC, photo credit: CEC unless otherwise stated

| Station Information | Station | Station | Station |
|---|---|---|---|
| Photograph | <br>Photo Credit: Iwatani Corporation | <br>Photo Credit: California Fuel Cell Partnership | <br>Photo Credit: Ontario Station |
| Name | Mountain View | Oakland | Ontario |
| Address | 830 Leong Drive | 350 Grand Avenue | 1850 E. Holt Boulevard |
| Open Retail Date | 2/28/2018 | 9/20/2019 | 4/24/2018 |
| Solicitation | PON-12-606 | GFO-15-605 | PON-13-607 |
| Photograph | <br>Photo Credit: Air Liquide | <br>Photo Credit: FirstElement Fuel | <br>Photo Credit: ITM Power |
| Name | Palo Alto | Playa Del Rey (Los Angeles) | Riverside |
| Address | 3601 El Camino Real | 8126 Lincoln Boulevard | 8095 Lincoln Avenue |
| Open Retail Date | 12/20/2018 | 8/18/2016 | 3/8/2017 |
| Solicitation | PON-13-607 | PON-13-607 | PON-13-607 |

Source: CEC, photo credit: CEC unless otherwise stated

| Station Information | Station | Station | Station |
|---|---|---|---|
| **Photograph** |  | <br>Photo Credit: California Fuel Cell Partnership | <br>Photo Credit: California Fuel Cell Partnership |
| **Name** | Sacramento | San Francisco Harrison Street | San Francisco Third Street |
| **Address** | 3510 Fair Oaks Boulevard | 1201 Harrison Street | 551 Third Street |
| **Open Retail Date** | 5/22/2019 | 12/2/2019 | 11/6/2019 |
| **Solicitation** | GFO-15-605 | GFO-15-605 | GFO-15-605 |
| **Photograph** | <br>Photo Credit: FirstElement Fuel | <br>Photo Credit: Iwatani Corporation | <br>Photo Credit: Iwatani Corporation |
| **Name** | San Jose | San Juan Capistrano | San Ramon[87] |
| **Address** | 2101 North First Street | 26572 Junipero Serra Road | 4475 Norris Canyon Road |
| **Open Retail Date** | 1/15/2016 | 12/23/2015 | 7/26/2017 |
| **Solicitation** | PON-13-607 | PON-09-608 | PON-13-607 |

Source: CEC, photo credit: CEC unless otherwise stated

87 Iwatani Corporation of America acquired four hydrogen refueling stations that were previously owned by Messer (formerly Linde, LLC) as announced on May 13, 2019. The four stations are Mountain View, San Juan Capistrano, San Ramon, and West Sacramento.

| Station Information | Station | Station | Station |
|---|---|---|---|
| **Photograph** |  Photo Credit: FirstElement Fuel |  |  |
| **Name** | Santa Barbara | Santa Monica | Saratoga |
| **Address** | 150 South La Cumbre Road | 1819 Cloverfield Boulevard | 12600 Saratoga Avenue |
| **Open Retail Date** | 4/9/2016 | 2/1/2016 | 3/14/2016 |
| **Solicitation** | PON-13-607 | PON-09-608 | PON-13-607 |
| **Photograph** |  Photo Credit: FirstElement Fuel |  |  |
| **Name** | South Pasadena | South San Francisco | Thousand Oaks |
| **Address** | 1200 Fair Oaks Avenue | 248 South Airport Boulevard | 3102 Thousand Oaks Boulevard |
| **Open Retail Date** | 4/10/2017 | 2/12/2016 | 3/30/2018 |
| **Solicitation** | PON-13-607 | PON-13-607 | PON-13-607 |

Source: CEC, photo credit: CEC unless otherwise stated

| Station Information | Station | Station | Station |
|---|---|---|---|
| **Photograph** |  Photo Credit: SCAQMD |  Photo Credit: FirstElement Fuel |  |
| **Name** | Torrance | Truckee | UC Irvine |
| **Address** | 2051 West 190th Street | 12105 Donner Pass Road | 19172 Jamboree Road |
| **Open Retail Date** | 8/18/2017 | 6/17/2016 | 11/12/2015 |
| **Solicitation** | SCAQMD Contract | PON-13-607 | PON-09-608 |
| **Photograph** |   |   Photo Credit: Iwatani Corporation |  Photo Credit: Air Products and Chemicals, Inc. |
| **Name** | West LA (Los Angeles) | West Sacramento | Woodland Hills |
| **Address** | 11261 Santa Monica Boulevard | 1515 South River Road | 5314 Topanga Canyon Road |
| **Open Retail Date** | 10/29/2015 | 7/7/2015 | 10/5/2016 |
| **Solicitation** | PON-09-608 | PON-09-608 | PON-12-606 |

Source: CEC, photo credit: CEC unless otherwise stated

Table E-2 lists the locations of 20 Clean Transportation Program funded stations in various development phases: planning, permitting, or under construction. The stations are listed in alphabetical order by city. Also provided is the CEC solicitation number or contract under which the station received funding. A station funded by CARB, located at 5151 State University Drive, Los Angeles, CA 90032, received operation and maintenance funding from the Clean Transportation Program.

**Table E-2: Clean Transportation Program Funded Stations in Development**

| Address | Solicitation or Contract |
|---|---|
| 1250 University Avenue, Berkeley, CA 94702 | GFO-15-605 |
| 145 West Verdugo Avenue, Burbank, CA 91510 | SCAQMD Contract |
| 337 East Hamilton Avenue, Campbell, CA 95008 | GFO-15-605 |
| 12600 East End Avenue, Chino, CA 91710 | PON-12-606 |
| 605 Contra Costa Boulevard, Concord, CA 94523 | GFO-15-605 |
| 11284 Venice Boulevard, Culver City, CA 90230 | GFO-15-605 |
| 18480 Brookhurst Street, Fountain Valley, CA 92708 | GFO-15-605 |
| 104 North Coast Highway, Laguna Beach, CA 92651[88] | GFO-15-605 |
| 5151 State University Drive, Los Angeles, CA 90032 | PON-13-607 |
| 15544 San Fernando Mission Boulevard, Mission Hills, CA 91345 | GFO-15-605 |
| 28103 Hawthorne Boulevard, Rancho Palos Verdes, CA 90275 | PON-09-608 |
| 503 Whipple Avenue, Redwood City, CA 94063 | GFO-15-605 |
| 5494 Mission Center Road, San Diego, CA 92108 | GFO-15-605 |
| 3550 Mission Street, San Francisco, CA 94110 | GFO-15-605 |
| 101 Bernal Road, San Jose, CA 95119 | GFO-15-605 |
| 24551 Lyons Avenue, Santa Clarita, CA 91321 | PON-09-608 |
| 14478 Ventura Boulevard, Sherman Oaks, CA 91423 | GFO-15-605 |
| 3780 Cahuenga Boulevard, Studio City, CA 91604 | GFO-15-605 |
| 1296 Sunnyvale Saratoga Road, Sunnyvale, CA 94087 | GFO-15-605 |
| 17287 Skyline Boulevard, Woodside, CA 94062 | PON-13-607 |

Source: CEC

88 Pending agreement execution.

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