



**CALIFORNIA  
ENERGY COMMISSION**



**CALIFORNIA  
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California Energy Commission

## **STAFF REPORT**

# **Joint Agency Staff Report on Assembly Bill 8: 2017 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Stations in California**

California Energy Commission  
California Air Resources Board



Edmund G. Brown Jr., Governor  
December 2017 | CEC-600-2017-011



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## ABSTRACT

The Joint Agency Staff Report on Assembly Bill 8: 2017 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California (2017 Joint Report) follows two previously published joint reports in accordance with Assembly Bill 8 (AB 8) (Perea, Chapter 401, Statutes of 2013). The 2017 Joint Report updates the time and cost assessments for establishing a network of publicly available hydrogen refueling stations to support the fuel cell electric vehicle (FCEV) market under the California Energy Commission's (CEC) Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP).

As of November 15, 2017, 31 open retail stations sell hydrogen for use as a transportation fuel to the public, and another 34 stations are planned to become open retail in California. Together, these are the 65 stations funded by the ARFVTP to date, including those awarded funding by the CEC in 2017, which are nearly two-thirds of the 100-station milestone in AB 8.

ARFVTP funding remains necessary to reach the milestone of constructing and operating 100 hydrogen refueling stations. This report presents a funding plan that could achieve the 100 station milestone at a lower cost and sooner than last year's reported estimates. Considering 10 hydrogen refueling stations funded per fiscal year, 100 stations will likely be funded in fiscal year 2021-22, with the total cost nearly \$201.6 million. The CEC is committed to achieving – through continued process improvement, technological advancement, and cooperation of public and private sector partners – an accelerated plan to support the development of a mature market for FCEVs as quickly as possible and to meet the state's zero-emission vehicle (ZEV) targets.

**Keywords:** California Energy Commission, California Air Resources Board, Alternative and Renewable Fuel and Vehicle Technology Program, AB 8, hydrogen, hydrogen refueling station, fuel cell electric vehicle, National Renewable Energy Laboratory

Please use the following citation for this report:

Baronas, Jean, Gerhard Ahtelik, et al. 2017. *Joint Agency Staff Report on Assembly Bill 8: 2017 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. California Energy Commission and California Air Resources Board. Publication Number: CEC-600-2017-011.

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# EXECUTIVE SUMMARY

The *Joint Agency Staff Report on Assembly Bill 8: 2017 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2017 Joint Report) describes the progress the State of California is making to deploy hydrogen refueling stations. These stations are critical infrastructure supporting the commercial growth of fuel cell electric vehicles (FCEVs), which is necessary to achieve Governor Edmund G. Brown Jr.'s vision of increasing the adoption of zero-emission vehicles (ZEVs) to reach 1.5 million ZEVs by 2025 in California.

Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) directs the CEC to allocate \$20 million annually, not to exceed 20 percent of the money appropriated by the Legislature, from the Alternative and Renewable Fuel and Vehicle Technology Fund for developing hydrogen refueling stations until there are at least 100 publicly available stations in California. This report satisfies an AB 8 requirement for the CEC and California Air Resources Board (CARB) to jointly report each year on the remaining cost and time needed to establish a network of at least 100 stations. This report uses information from CARB's *2017 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development* (2017 Annual Evaluation) to assess the progress to date and the outlook for station cost and development time.

In its role as Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) administrator and under AB 8, the CEC funds the development of at least 100 hydrogen refueling stations as quickly as possible to support the early FCEV market and to provide fuel for the increasing population of on-road FCEVs. The CEC funds the stations and technologies that, together, have the greatest success in achieving self-sufficiency, which is important to ensure that the state's investment enables the successful launch of this new market and to prevent it failing after state funding ends. The focus of the ARFVTP is not just on developing at least 100 stations, but on developing the right stations, in the right places, and at the right times.

Identifying which stations are the right stations is not a static pursuit. The characteristics of the right station are not necessarily the same in every community, and they evolve with the growing market and new technologies. California's hydrogen stations provide a refueling process that strives to be comparable to or better than drivers' experience with gasoline fueling. FCEV drivers refueling at California's hydrogen stations can simply pull up to the dispenser, pay with their preferred method of payment, refuel within three to five minutes, and return to their drive. All of this is accomplished with no additional attendants, access agreements, or training required.

California is on the leading edge of hydrogen infrastructure development for transportation, and public and private partners are working together to keep station development on the right track. At the close of 2017, 31 hydrogen refueling stations are open to the public, and another 34 stations are funded and well on the way through the development process.

## **California Reports Steady Progress in Station Rollout**

Since 2015, California has made steady progress in station rollout. The CEC awarded 21 new stations under the GFO-15-605, now part of the total 65 ARFVTP-funded stations that together

provide 14,875 kilograms (kg) of hydrogen per day in nameplate capacity. The funded stations are located in priority areas identified through technical analyses and stakeholder input. Table ES-1 shows the number of funded stations in Northern California, Southern California, and in connector/destination locations (including a temporary refueler), and related fueling capacities. The stations are divided into two categories, open retail (meaning they are selling hydrogen for use as a transportation fuel to the public) and planned (meaning the stations are not yet completed and open to the public). The total capacity of 14,875 kg per day can support more than 21,000 FCEVs.

**Table ES-1: 65 ARFVTP-Funded Stations Location and Capacity Summary**

|                         | Northern California |                             | Southern California |                             | Connector/Destination |                             |
|-------------------------|---------------------|-----------------------------|---------------------|-----------------------------|-----------------------|-----------------------------|
|                         | Station Quantity    | Nameplate Capacity (kg/day) | Station Quantity    | Nameplate Capacity (kg/day) | Station Quantity      | Nameplate Capacity (kg/day) |
| Open Retail Stations    | 9                   | 1,960                       | 19                  | 3,450                       | 3                     | 540                         |
| Planned Stations        | 16                  | 5,140                       | 16                  | 3,560                       | 2                     | 225                         |
| <b>Totals</b>           | <b>25</b>           | <b>7,100</b>                | <b>35</b>           | <b>7,010</b>                | <b>5</b>              | <b>765</b>                  |
| <b>Statewide Totals</b> | <b>65 stations</b>  |                             |                     | <b>14,875 kg/day</b>        |                       |                             |

Source: CEC

A station funded by CARB at Newport Beach is non-retail but sells hydrogen to drivers of FCEV models only with approval from the auto manufacturers. The 65 ARFVTP-funded stations include the station at California State University, Los Angeles, which was constructed with funds from CARB, and ARFVTP provided operation and maintenance funds. This station is a non-retail station like the Newport Beach station and sells hydrogen to drivers of FCEV models only with approval from the auto manufacturers. It is under consideration for an upgrade.

Between November 2016 and March 2017, two stations and a station upgrade were not completed prior to state funding liquidation: Encinitas, Los Altos, and the upgrade of Newport Beach, which was under consideration as a station location change for the station originally planned for Foster City. These stations are not included in the station network numbers above nor are they included in any analyses of this report. In addition, stations proposed in Rohnert Park, Orange, and North Hollywood are not included in the report analyses.

## **Fuel Cell Electric Vehicle Deployment Triples**

As of October 6, 2017, 2,473 FCEVs are registered with the California Department of Motor Vehicles, which is a nearly 170 percent increase compared to 925 FCEVs registered as of October 2016. Industry reports that 3,234 FCEVs have been sold or leased in California through December 1, 2017. CARB's 2017 Annual Evaluation projects 13,400 FCEVs in California by 2020 and 37,400 by 2023.

Some subregions in California experience high hydrogen fuel demand already. Of the 31 open retail stations, a few require fuel deliveries two or three times a day because of high station usage. In these high usage cases, either the station is dispensing more fuel in a day than one fuel delivery truck can hold, or the demand for fuel is exceeding the storage capacity of the station.

The 2017 Annual Evaluation concludes that long-term FCEV deployment plans continue to indicate a need for larger capacity stations to be opened at a faster pace, and the current business-as-usual scenario (funding eight 300 kg/day stations per year) may allow the supply of hydrogen dispensing capacity to keep up with demand until 2021, at which point a shortfall in capacity is expected. This capacity shortfall, which could slow down FCEV deployment when the commercial ZEV market needs to expand greatly to meet environmental goals, is critical to avoid. This report presents additional analysis around this capacity shortfall issue in Chapter 5, to better understand the implications on a regional level, and provides ideas in Chapter 7 for alternative funding mechanisms that could increase the pace of station development.

## **California Reports Steady Progress in Station Permitting and Construction**

The time required to permit and construct hydrogen refueling stations slightly increased in 2017 because some of the earliest-funded stations continued to experience delays. The 2016 Joint Report explained how developers have cut station development time in half (from roughly four years to two years) from the earliest-funded stations in 2010 to the stations funded in 2014. The CEC expects that the length of station permitting and construction time should decrease again once stations funded under GFO-15-605 progress through the station development phases and those results are analyzed.

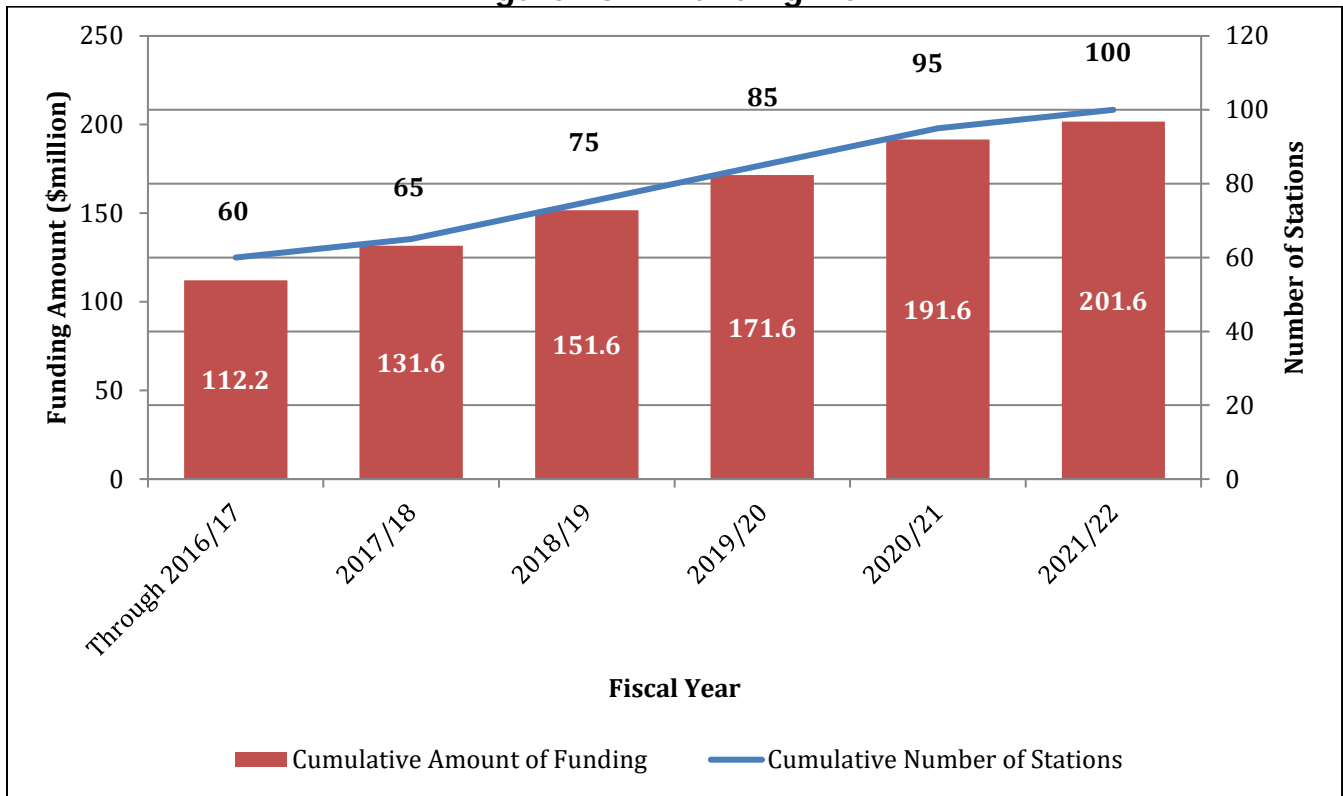
The CEC built safeguards into GFO-15-605 to ensure that the length of time to permit and construct stations is minimized. Firstly, grant funds are awarded on a sliding scale based on the time it takes to permit, construct, and complete stations, such that those taking longer than 20 months are ineligible for maximum funding. The CEC also reserves the right to cancel the grant award if a station location changes, which historically delayed station development. To date, no grant funded under GFO-15-605 has been canceled since most applicants secured sites or are well in the process of securing sites.

Secondly, the grant recipients are held to two “critical milestones”: they are required to hold in-person, pre-application meetings with the authority having jurisdiction (AHJ) over the station location (Critical Milestone 1) and to have control of the site (Critical Milestone 2) before eligible expenses are reimbursed by the CEC. Although some station developers must still submit evidence of pre-application meetings, 18 of the 21 stations awarded under GFO-15-605 met Critical Milestone 1 before station applications were submitted, 18 had site control at the time of application, and site control was obtained for one other station within one month of receiving CEC business meeting approval. The critical milestones are designed to ensure that the siting issues that have slowed or stopped station development in the past are avoided, and that station development timelines remain on track.

**The Remaining Time Needed to Reach 100 Open Retail Hydrogen Refueling Stations Is Estimated to Be Seven Years With the Remaining Cost at \$70 Million**

The estimated remaining amount of time needed to reach 100 open retail hydrogen refueling stations is seven years, to 2024. This estimate is based on an updated business-as-usual scenario that would fund 10 stations per fiscal year, as shown in Figure ES-1. The estimated remaining cost to establish a network of 100 publicly available hydrogen refueling stations is about \$70 million. Added to the \$131.6 million already invested to fund 65 stations including operation and maintenance obligations, the total cost for the 100 stations is estimated to be nearly \$200 million.

**Figure ES-1: Funding Plan**



Source: CEC

The CEC developed this updated business-as-usual scenario considering the findings from stations funded under GFO-15-605. First, 12 out of 21 awarded stations under GFO-15-605 budgeted, on average, \$1.9 million or 18 percent less than the maximum available funding amount of \$2.3 million. If all stations funded in the next solicitation receive \$1.9 million, then 10 stations could be funded from the \$20 million annual ARFVTP allocation.

Second, the average cost per kilogram of station capacity decreased from \$8,689 to \$6,409 in two years. This cost per kilogram of hydrogen capacity for stations funded under GFO-15-605 decreased with stations that are in many cases double the size of those funded under PON-13-607. Comparing all previous hydrogen station grant solicitations, the stations funded under GFO-15-605 can fuel the greatest number of FCEVs per dollar invested. This is another sign that station development costs are decreasing.

Third, the large volume of applications to GFO-15-605 may indicate that the market for developing and operating hydrogen stations is strong enough for the CEC to incrementally lower the maximum available funding amount per station in future solicitations to fund more

stations per fiscal year. With these findings, funding 10 stations per year should be achievable and realistic.

Beyond the updated business-as-usual scenario described above, the CEC is considering alternative funding mechanisms to accelerate station deployment and to fund more stations sooner. These mechanisms have the potential to expedite the maturation of the infrastructure supply chain (thus reducing costs), encourage faster adoption of FCEVs, and achieve greenhouse gas emissions reduction goals sooner. Some alternative funding mechanisms involve longer-term strategies such as developing new financing programs to either augment or replace the grant funding process. These types of strategies would attempt to leverage additional outside investment to increase the number of stations funded per year.

Other short-term funding strategies could be deployed and involve working within the current grant funding structure to advance available funds more efficiently and help accelerate station deployment. Such ideas include providing greater flexibility on how grant funds are used (toward capital or operation and maintenance [O&M] expenses) to enable station developers to choose the type of assistance that best fits their business model and available resources. Other possible strategies aim to encourage cost reduction more effectively by providing station developers with more certainty that, if proposed for an award, they would be responsible for building multiple stations that could enable them to plan a station network more effectively and achieve economies of scale.

## **Looking to the Future of the Infrastructure**

The state's financial support of hydrogen refueling stations is providing the infrastructure to launch the early FCEV market, with the intention of building a sustainable and self-sufficient market for this ZEV technology. Achieving this market means that stakeholders must look beyond the 100-station milestone. Stakeholders, including the CEC as the primary hydrogen refueling station funder, and CARB are engaged in and provide input to this planning as part of the California Fuel Cell Partnership (CaFCP). A vision document that characterizes the next level of commercial market development by 2030 is under development. To reach this next level, a faster and larger deployment of hydrogen refueling stations will be necessary to support rapid growth in FCEVs. Stakeholders are working to identify private investors to enable large clusters of stations to be developed, enabling economies of scale to be achieved that reduce costs to a level that results in a positive return on investment. CARB and the CEC are also examining the path to self-sufficiency in a study explained in Appendix A. Through these efforts, the achievements and lessons learned thus far from the ARFVTP-funded hydrogen refueling infrastructure projects are being applied to set an aggressive but achievable vision for the future.



# CHAPTER 1: Introduction

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This *Joint Agency Staff Report on Assembly Bill 8: 2017 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2017 Joint Report) reviews and reports on the progress of fuel cell electric vehicle (FCEV) deployment and hydrogen refueling stations opening in California. Based on these findings, the 2017 Joint Report estimates the additional time and funding required for reaching the goal of 100 publicly available hydrogen refueling stations in California. These estimates are based on actual development timelines and expenditures from funded stations, the use of these stations, and the projections of how station revenue and expenses may change in the future.

Assembly Bill (AB) 8 (Perea, Chapter 401, Statutes of 2013) directs the CEC to allocate \$20 million annually, not to exceed 20 percent of the amount of funds appropriated by the state Legislature from the Alternative and Renewable Fuel and Vehicle Technology Fund, for developing hydrogen refueling stations “until there are at least 100 publicly available hydrogen-fueling stations in operation in California” (Health and Safety Code § 43018.9[e][1]). AB 8 reauthorized the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) created by Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) until January 1, 2024.

AB 118 named the CEC as the ARFVTP administrator, tasked with providing various financial incentives to develop and deploy innovative technologies to transform the transportation sector and help attain climate change goals defined in Assembly Bill 32 (Núñez and Pavley, Chapter 488, Statutes of 2006) and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016). An FCEV is one type of zero-emission vehicle (ZEV), along with other types of electric vehicles, identified in the *State Implementation Plan*<sup>1</sup> and the *Climate Change Scoping Plan*<sup>2</sup> to help California reduce air pollution and greenhouse gas (GHG) emissions.

AB 8 also requires that, by December 31 of each year, the CEC and CARB work together to review and report on progress toward establishing a hydrogen refueling network. This 2017 Joint Report satisfies this requirement and is the third such report.<sup>3</sup> This report estimates an updated business case for achieving the 100-station milestone. This report uses data through the third quarter of 2017 with the exception of station counts current as of November 15, 2017, and FCEV numbers as of December 1, 2017.

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<sup>1</sup> California Air Resources Board. [Mobile Source Strategy](https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrsrc.pdf). May 2016. p. 66. (https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrsrc.pdf.)

<sup>2</sup> California Air Resources Board. [First Update to the Climate Change Scoping Plan, Transportation Appendix](https://www.arb.ca.gov/cc/scopingplan/2013_update/transportation.pdf). May 2014. (https://www.arb.ca.gov/cc/scopingplan/2013\_update/transportation.pdf.)

<sup>3</sup> The previous reports are McKinney, Jim, et al. 2015. [Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California](http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf). California Energy Commission. Publication Number: CEC-600-2015-016. http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf. Baronas, Jean, Gerhard Achtelik, et al. [Joint Agency Staff Report on Assembly Bill 8: 2016 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California](http://www.energy.ca.gov/2017publications/CEC-600-2017-002/CEC-600-2017-002.pdf). California Energy Commission. Publication Number: CEC-600-2017-002. (http://www.energy.ca.gov/2017publications/CEC-600-2017-002/CEC-600-2017-002.pdf.)

In its role as ARFVTP administrator, and under AB 8, the CEC is dedicated to funding the development of 100 hydrogen refueling stations as quickly as possible to support the early FCEV market and to fuel the increasing population of FCEVs. The CEC also attempts to fund the stations and technologies that, together, have the greatest chance of achieving self-sufficiency. This goal is important to ensure that the state's investment enables the successful launch of this new market, and to prevent it from failing after the state funding ends.

The focus is not just on developing 100 stations, but on developing the *right* 100 stations, in the *right* places and at the *right* times, meaning the stations are high throughput and high performance and they serve the first adopter markets in important FCEV launch areas like San Francisco, the Berkeley/Oakland area, Los Angeles, San Diego, and Orange County.<sup>4</sup> To maximize adoption rates of FCEVs, the transition from refueling with gasoline to refueling with hydrogen must be as seamless as possible. FCEV drivers refueling at California's hydrogen stations can simply pull up to the dispenser, pay with their preferred method of payment, refuel, within three to five minutes, and return to their drive. All of this is accomplished with no additional attendants, access agreements, or training required. This is a major milestone on the path toward commercialization. In past years, when FCEVs and hydrogen fueling were undergoing technical demonstration in everyday application, refueling required unique protective clothing, and the stations worked with fueling cards based on specific codes the driver had to use to gain access to the fuel.

Knowing which stations are the right stations is not easy or straightforward, and it is not a static pursuit; it evolves with the growing market and changing technology. With California on the leading edge of hydrogen infrastructure development for transportation, knowledge comes from experience.

Achievements include the completion of 31 stations (including 6 in 2017), 13 previously funded stations making progress toward completion, and the addition of 21 newly funded stations in development. Between November 2016 and March 2017, two stations and a station upgrade were not completed before state funding liquidation: Encinitas, Los Altos, and the upgrade of Newport Beach, which was under consideration as a station location change for the station originally planned for Foster City. These stations are not included in the analyses of this report. In addition, stations proposed in Rohnert Park, Orange, and North Hollywood were heard at the October 2017 CEC Business Meeting and removed from the station network numbers in this Joint Report. The Chino station is planned for completion in 2018. When planning the network, the CEC relies on input from sources, including:

- Partners such as CARB, the Governor's Office of Business and Economic Development (GO-Biz), the California Department of Food and Agriculture, Division of Measurement Standards (CDFA/DMS), South Coast Air Quality Management District (SCAQMD), Bay Area Air Quality Management District (BAAQMD), local permitting officials, fire experts, and safety experts.

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<sup>4</sup> California Air Resources Board, [2017 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf). August 2017. [https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8\\_report\\_2017.pdf](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf) page 20.



- National experts at the U.S. Department of Energy (U.S. DOE) and national laboratories including the National Renewable Energy Laboratory (NREL), Sandia National Laboratories, and Pacific Northwest National Laboratory.
- Tools such as CARB's California Hydrogen Infrastructure Tool, NREL's Hydrogen Financial Analysis Scenario Tool, and the Office of Environmental Health Hazard Assessment's CalEnviroScreen™.
- Industry stakeholder groups including the California Fuel Cell Partnership (CaFCP), the California Hydrogen Business Council, and SAE International.
- Public comments received through workshops and dockets from industry experts, fuel cell electric vehicle (FCEV) drivers, and the public.

With this input, the CEC develops funding solicitations to elicit the most technically sound and sustainable projects from the most capable people. This 2017 Joint Report presents information about the status of California's hydrogen refueling station network as follows:

- CHAPTER 2: Coverage and Capacity of the Hydrogen Refueling Station Network
- CHAPTER 3: Fuel Cell Electric Vehicle Deployment
- CHAPTER 4: Time Required to Permit and Construct Hydrogen Refueling Stations
- CHAPTER 5: Amount and Timing of the Growth of the Hydrogen Refueling Network
- CHAPTER 6: Network Planning
- CHAPTER 7: Remaining Cost and Timing to Establish a Network of 100 Publicly Available Hydrogen Refueling Stations
- CHAPTER 8: Conclusions

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

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On April 20, 2017, executives from three state agencies – the CEC, CARB, and GO-Biz – caravanned from Sacramento to the Bay Area and back in FCEVs to witness firsthand the coverage of the network and the station fueling capabilities. The caravan drove from the State Capitol to hydrogen stations in Hayward and San Jose, with a photo stop at Treasure Island. Figure 1 shows a photograph from the event.

**Figure 1: CEC Commissioner Janea Scott Driving a FCEV**



Source: CEC

An ARFVTP goal is to ensure the coverage and capacity of the state-funded hydrogen refueling station network effectively meets the anticipated demand from FCEV consumers. California's hydrogen refueling station network consists of 65 ARFVTP-funded stations<sup>5</sup> (two-thirds of the 100-station goal), with 31 being open retail. These 65 stations include a CARB-funded non-retail station at California State University, Los Angeles, for which the ARFVTP provided O&M funds. There is also a CARB-funded non-retail station in Newport Beach. This report focuses on the 65 ARFVTP-funded stations. In this early market, the coverage of a station and the capability of a station in meeting the local fueling needs are essential to establishing confidence in the hydrogen refueling network. Greater coverage – providing convenient fueling access to current and potential FCEV drivers in areas with high market viability and providing

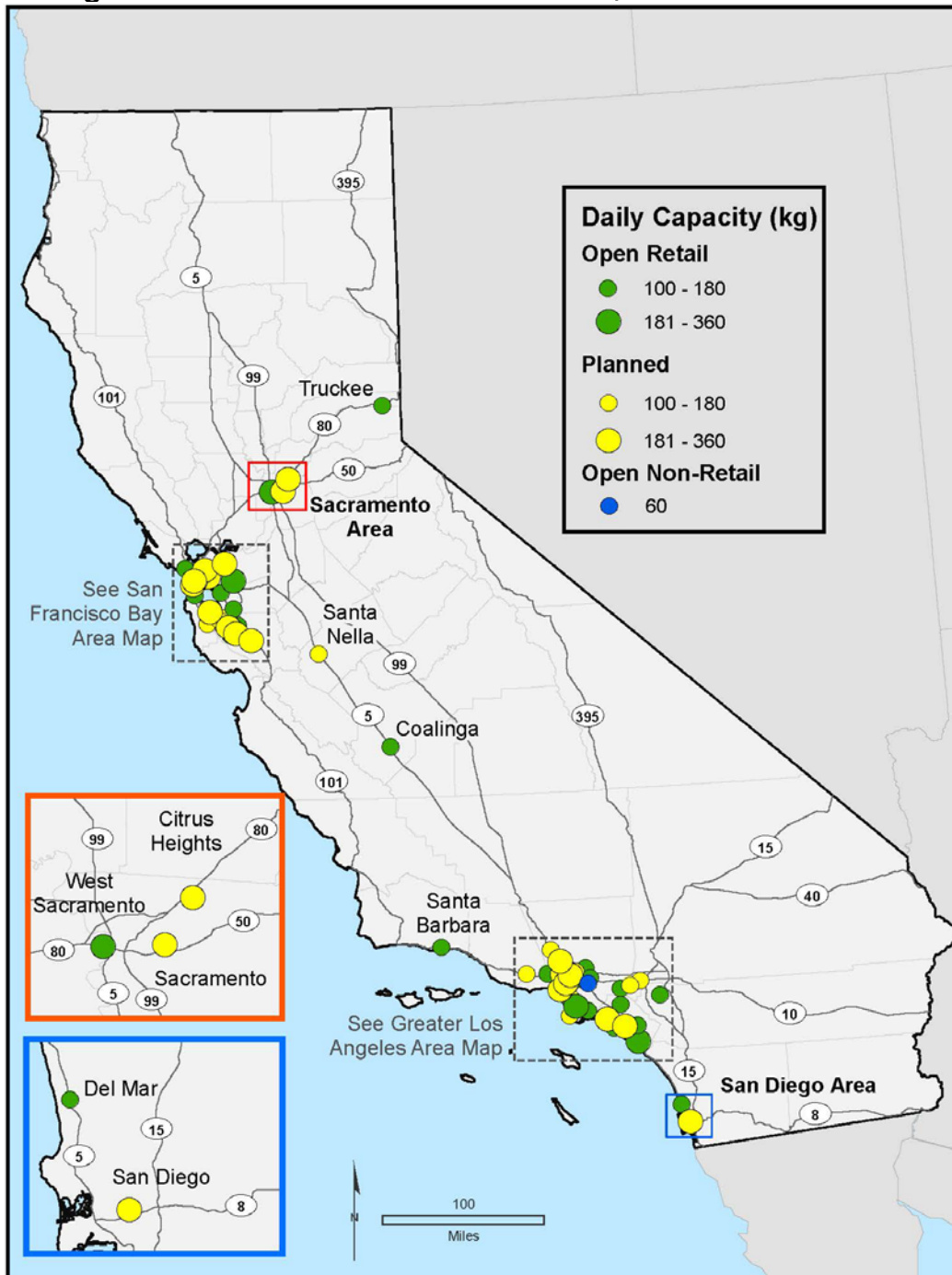
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<sup>5</sup> At the time of writing this report, the five stations that were proposed for award under GFO-15-605 on November 8, 2017, have not been approved at a CEC business meeting. For this report, these five stations are counted with the ARFVTP-funded stations.

multiple fueling opportunities to these drivers – is vital to making FCEVs attractive to more customers.

Figure 2 shows the statewide station locations. The Coalinga station (in Fresno County, Central Valley) enables travel between Northern and Southern California. The CEC recently awarded another connector station in Santa Nella in Merced County, a second place to stop for fuel in California’s Central Valley. The Lake Tahoe destination is covered by the Truckee station. Santa Barbara, which can be considered a destination, a connector, and a potential market area of its own, is also covered.

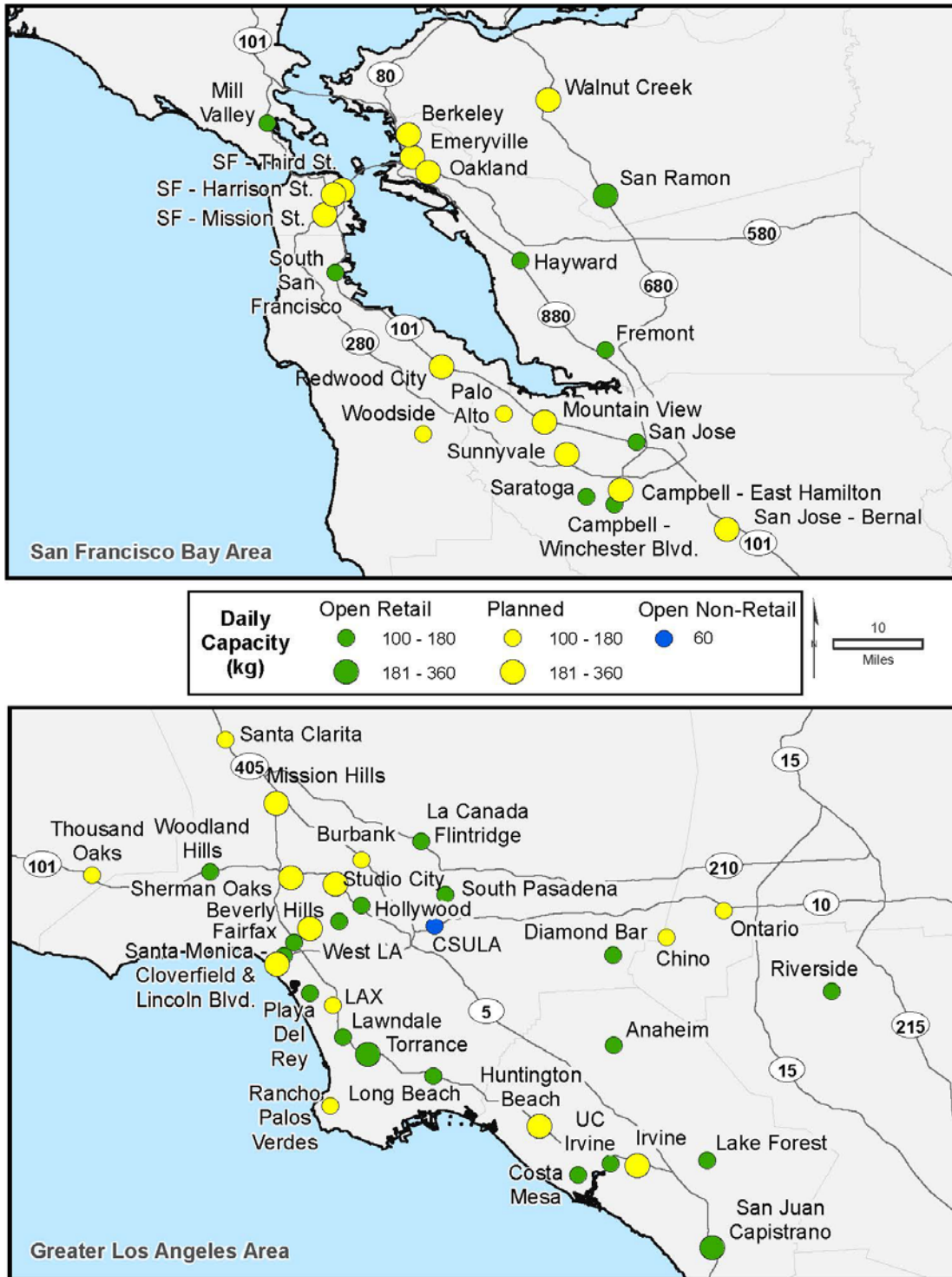
**Figure 2: Statewide Station Locations, as of October 2017**



Source: CEC staff. Map does not include a temporary refueler.

Figure 3 shows the San Francisco Bay Area and the Greater Los Angeles area, where many of the stations are located and selling fuel or are planned and in construction.

**Figure 3: San Francisco Bay Area and Greater Los Angeles Area Stations, October 2017**



Source: CEC. Maps do not include a temporary refueler.

## Station Coverage

Figure 4 shows the coverage provided by the hydrogen refueling stations to date. In the figure, warmer colors indicate higher degrees of coverage (accounting for redundant and overlapping coverage provided by stations located near each other), cooler colors indicate lesser degrees of coverage, and areas with no color shading are considered to have no coverage at all.

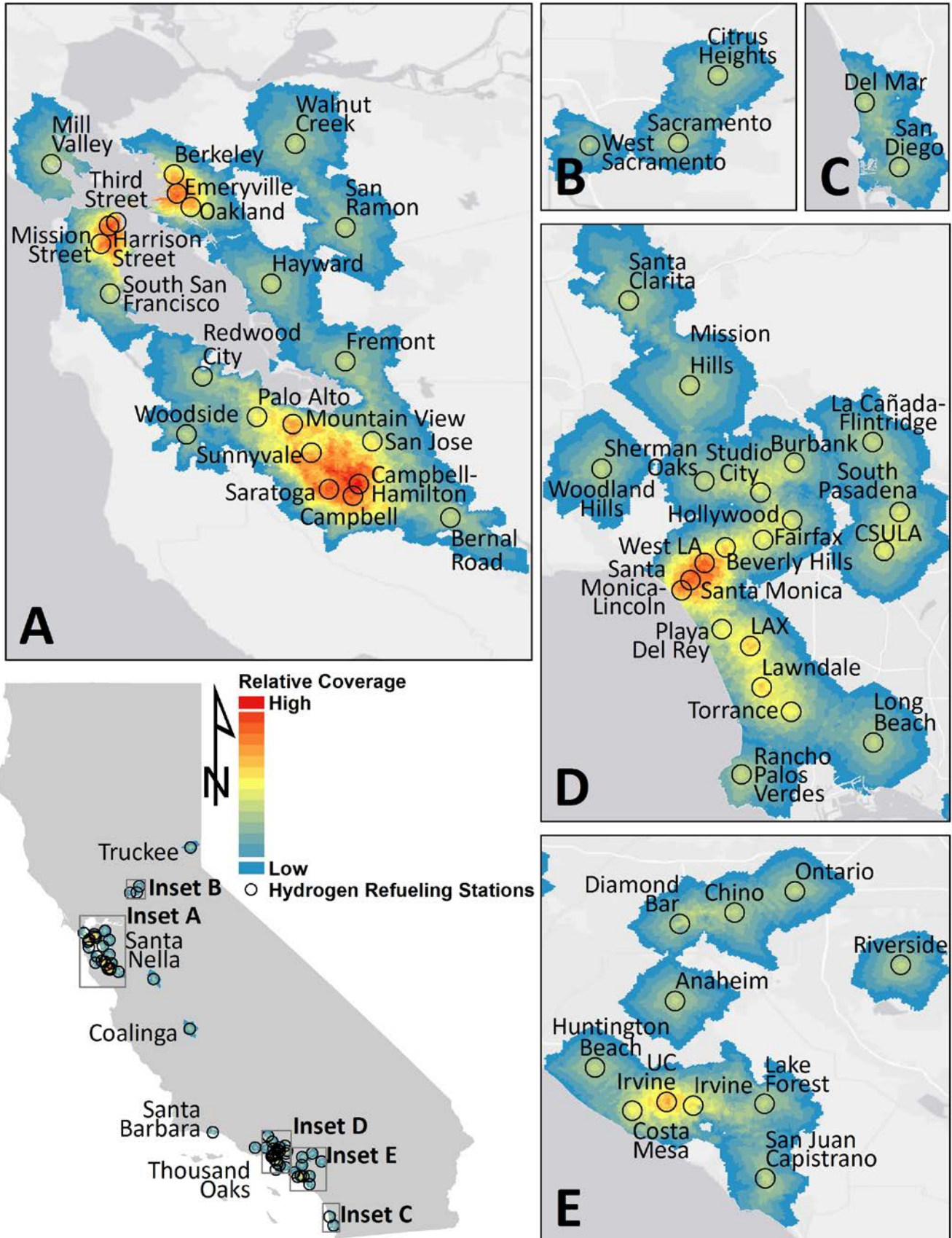
Compared to the similar figure presented in the 2017 Annual Evaluation by CARB (Figure 9 in that report), relative coverage has increased in the neighborhoods near the five new stations proposed for award under GFO-15-605 on November 8, 2017. In particular, the newly funded Redwood City station has filled a previous gap in coverage on the western side of the San Francisco Bay Area. The Bernal Road station in the southern end of San Jose has extended regional coverage farther south than the network had previously provided. The Beverly Hills station has solidified redundancy in the western Los Angeles region, contributing substantially to a growing linkage of stations along and near Santa Monica Boulevard, a highly used route in Los Angeles. The Mission Hills station also fills a previous gap that existed between the Santa Clarita station and the previous coverage of the northern end of the Los Angeles-area stations (previously provided at the northernmost point by the North Hollywood station, which is not included in the 2017 Joint Report analyses). Finally, the Studio City station also increases redundant coverage in the region between the Hollywood and former North Hollywood stations.

Given updates in planning for completion of the Chino station, Figure 4 demonstrates the coverage this station provides between Diamond Bar and Ontario. Three stations that encountered completion difficulties – North Hollywood, Rohnert Park, and Orange – are not included in the 2017 Joint Report analyses; the removal of these stations from analysis results in reduced assessment coverage in the respective nearby neighborhoods. The removal of the North Hollywood station reduced the degree of redundant coverage in nearby neighborhoods, though it has not introduced a significant gap in coverage. This is because other nearby stations (Studio City, Burbank, and Sherman Oaks) also provide coverage to many of the same communities. Removal of the Rohnert Park and Orange stations has completely removed coverage for some nearby communities. This is especially true in the case of Rohnert Park, which was not previously within the extent of coverage provided by any other station.

As mentioned in the 2017 Annual Evaluation, in comparing the coverage presented in maps like

Figure 4 here or Figure 9 of that report by CARB, coverage is presented on a relative basis, normalized to the maximum degree of coverage assessed for the network as a whole at the time of analysis. Thus, slight changes in shading between figures do not necessarily indicate an absolute change in the degree of coverage at any given location.

**Figure 4: Coverage of Open and Funded ARFVTP-Funded Hydrogen Refueling Stations**



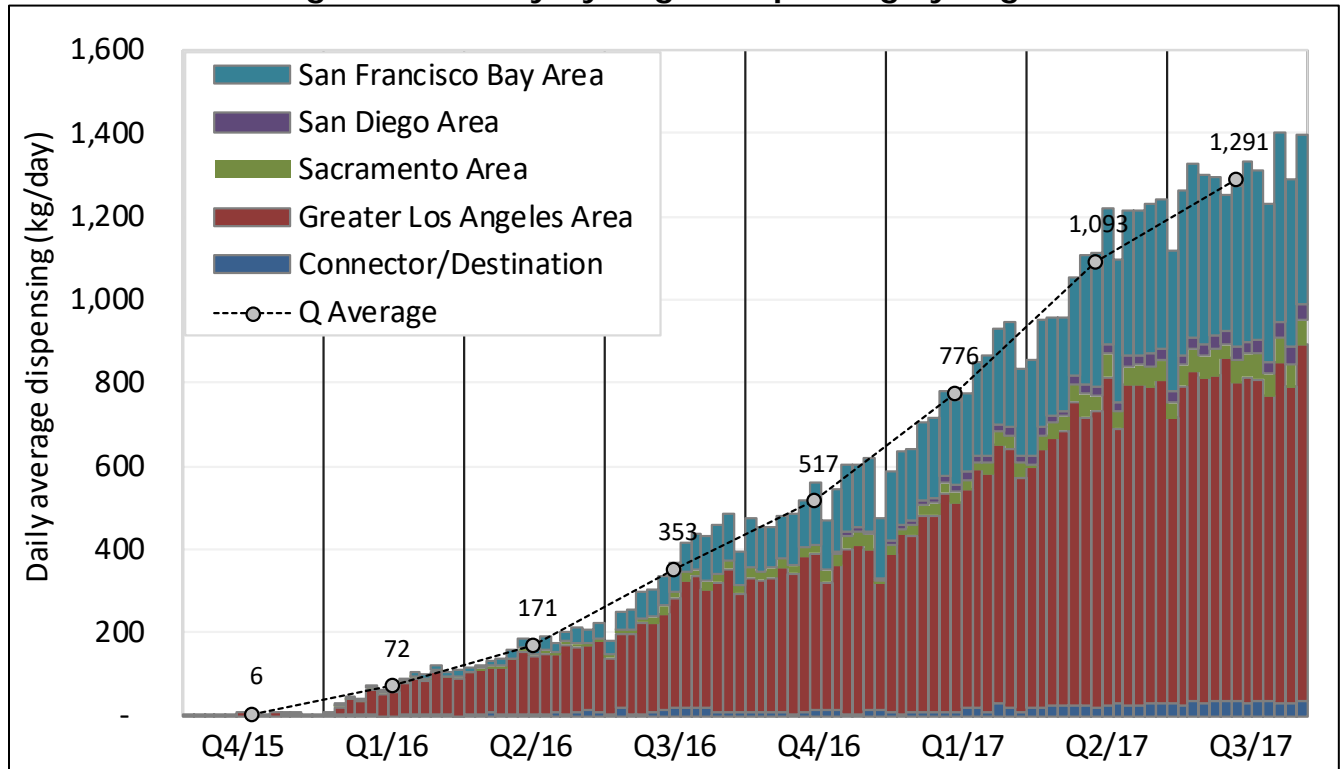
Source: CARB

## Station Usage

As the number of FCEVs on the road increases, the hydrogen refueling station network usage has been steadily increasing. Figure 5 shows weekly hydrogen dispensing by the main urban regions of the state in which FCEVs are being deployed.<sup>6</sup> A separate category of connector/destination includes the information from the three stations – Coalinga, Santa Barbara, and Truckee – that are outside these regions. The numbers in the figure show the average dispensed hydrogen in kilograms per day in each quarter. In the third quarter of 2017, nearly 1,300 kilograms of hydrogen were dispensed a day on average. Using the average fueling quantity of 3.1 kilograms per fill observed in the same quarter in the existing network, this amount of dispensing equates to filling nearly 420 FCEVs a day.<sup>7</sup> On July 19, 2017, FirstElement Fuel's network alone sold more than 1,000 kilograms of hydrogen in one day, or enough to fill about 320 FCEVs.<sup>8</sup>

FCEVs are not only taking hold in California. The benefits of FCEVs are becoming more widely known, and a refueling network is taking shape in the Northeast. National media including [The New York Times](https://nyti.ms/2rwnPBx) are taking notice. (<https://nyti.ms/2rwnPBx>)

**Figure 5: Weekly Hydrogen Dispensing by Region**



Source: NREL

<sup>6</sup> *The Greater Los Angeles Area* is defined as Los Angeles, Orange, Riverside, San Bernardino, and Ventura Counties. *The San Francisco Bay Area* is defined as Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma Counties. *The San Diego Area* is defined as San Diego County. The Sacramento Area is defined as El Dorado, Placer, Sacramento, and Yolo Counties.

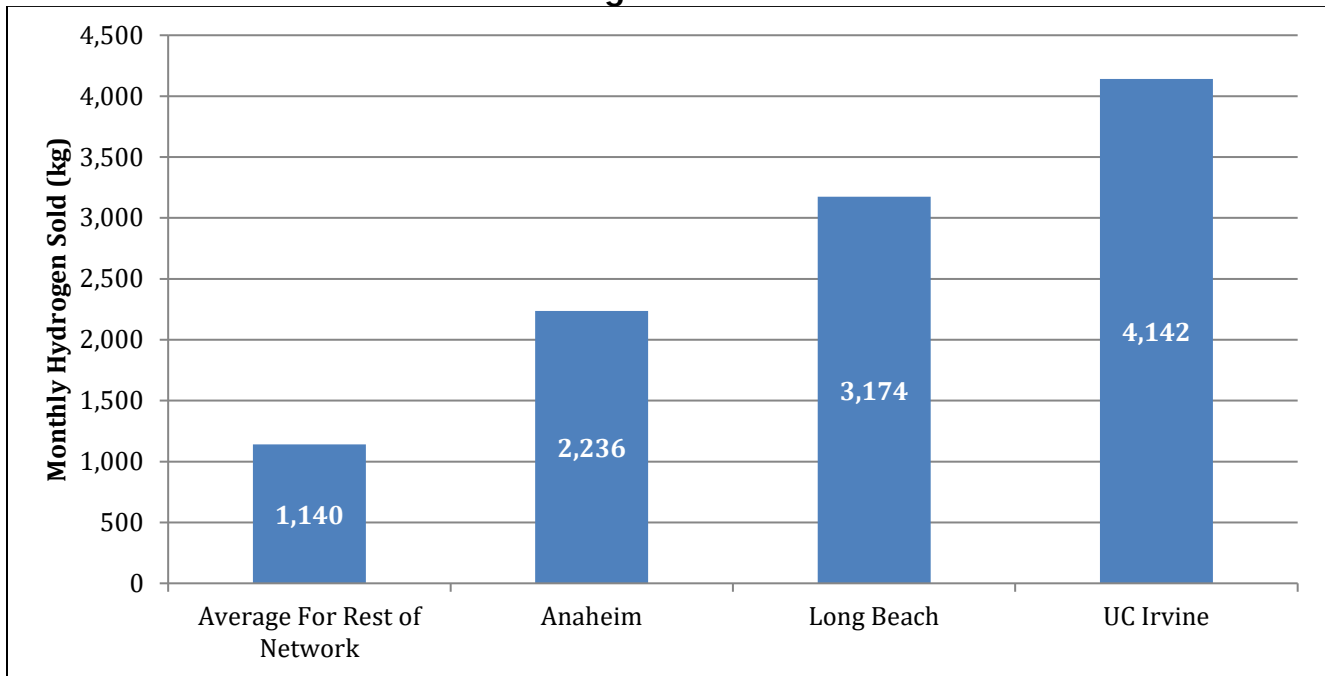
<sup>7</sup> Table D-1 in Appendix D of this report presents quarterly statistics on the average fueling quantity.

<sup>8</sup> Email communication with Dr. Shane Stephens from FirstElement Fuel on July 20, 2017.

As shown in Figure 5, stations in the Greater Los Angeles area in Quarter 3 dispensed more than 800 kg of hydrogen per week. This 2017 Joint Report presents regional analyses of usage trends and focuses on areas where demand is approaching network capacity. Appendix D describes the statewide usage trends.

Some stations (such as Anaheim and Long Beach) experience high usage to the point that they require up to two truck deliveries of 100 kg of hydrogen per day.<sup>9</sup> Figure 6 shows a comparison of the amount of hydrogen that was sold during June 2017 for each of the high-throughput stations and the rest of the network.

**Figure 6: Comparison of the Amount of Hydrogen Sold for High-Throughput Stations and the Average for the Rest of the Network**



Source: CEC

Similarly, station usage may increase when other nearby stations go off-line because of station upgrades. For example, when the Torrance hydrogen station was taken out of service for an upgrade in March 2017, the Long Beach hydrogen station experienced an increase in usage. The increased use of the Long Beach station was most likely because FCEV drivers who would have normally refueled at Torrance used the Long Beach station instead.

### Station Network Reliability

Reliability is a key aspect of building consumer acceptance of FCEV technology and consumer confidence in the network and the ability of consumers to incorporate FCEVs as their primary vehicle choice. In GFO-15-605, the CEC incorporated evaluation criteria that support reliable stations and provide redundancy in the network. Reliability is tracked through the Station Operational Status System, which is managed by the California Fuel Cell Partnership (CaFCP). According to the data collected by Station Operational Status System, the current network of

<sup>9</sup> Electronic and phone communications with Aaron Harris from Air Liquide and Dr. Tim Brown from FirstElement Fuel on November 15 and 16, 2017.



31 open retail stations in California had a 92.4 percent uptime for September 2017, on average. This means that the open retail stations were available to provide fuel to customers 92.4 percent of the time in September 2017. Of these stations, FirstElement Fuel operates 18, and it had an average station uptime of 98.5 percent during the same period. Because of the quantity of the stations that FirstElement Fuel operates at high uptime, the strong performance of these stations helps build confidence in the network among FCEV drivers.

One developer awarded under the GFO-15-605 is developing stations with two dispensers and two independent compressor/cooling chains to provide redundancy to its stations in addition to the ability to provide fuel to multiple drivers at the same time. Another set of stations awarded under GFO-15-605 will offer two fueling positions, each with an independent H70<sup>10</sup> hose allowing simultaneous fueling, in addition to one H35<sup>11</sup> hose.

To increase the network reliability, the CEC funded construction of a temporary refueler to move/drive around California to provide temporary refueling to stations that go off-line. The temporary refueler is included in the 65-station count used in this report.

## **GFO-15-605, Light Duty Vehicle Hydrogen Refueling Infrastructure**

The CEC released the Notice of Proposed Awards for GFO-15-605 on February 17, 2017, and awarded funding to 16 hydrogen refueling stations at the June and August 2017 CEC Business Meetings. The CEC also proposed awards for five additional stations in November 2017. The GFO-15-605 funding and awards are summarized below.

- A total of \$33.4 million was made available for new station development, station upgrades, and operation and maintenance (O&M) of the stations.
- A total of 111 proposed station locations from 13 applicants requesting a total of nearly \$217 million were received.
- Consistent with the intent of Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006), the 16 funded stations and 5 stations proposed for award will dispense hydrogen with a content of 33 percent renewable hydrogen, on a per-kilogram basis.

These 21 stations will add 6,780 kg/day to the overall network. Table 1 displays the general geographic distribution and capacity of the 65 ARFVTP-funded stations.<sup>12</sup> The total capacity of 14,875 kg per day can support more than 21,000 FCEVs.

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<sup>10</sup> H70 is hydrogen dispensed at a pressure of 70 megapascals (MPa). A *pascal* is a unit of pressure defined as one newton per square meter, and a *megapascal* is 1,000,000 pascals.

<sup>11</sup> H35 is hydrogen dispensed at a pressure of 35 MPa.

<sup>12</sup> At the time of writing this report, five stations that have been proposed for awards have yet to be approved at a CEC business meeting. For this report, these five stations are included in the 65 ARFVTP-funded stations.

**Table 1: Station Location and Capacity Summary for 65 ARFVTP-Funded Stations**

|                         | Northern California |                             | Southern California |                             | Connector/Destination |                             |
|-------------------------|---------------------|-----------------------------|---------------------|-----------------------------|-----------------------|-----------------------------|
|                         | Station Quantity    | Nameplate Capacity (kg/day) | Station Quantity    | Nameplate Capacity (kg/day) | Station Quantity      | Nameplate Capacity (kg/day) |
| Open Retail Stations    | 9                   | 1,960                       | 19                  | 3,450                       | 3                     | 540                         |
| Planned Stations        | 16                  | 5,140                       | 16                  | 3,560                       | 2                     | 225                         |
| <b>Totals</b>           | <b>25</b>           | <b>7,100</b>                | <b>35</b>           | <b>7,010</b>                | <b>5</b>              | <b>765</b>                  |
| <b>Statewide Totals</b> | <b>65 stations</b>  |                             |                     | <b>14,875 kg/day</b>        |                       |                             |

Source: CEC

To help assess capacity and location of the proposed stations, the CEC staff used the California Hydrogen Infrastructure Tool,<sup>13</sup> developed and administered by CARB, to evaluate station coverage and capacity in GFO-15-605, Hydrogen Refueling Infrastructure for Light Duty Vehicles, along with market viability characteristics of the stations.

Table 2 shows the market viability characteristics in the GFO-15-605 evaluation criterion named Coverage, Capacity, and Market Viability. The GFO-15-605 applications were evaluated on the degree to which they met the criteria in Table 2 along with other evaluation criteria. The other evaluation criteria were qualifications of the applicant/project team, safety planning, project readiness, station operation and maintenance, project budget, financial plan, hydrogen refueling station performance, economic and social benefits, innovation, renewable hydrogen content, renewable hydrogen from direct sources, and sustainability and environmental impacts.

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<sup>13</sup> California Air Resources Board, [Hydrogen Fueling Infrastructure Assessments](https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm) (https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm.)

**Table 2: GFO-15-605 Coverage, Capacity, and Market Viability Evaluation Criterion**

- The proposed station location results in a high California Hydrogen Infrastructure Tool station coverage value.
- The proposed station capacity results in a high California Hydrogen Infrastructure Tool station capacity value.
- The proposed station provides refueling service that meets the hydrogen refueling needs for the projected vehicle demand (light-duty vehicle traffic count and patterns).
- The proposed station provides redundancy and backup in a location needing fueling capacity.
- The proposed station provides refueling service for local fleets, as practicable.
- The proposed station provides refueling service that is available during peak fueling periods for light -duty vehicles passing the station (daily, weekly, or during other time periods) and the peak fueling periods for the location do not conflict with time frames allowed by local ordinances.
- The proposed station meets the needs of a higher average number of fills over a 1- and 12-hour period.
- The proposed station provides refueling service for vehicles tested and deployed at automotive parts assembly, testing, distribution, and demonstration facilities.
- The proposed station's refueling service complements the coverage and capacity of the network of existing and planned hydrogen refueling stations in Table 1 and any other new stations proposed for funding by the applicant under this solicitation.

Source: GFO-15-605 Light Duty Vehicle Hydrogen Refueling Infrastructure Application Manual<sup>14</sup>

During the GFO-15-605 proposal evaluation, the CEC evaluation team considered how proposals met each element of each evaluation criterion. For example, under coverage, capacity, and market viability shown in Table 2, the team members individually assessed and then discussed, as a team, an applicant's information about how the station being applied for would meet the hydrogen refueling needs of the projected FCEVs, provide station and network redundancy and backup, provide refueling services for local fleets, and provide refueling service during peak fueling periods. These evaluations are in addition to the California Hydrogen Infrastructure Tool evaluations.

The evaluation team also considered if an application included letters of support from station owners, potential station operators, site owners, auto manufacturers or dealers, fleet managers, local government representatives, or other stakeholders that supported the market viability claims contained in the application. The level of detail and veracity of submitted information was considered by the evaluation team. Well-argued, supported, and specific market viability information could counterbalance the performance of a station with relatively low California Hydrogen Infrastructure Tool values and enable it to still score well under this criterion.

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<sup>14</sup> CEC, [Light Duty Vehicle Hydrogen Refueling Infrastructure Application Manual](https://www.energy.ca.gov/solicitations/2016-04/gfo-15-605-light-duty-vehicle-hydrogen-refueling-infrastructure), Table 9: Evaluation Criteria, <https://www.energy.ca.gov/solicitations/2016-04/gfo-15-605-light-duty-vehicle-hydrogen-refueling-infrastructure>

## Network Capacity Progression

Through four solicitations and one station upgrade contract with SCAQMD, the CEC has funded stations that continue to increase and progress the network capacity. Table 3 shows the network capacity progression per funding opportunity using the station nameplate capacities stipulated in each grant agreement. The total capacity funded per funding opportunity and the average station capacity have increased substantially in the most recent solicitation, GFO-15-605. Table 4 summarizes the station counts included in the Joint Report analyses.

**Table 3: Network Capacity Progression per Funding Opportunity**

| <b>Funding Opportunity</b> | <b>Number of Stations Funded</b> | <b>Total Capacity Funded (kg/day)</b> | <b>Average Station Capacity (kg/day)</b> |
|----------------------------|----------------------------------|---------------------------------------|--|
| PON-09-608                 | 10                               | 2,140                                 | 214                                      |
| PON-12-606                 | 4                                | 730                                   | 183                                      |
| SCAQMD Upgrade             | 3                                | 480                                   | 160                                      |
| PON-13-607*                | 27                               | 4,745                                 | 176                                      |
| GFO-15-605                 | 21                               | 6,780                                 | 323                                      |
| <b>Network Totals</b>      | <b>65</b>                        | <b>14,875</b>                         | <b>229</b>                               |

\* California State University, Los Angeles received ARFVTP O&M funding in PON-13-607, and its capacity is included in the total.

Source: CEC

**Table 4: Changes in Cumulative Number of ARFVTP-Funded Stations**

| <b>Year</b> | <b>Description</b>   | <b>Cumulative Number of Stations</b> |
|-------------|--|--------------------------------------|
| 2016        | ARFVTP-funded stations reported without the temporary refueler   | 48                                   |
| 2017        | Temporary refueler   | 49                                   |
| 2017        | ARFVTP provided O&M funds to CARB-funded California State University, Los Angeles station  | 50                                   |
| 2017        | The stations planned for Encinitas (ARV-10-048) and Foster City and Los Altos (ARV-12-057) were cancelled due to lack of clear path to completion. | 47                                   |
| 2017        | Sixteen new stations were approved under GFO-15-605.   | 63                                   |
| 2017        | Three HyGen Industries stations were addressed at the October 2017 CEC Business Meeting and removed from the analyses in this Joint Report.        | 60                                   |
| 2017        | Five additional stations were proposed for funding under GFO-15-605.   | 65                                   |

Source: CEC

## Emissions Reduction

Table 5 shows the emissions reduction based on the expected traffic flow to the hydrogen refueling stations funded by the ARFVTP. The carbon dioxide equivalent (CO<sub>2e</sub>) is calculated using the methods in the CEC's most recent solicitation for hydrogen refueling stations.<sup>15</sup>

The emissions reduction is realized when people drive FCEVs instead of gasoline cars. The emission reduction values are calculated using the carbon intensity (CI) for gasoline, hydrogen, and the Energy Economy Ratio, the value representing the efficiency of hydrogen as transportation fuel compared to gasoline, in the California Air Resources Board's Low Carbon Fuel Standard (LCFS). The CI is the amount of life-cycle greenhouse gas emissions per unit of fuel energy, expressed in grams of carbon dioxide equivalent per megajoule (gCO<sub>2e</sub>/MJ).<sup>16</sup>

Table 5 reflects the actual hydrogen dispensing by 27 ARFVTP-funded stations in 2016 and the potential of the 65 ARFVTP-funded stations to dispense hydrogen at the associated nameplate capacities in 2020. Los Angeles and Orange Counties show the greatest amount for all emissions reductions listed in Table 5, due to the concentration of hydrogen refueling stations in these areas.

**Table 5: Emissions Reduction**

| County       | 2016 CO <sub>2e</sub> Reduction (metric tons/year) | 2020 Projected CO <sub>2e</sub> Reduction (metric tons/year) | 2020 Projected NOx Reduction (kg/year) <sup>17</sup> | 2020 Projected PM2.5 Reduction (kg/year) <sup>17</sup> |
|--------------|--|--|--|--|
| Alameda      | 62   | 2,270  | 2,300  | 94   |
| Contra Costa | 8  | 1,150  | 1,280  | 52   |
| Fresno       | 34   | 482  | 326  | 13   |
| Los Angeles  | 708  | 22,900   | 16,000   | 655  |
| Marin        | 3  | 28   | 27   | 1  |
| Merced       | -  | 73   | 65   | 3  |
| Orange       | 749  | 8,260  | 6,460  | 265  |
| Placer       | 9  | 354  | 369  | 15   |
| Riverside    | 8  | 1,140  | 732  | 30   |
| Sacramento   | 69   | 809  | 1,040  | 43   |
| San          | 8  | 479  | 285  | 12   |
| San Diego    | 9  | 3,240  | 2,280  | 93   |
| San          | 76   | 2,770  | 2,990  | 122  |

<sup>15</sup> CEC, *Light Duty Vehicle Hydrogen Refueling Infrastructure Application Manual*, Attachment 13: [Greenhouse Gas Emission Calculation Example](http://www.energy.ca.gov/contracts/GFO-15-605/) (http://www.energy.ca.gov/contracts/GFO-15-605/)

<sup>16</sup> California Air Resources Board, [Low Carbon Fuel Standard](https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard), https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

<sup>17</sup> Elgowainy, A., et al. *Life-Cycle Analysis of Air Pollutants Emission for Refinery and Hydrogen Production from SMR*. Argonne National Laboratory. 2017. pp 22-24. (https://www.hydrogen.energy.gov/pdfs/review17/sa066\_elgowainy\_2017\_o.pdf)

| County        | 2016 CO <sub>2</sub> e Reduction (metric tons/year) | 2020 Projected CO <sub>2</sub> e Reduction (metric tons/year) | 2020 Projected NO <sub>x</sub> Reduction (kg/year) <sup>17</sup> | 2020 Projected PM <sub>2.5</sub> Reduction (kg/year) <sup>17</sup> |
|---------------|---|---|--|--|
| San Mateo     | 51  | 1,300   | 1,300  | 53   |
| Santa         | 17  | 482   | 326  | 13   |
| Santa Clara   | 154   | 4,720   | 4,010  | 164  |
| Solano        | -   | 119   | 152  | 6  |
| Sonoma        | 0   | 0   | 0  | 0  |
| Ventura       | 1   | 93  | 68   | 3  |
| Yolo          | 2   | 23  | 23   | 1  |
| <b>Totals</b> | <b>1,968</b>  | <b>50,692</b>   | <b>40,033</b>  | <b>1,638</b>   |

Source: CEC

### Low Carbon Fuel Standard (LCFS) and Financial Incentives

The potential LCFS revenue for 2020 is based on the projected amount of hydrogen dispensed at each ARFVTP-funded station, the pathway(s) for that hydrogen, and the value of each LCFS credit. Although the credit values ranged from \$20 to \$126 per metric ton CO<sub>2</sub>e reduced<sup>18</sup> for this analysis, an LCFS credit is assumed to be worth \$100 per metric ton CO<sub>2</sub>e reduced.

The total potential LCFS revenue stream for the ARFVTP-funded 65 stations is \$5,150,000, based on the 2020 projection of CO<sub>2</sub>e reduction in Table 5. This revenue represents an incentive to offset the cost of hydrogen sale, especially if the hydrogen is produced using a low-CI pathway. The renewable portion of the hydrogen could garner \$2,510,000, or 48.7 percent, of the forecast incentive regardless of the fact that it represents 38.5 percent of total hydrogen dispensed.

The LCFS fuel premium is derived by Equation 1, as follows.<sup>19</sup>

*Pathway LCFS Revenue*

$$= (CI_{gasoline,x} * EER_{Hydrogen} - CI_{Hydrogen}) * LHV_{Hydrogen} * \frac{1}{1,000,000} * P_{Credit}$$

*Equation 1*

Where  $CI_{gasoline,x}$  indicates the regulated carbon intensity of gasoline sold in year  $x$  as specified in the LCFS program,  $EER_{Hydrogen}$  is the Energy Economy Ratio for hydrogen (2.5),  $CI_{Hydrogen}$  is the carbon intensity of the hydrogen production pathway as declared by the station award applicant,  $LHV_{Hydrogen}$  is the lower heating value (energy density) of hydrogen (120 MJ/kg),  $\frac{1}{1,000,000}$  is the number of metric ton per gram, and  $P_{Credit}$  is the assumed trading price of each LCFS credit (\$100/metric ton of CO<sub>2</sub>e). In Equation 2,  $i$  indicates a station, and  $j$  indicates each production pathway used for hydrogen dispensed at station  $i$ . For many

<sup>18</sup> California Air Resources Board, [Data Dashboard](https://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm) (https://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm)

<sup>19</sup> California Air Resources Board, [Credit Price Calculator](http://www.arb.ca.gov/fuels/lcfs/dashboard/creditpricecalculator.xlsx), (http://www.arb.ca.gov/fuels/lcfs/dashboard/creditpricecalculator.xlsx)

applicants, hydrogen is provided by both renewable and nonrenewable production pathways, each of which has a carbon intensity.

$$\text{Station LCFS Revenue}_i = \sum_j \text{Pathway LCFS Revenue}_j$$

Equation 2

## Localized Health Impacts

The CEC assesses the localized health impacts of proposed projects in terms of potential health impacts on the communities in which they will be located, as well as surrounding communities. A localized health impacts report is posted for public review and comment for 30 days before a CEC business meeting. In this assessment, environmental justice (EJ) communities, low-income communities, and minority communities are considered the most impacted by any project that could potentially result in increased criteria emissions and toxic air pollutants.

On February 17, 2017, the CEC posted the Notice of Proposed Awards for GFO-15-605, Hydrogen Refueling Infrastructure for Light Duty Vehicles, resulting in a connector station located on Interstate 5 (I-5) and 15 main stations. The CEC prepared an associated localized health impacts report.<sup>20</sup> The localized health impacts report assesses and reports on the potential localized health impacts of the proposed projects. The localized health impacts report underwent a 30-day comment period; no comments were received. The localized health impacts report shows that the hydrogen refueling stations proposed for funding under GFO-15-605 are in communities having one or more of the EJ indicators: minority, poverty, unemployment, and high percentage of population under 5 years of age or older than 65 years of age. It is not anticipated that implementing these projects will have any negative impacts because there will not be a net increase in criteria and toxic emissions in the communities.

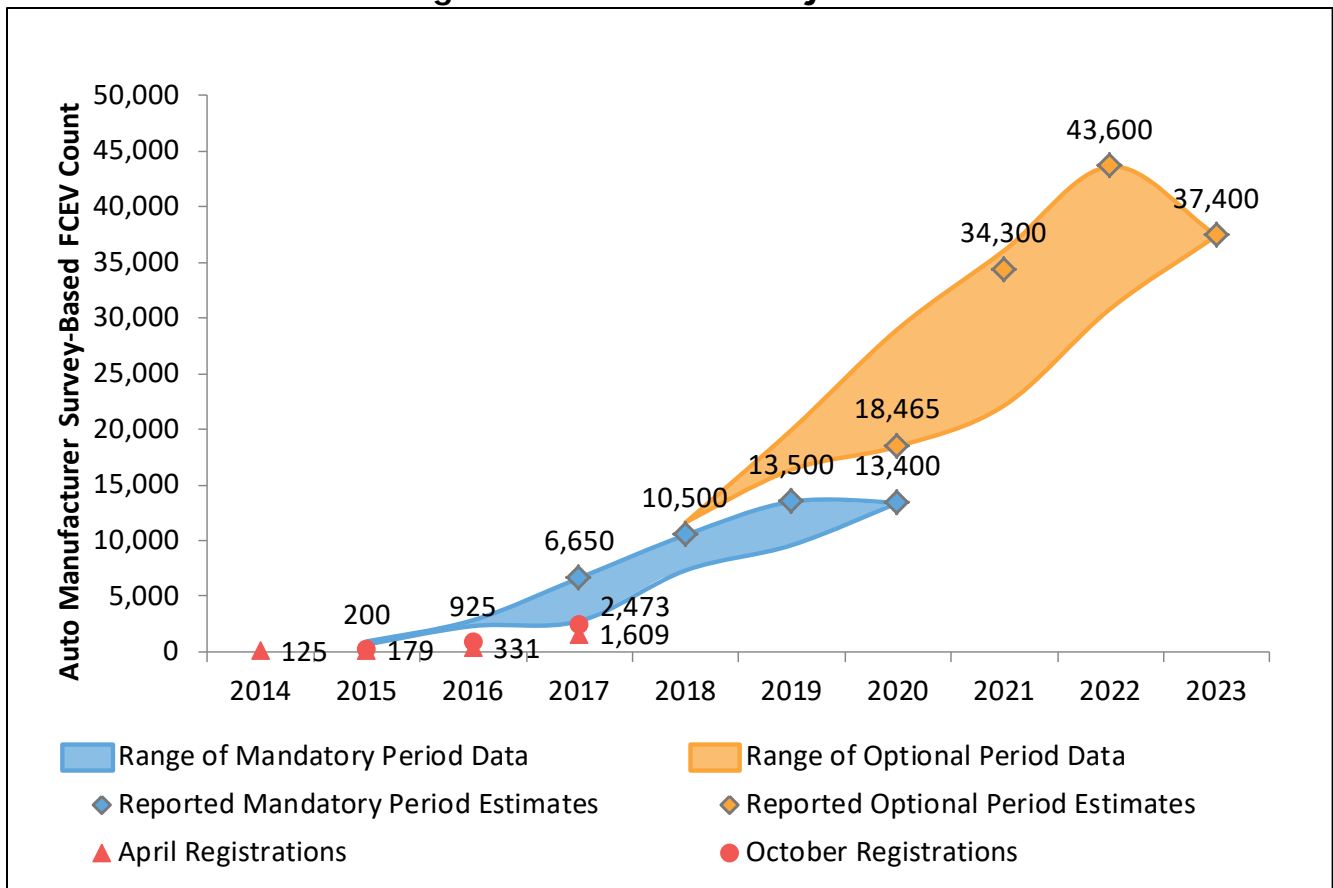
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<sup>20</sup> Brecht, Patrick. 2017. [Localized Health Impacts Report For Selected Projects Awarded Funding Through the Alternative and Renewable Fuel and Vehicle Technology Program Under Solicitation GFO-15-605 – Light Duty Vehicle Hydrogen Refueling Infrastructure](http://www.energy.ca.gov/2017publications/CEC-600-2017-006/CEC-600-2017-006.pdf). CEC, Fuels and Transportation Division. Publication Number: CEC-600-2017-006. (<http://www.energy.ca.gov/2017publications/CEC-600-2017-006/CEC-600-2017-006.pdf>.)

# CHAPTER 3: Fuel Cell Electric Vehicle Deployment

Figure ES4 in CARB's 2017 Annual Evaluation shows 1,609 FCEVs registered with the California Department of Motor Vehicles as of April 2017. Figure 7, below, is an updated version of CARB's Figure ES4, shows the latest FCEV California Department of Motor Vehicles registration data as of October 6, 2017, which is 2,473 FCEVs. Industry reports that 3,234 FCEVs have been sold or leased in California as of December 1, 2017, which is the most recent available data as of this report publication.<sup>21</sup> This is encouraging growth in FCEV deployment over the past six months. The pace of market growth is expected to increase in the years ahead.

**Figure 7: FCEV Count Projections**



Source: CARB

Figure 7 shows CARB's latest results from auto manufacturer surveys that project 13,400 FCEVs in 2020 and 37,400 in 2023. CARB's latest survey suggests that the estimated FCEV deployment is reduced by one to two years behind previous estimates, which projected that these volumes would be achieved earlier. The figure presents FCEV projections in what is both the mandatory reporting period (shown in blue in the figure, which is the next three model years at the time of survey) and the optional reporting period (shown in orange in the figure,

<sup>21</sup> California Fuel Cell Partnership, [By The Numbers](https://cafcp.org/by_the_numbers), (https://cafcp.org/by\_the\_numbers), as of December 1, 2017.



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 the figure, represented by the diamond-shaped icons, are the end-of-period values from the estimates that CARB received from auto manufacturers in each survey year. For instance, in 2014, the end of the mandatory survey period corresponded to 2017.

Therefore, the 6,650 FCEV estimate was made in 2014 for 2017. The end of the optional reporting period in that year was 2020, and the reported value was 18,465 FCEVs. Continuing with this example, in 2015 and 2016, CARB again asked auto manufacturers for FCEV projections for 2017. The blue shaded area for 2017 represents the range of estimates that CARB made from these other years of surveying. In the example of 2017, one can see that, because the blue range extends down only from 6,650, the subsequent estimates were lower than what was originally estimated in 2014. As the State builds stations, auto manufacturers update the number of FCEVs they want to sell and the FCEV projections based on the most up-to-date information available at the time. Over the years, CARB and the CEC have witnessed a dynamic relationship among the reported rate of future FCEV deployment, the pace of hydrogen refueling station network growth, and major developments in the state's hydrogen refueling industry. The elastic relationship between stations and vehicles is reflected in the FCEV deployment projections provided by auto manufacturers from one year to the next.

The 2017 Annual Evaluation states that the current station deployment rate affects the short- and long-term FCEV deployment plans by auto manufacturers. Although most stations are still operating well under their nameplate capacities, "with many core market areas still without sufficient coverage and backup fueling options, halting or slowing investment in hydrogen fueling stations will push auto manufacturers' FCEV deployment plans further into the future."<sup>22</sup>

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<sup>22</sup> California Air Resources Board, [2017 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf). August 2017. [https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8\\_report\\_2017.pdf](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf), page 13.

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

The four development phases to analyze length of time required to permit and construct hydrogen refueling stations are described in Table 6. Refer to Appendix H for definitions of operational and open retail and for details on the testing that must occur before a station achieves open retail status. For the analyses in this chapter, only stations that were funded under PON-09-608, PON-12-606, PON-13-607 (excluding the temporary refueler), and GFO-15-605 were used, and the analyses do not include data for station upgrades and California State University, Los Angeles (only O&M funded).

**Table 6: Typical Station Development Phases and Responsible Entities**

| Phases  | Description  | Responsible Entity(ies)                                     |
|---|--|---|
| <b>Phase One:</b><br>Start of CEC grant-funded project to initial permit application filing | This phase begins when the grant-funded project is executed and includes site selection and site control, station planning, participation in pre-permitting meetings for confirmation of station design consistent with local zoning and building codes, and filing the initial permit application with the authority having jurisdiction (AHJ). Equipment ordering could occur during this phase, depending on financial investment optimization. | Grant recipient and AHJ                                     |
| <b>Phase Two:</b><br>Initial permit application filing to receipt of approval to build      | Phase two 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                                     |
| <b>Phase Three:</b><br>Approval to build to becoming operational                            | This phase 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 J2601), successfully fuels one FCEV, and receives the occupancy permit from the AHJ.  | Grant recipient and AHJ                                     |
| <b>Phase Four:</b><br>Operational to open retail  | In this phase, the station undergoes accuracy testing with the 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 fueling protocol, the station is categorized as open retail.   | Grant recipient, DMS, CARB (HyStEP), and auto manufacturers |

Source: CEC

## Average Station Development Remains Shorter for the Newest Stations

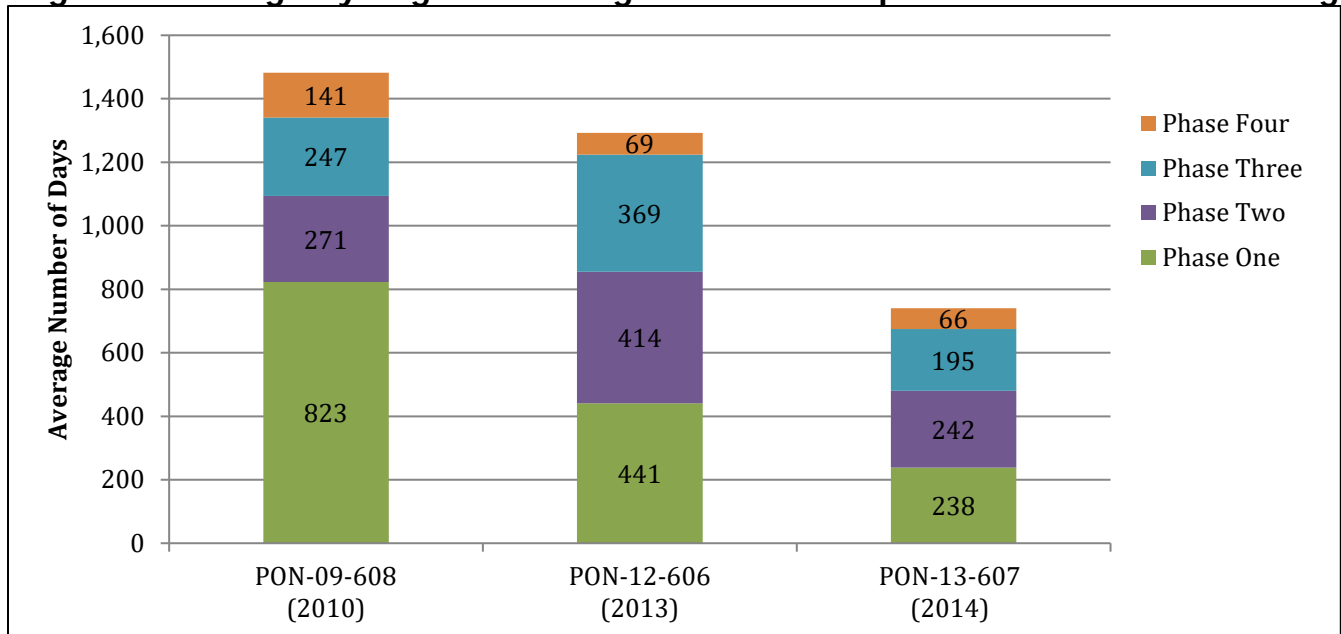
Six stations became open retail in 2017: one station funded under PON-09-608, four stations funded under PON-13-607, and one funded as an upgrade under the SCAQMD contract. Some stations that experienced delays as reported in the 2016 Joint Report still experience delays

and have not completed the development phase they were in last year. These delays increased the average development durations for those phases.

Figure 8 shows updated average station development durations. Overall, the stations funded under PON-13-607 continue to progress and added 11 days to the average of overall station development (741 days total) compared to what was reported in the 2016 Joint Report (730 days total). This analysis excludes the time spent on the Riverside station to become open retail from operational because it took 494 days due to technical difficulties and excludes the time spent on the Ontario station to become operational from receiving approval to build because it took 686 days due to technical difficulties and the construction of an underpass that precluded connection of the station utilities. The extra time from these stations would skew the trend displayed by the rest of the stations funded under this solicitation. For stations funded under PON-12-606, the overall station development average increased by 60 days (from 1,233 days to 1,293 days).

Several factors contributed to this increase, but the most notable factor is that the stations that had not completed phases in 2016 completed some phases in 2017, naturally increasing the average duration spent in those phases. For the stations funded under PON-09-608, the average overall station development increased only by one day (from 1,481 days to 1,482 days).

**Figure 8: Average Hydrogen Refueling Station Development Times Are Decreasing**



Source: CEC

The time required to permit hydrogen refueling stations is decreasing because of several factors. First, the increased experience of station developers and increased knowledge and experience of local agencies yield a more informed stakeholder group. The development and review of permit applications reflect the informed stakeholders. Second, representatives of the CEC and GO-Biz participate in local permitting meetings and hearings to articulate the network perspective of the stations and the importance of FCEV and station deployment in supporting the commercial growth of FCEVs, which is necessary to achieve Governor Edmund G. Brown Jr.'s vision of increasing the adoption of ZEVs to reach 1.5 million ZEVs by 2025 in California.

Finally, the CEC, CARB, and GO-Biz participate in public panel discussions and workshops with permitting agencies, fire marshals, and code experts to spread the word about station rollout. The combination of the broadened knowledge and mindshare contribute generally to shorter permitting durations and hydrogen acceptance.

Table 7 summarizes the station development phases and significant changes during this reporting year:

- GFO-15-605
  - The analysis of average duration of hydrogen refueling station development phases for the stations funded under this solicitation will begin in the 2018 Joint Report.
  - Prior to applying for the solicitation, GFO-15-605 awardees executed lease agreements for 18 of 21 stations.
  - Five additional stations were proposed for funding in November 2017.

The following summarizes the minor changes between the 2016 Joint Report<sup>23</sup> and the 2017 Joint Report:

- PON-13-607
  - Three stations are no longer included in the analysis as mentioned in this report, decreasing the average by three days for Phase 1.
  - Two stations completed Phase 2, adding two days to the average.
  - Three stations completed Phase 3, adding 18 days to the average.
  - Four stations completed Phase 4, decreasing the average by 11 days.
- PON-12-606
  - Three stations are no longer included in the analysis as mentioned in this report.
  - One station completed Phase 2, adding 60 days to the average.
- PON-09-608
  - One station completed both Phase 3 and Phase 4, adding 19 days to the Phase 3 average and decreasing the Phase 4 average by 18 days.

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<sup>23</sup> Baronas, Jean, Gerhard Achteik, et al. [Joint Agency Staff Report on Assembly Bill 8: 2016 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California](http://www.energy.ca.gov/2017publications/CEC-600-2017-002/CEC-600-2017-002.pdf). CEC. Publication Number: CEC-600-2017-002. (<http://www.energy.ca.gov/2017publications/CEC-600-2017-002/CEC-600-2017-002.pdf>)

**Table 7: Average Duration of Hydrogen Refueling Station Development Phases**

| Solicitation/Contract        | Phase One  | Phase Two                    | Phase Three                  | Phase Four                   |
|------------------------------|--|------------------------------|------------------------------|------------------------------|
| <b>GFO-15-605<br/>(2016)</b> | Analysis to be reported in the 2018 Joint Report |                              |                              |                              |
| <b>PON-13-607<br/>(2014)</b> | <b>238 days</b>                                  | <b>242 days</b>              | <b>195 days</b>              | <b>66 days</b>               |
|                              | <i>24 of 25<br/>stations</i>                     | <i>23 of 25<br/>stations</i> | <i>20 of 25<br/>stations</i> | <i>20 of 25<br/>stations</i> |
| <b>PON-12-606<br/>(2013)</b> | <b>441 days</b>                                  | <b>414 days</b>              | <b>369 days</b>              | <b>69 days</b>               |
|                              | <i>4 of 4<br/>stations</i>                       | <i>4 of 4 stations</i>       | <i>2 of 4 stations</i>       | <i>2 of 4 stations</i>       |
| <b>PON-09-608<br/>(2010)</b> | <b>823 days</b>                                  | <b>271 days</b>              | <b>247 days</b>              | <b>141 days</b>              |
|                              | <i>8 of 10<br/>stations</i>                      | <i>8 of 10<br/>stations</i>  | <i>8 of 10<br/>stations</i>  | <i>8 of 10 stations</i>      |

Source: CEC

The same factors described in the 2016 Joint Report affect station development time. Station location changes in 2016 caused delays that are still affecting the progress of those stations. Other factors include business environments, financial incentives, costs, available funding, and project readiness. In addition, factors such as expressed needs for esthetic or infrastructure upgrades at the host site, requirements for environmental mitigation to accompany any new development at the host site, and coordination with local utility schedules for connection to the new on-site equipment were observed. These obstacles are not necessarily inherent to the installation of hydrogen fueling equipment and could apply to any developers.

## Strategies for Acceleration

The following sections describe strategies and actions that the CEC and other government agencies are implementing to accelerate hydrogen station development. The CEC instituted several mechanisms including critical milestones, described below, and it reserved the right to cancel awards that propose to undergo station location changes. The CEC also supports regional planning so that communities across the state are aware of hydrogen technology and ready to implement projects to support FCEV adoption.

### Critical Milestones

GFO-15-605 requires grant recipients to comply with critical milestones before they can be reimbursed for eligible expenses. Critical Milestone 1 requires the recipient to have held an in-person, pre-application meeting with the AHJ in the area where a station is proposed to discuss the station design and start obtaining permits to build and operate the station. In fact, 18 out of 21 stations awarded under GFO-15-605 completed Critical Milestone 1 before applying for funding (some pending submission of the evidence).

Critical Milestone 2 requires the recipient to obtain and keep site control where the hydrogen refueling station is to be constructed. Eighteen out of 21 stations awarded under GFO-15-605 obtained site control at the time of the applications, and one station obtained site control within one month after the CEC business meeting approval. Table 8 summarizes the critical milestones.

**Table 8: Critical Milestones**

|  | <b>Deadline</b>   | <b>GFO-15-605 Recipients</b>   | <b>Comments</b>   |
|--|---|--|---|
| <b>Critical Milestone 1:</b><br>Pre-application meeting for permits with AHJs.   | Due date was proposed by the applicants.<br>Must be completed before receiving any payment by the CEC under an agreement resulting from the solicitation, GFO-15-605.   | <ul style="list-style-type: none"> <li>• Eighteen out of 21 awarded stations have already completed Critical Milestone 1 at the time of the applications.</li> </ul>   | The CEC reserves the right to terminate the agreement if either critical milestone is missed. |
| <b>Critical Milestone 2:</b><br>Have control and possession of the project site. | Due date was proposed by the applicants.<br>Must be completed prior to receiving any payment by the CEC under an agreement resulting from the solicitation, GFO-15-605. | <ul style="list-style-type: none"> <li>• Eighteen out of the 21 awarded stations completed Critical Milestone 2 at the time of the applications.</li> <li>• An additional awarded station obtained site control within one month after the CEC business meeting approval.</li> </ul> | The CEC reserves the right to terminate the agreement if either critical milestone is missed. |

Source: CEC

### **Incentive Funding**

The CEC offered financial incentives for accelerated permitting and station construction under GFO-15-605. Stations becoming operational within 20 months after a project is approved at a CEC business meeting are eligible for full funding. PON-13-607 offered similar incentives. Although other factors play roles in a station becoming operational, some stations met the incentive funding deadline in PON-13-607 through accelerated permitting and construction. As of September 30, 2016, 19 stations met the financial incentives (for capital expenditures, O&M, or both) of PON-13-607.

### **Project Planning and Readiness**

To expedite hydrogen refueling station development, it is imperative for hydrogen refueling station developers to work closely with city and county project planners to envision the project, determine potential project acceptance, and make the project ready for the locale. The CEC and GO-Biz often participate in planning meetings and public hearings to provide the perspective of California’s hydrogen refueling network. The combination of experts provides recommendations for developers and, with collaboration, expedites results. The city and county project planners have provided invaluable assistance throughout the entire station deployment and network rollout. Local requirements are specific; general information on station planning, including discussion of the land-use ordinances and safety codes and standards that apply to hydrogen station development, is provided in Appendix E.

Also integral to the project planning and readiness of a station are timely equipment delivery, effective contract negotiations; quick and effective utility connections; conformance to applicable building, safety, zoning codes; and, if needed, the ability and flexibility to customize a station to blend with local aesthetics. Readiness also includes the ability to size the station equipment accurately for the site. This ability requires analysis of the space needed for equipment, pedestrian traffic, and vehicular movement through the site – not only for light-duty vehicles to reach the hydrogen dispenser, but for heavy-duty vehicles to deliver hydrogen (if not generated on-site). Likewise, project planning that considers California Title 24

requirements for the Americans with Disabilities Act<sup>24</sup> and that identifies and addresses any residual chemicals, leaks, and old equipment from previous fueling stations is most likely to result in satisfactory readiness.

Since AHJs and communities often prioritize aesthetics according to the people who live in an area, the businesses that operate there, and the local “norms” established by the citizens, the utmost attention is needed for the cost and the time needed to meet such requirements. For example, some value design, color, and appearance of the hydrogen refueling station. Others insist on updating the entire station where the hydrogen refueling station is planned, leading to potentially unforeseen civil engineering costs and time to complete the station.

Outreach and education are also essential to the success of a hydrogen refueling station. The public acceptance of hydrogen refueling is often very influential to the success of a station, and community outreach should therefore be planned and carried out by the station developer, station owner, AHJ, auto manufacturers, CEC, and GO-Biz. Station planning, readiness, and outreach are essential to California meeting the 100 hydrogen refueling station milestone; the contributions on the part of people at the local levels are key to successful station deployment.

### **Regional Readiness Planning**

To help support ZEV planning, increase local awareness, and potentially decrease the time required for permitting and construction of hydrogen refueling stations and other alternative fuels, the CEC provides funds to support the development of ZEV regional readiness plans. The most recent is a \$299,280 grant to the San Luis Obispo County Air Pollution District to implement a ZEV readiness plan. The plan includes creating an ombudsman position, conducting ZEV siting analysis, and conducting outreach to increase consumer acceptance of ZEVs and encourage fleet adoption of medium- and heavy-duty ZEVs in the Central Coast region. Several ZEV readiness plans for alternative fuel types, including hydrogen, are completed.

The City and County of San Francisco received more than \$400,000 in ARFVTP funding to prepare an alternative fuel vehicle readiness plan to accelerate adoption of alternative fuel vehicles and promote deployment and use of alternative fuel infrastructure in San Francisco and surrounding areas. This plan details policies and practices to promote accelerated alternative vehicle adoption and use. It also addresses the specific alternative vehicle type and associated pathways and infrastructure, including hydrogen refueling infrastructure.

The Santa Barbara County Air Pollution Control District received more than \$200,000 in ARFVTP funding to prepare a readiness plan for developing hydrogen infrastructure in Santa Barbara, San Luis Obispo, and Ventura Counties. The plan identified three key priorities for ongoing hydrogen readiness planning efforts:

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<sup>24</sup> California Code of Regulations, Title 24, California Building Standards Code, Part 2 California Building Code, Vol I, Chapter 11B – Accessibility to Public Buildings, Public Accommodations, Commercial Building and Public Housing.

- To secure funding to support hydrogen infrastructure buildout, vehicle incentives and outreach (for example from public-private partnerships, California Environmental Quality Act mitigation, settlements, enforcement actions, and grants)
- To develop a strategy for creating commercial opportunities locally for the production and delivery of low-carbon hydrogen
- To increase public awareness of hydrogen and FCEVs to promote early adoption and create a foundation for broad consumer acceptance

The San Diego Association of Governments (SANDAG) received a \$200,000 grant from the CEC for an alternative fuel readiness plan that addresses the barriers to alternative fuel deployment. The plan aims to accelerate deployment of alternative fuel vehicles and alternative fuel infrastructure in the San Diego region. This readiness plan includes recommendations to further the growth of alternative fuel vehicles and infrastructure and could help establish the San Diego region as one of the most comprehensive zero-emissions infrastructure network in the country. Implementation of the readiness plan should help increase awareness, accessibility, and use of alternative fuels through the region while reducing GHG emissions.

The County of Santa Barbara – Central Coast received nearly \$300,000 in CEC grant funds to prepare a readiness plan intended to guide development of alternative fuel vehicle policies and infrastructure for the tri county Central Coast region. This plan builds on the *Central Coast PEV Readiness Plan* developed in 2014. The plan encourages local residents and fleet managers to purchase and use alternative fuel vehicles with improved environmental benefits.

There are several ongoing regional planning efforts. For example, the Redwood Coast Energy Authority received \$300,000 in grant funding for the North Coast and Upstate regions. The draft readiness plan is on the Redwood Coast Energy Authority website, but the final plan has not yet been published. The plan has a detailed analysis for siting hydrogen refueling stations in the North Coast and Upstate regions. It also contains resources to create early adoption of FCEVs and incorporation of FCEVs in fleets. This plan is for multiple alternative fuel types. The Redwood Coast Energy Authority is also using output data from California Hydrogen Infrastructure Tool <sup>25</sup> for regional hydrogen station siting in a different CEC agreement, and this grant amount is \$169,000. The goal is to create a coordinated effort throughout the region to support the successful introduction and deployment of FCEVs.

### **Regional Air District Funding**

Some air districts, most notably the Bay Area Air Quality Management District (BAAQMD) and the South Coast Air Quality Management District (SCAQMD), offer financial assistance to hydrogen refueling stations in their jurisdictions. In many cases, they have supplemented state grant support for hydrogen refueling stations with their own grant awards.

BAAQMD includes “Hydrogen Stations” as a project category eligible for funding under its Transportation Fund for Clean Air Regional Fund. The Transportation Fund for Clean Air includes several eligible project types related to clean air vehicles and infrastructure, including support for light-duty zero- and partial-zero-emission vehicles for fleets and heavy-duty zero- and partial-zero-emission vehicles, under which hydrogen fuel cell technologies are typically

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<sup>25</sup> [California Hydrogen Infrastructure Tool](https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm) (https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm)



eligible. Each fiscal year, BAAQMD reevaluates the Transportation Fund for Clean Air policies and evaluation criteria, and proposed updates are open for public comment before they are considered by the BAAQMD's board of directors. Information related to this process for the fiscal year ending 2018 is available on the Transportation Fund for Clean Air Regional Fund website.<sup>26</sup>

To date, BAAQMD has awarded nearly \$2.2 million in Transportation Fund for Clean Air funding to accelerate installation of 12 hydrogen refueling stations in the San Francisco Bay Area. Any future solicitations for hydrogen stations will be announced on the Hydrogen Station Grant Program website, which also provides contact information for anyone wanting to ask questions about the program.<sup>27</sup>

SCAQMD identifies "hydrogen and mobile fuel cell technologies and infrastructure" among the core technologies of focus for its Clean Fuels Program. In calendar year 2016, this program funded \$21.8 million in executed contracts, of which 18 percent went to the hydrogen technology area. The agency has invested \$13.1 million in hydrogen refueling stations to date through the program. These investments include \$10.1 million in co funding for the first five Cities Technology Demonstration hydrogen refueling stations in California and for the eight CARB-funded Technology Demonstration stations in the 2000s. SCAQMD has provided an additional \$2.9 million in supplemental capital and operating expense support to the modern network of hydrogen refueling stations in Southern California between 2010 and 2016. These grants average about \$125,000 per station and range from \$100,000 to \$330,000.

SCAQMD has also supported the hydrogen refueling network in other ways, such as by co funding CDFA/DMS metrology activities, the HyStEP device (a tool used in performance testing and validation), codes and standards research, and a study on renewable hydrogen. It has also been a leader in supporting hydrogen fuel cell technology in public transportation and medium- and heavy-duty applications over the years. In calendar year 2017, SCAQMD plans to direct about 33 percent of Clean Fuels Program funding to hydrogen and fuel cell technology and infrastructure projects, and the bulk of this will emphasize medium- and heavy-duty vehicles and infrastructure, with \$450,000 planned for light-duty vehicle and infrastructure development in Southern California.<sup>28</sup>

## **Mobile Source Air Pollution Reduction Review Committee Recommends Approval of an Award**

On October 5, 2017, the Mobile Source Air Pollution Reduction Review Committee Technical Advisory Committee recommended approval of a \$3 million award to the CEC, contingent on the negotiation of mutually satisfactory procedures regarding the flow of funds. The Mobile Source Air Pollution Reduction Review Committee approved the award on November 16, 2017. This sole-source contract award to the CEC, in an amount not to exceed \$3 million to fund

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<sup>26</sup> [Transportation Fund for Clean Air Regional Fund website](http://www.baaqmd.gov/grant-funding/public-agencies/regional-fund) <http://www.baaqmd.gov/grant-funding/public-agencies/regional-fund>, accessed October 6, 2017.

<sup>27</sup> [Hydrogen Station Grant Program website](http://www.baaqmd.gov/grant-funding/businesses-and-fleets/hydrogen-stations), <http://www.baaqmd.gov/grant-funding/businesses-and-fleets/hydrogen-stations>, accessed October 6, 2017.

<sup>28</sup> South Coast Air Quality Management District, Technology Advancement Office. [Clean Fuels Program 2016 Annual Report and 2017 Plan Update](http://www.aqmd.gov/docs/default-source/technology-research/annual-reports-and-plan-updates/2016annualreport_2017planupdate.pdf?sfvrsn=6). March 2017. [http://www.aqmd.gov/docs/default-source/technology-research/annual-reports-and-plan-updates/2016annualreport\\_2017planupdate.pdf?sfvrsn=6](http://www.aqmd.gov/docs/default-source/technology-research/annual-reports-and-plan-updates/2016annualreport_2017planupdate.pdf?sfvrsn=6).

hydrogen infrastructure projects, was approved by the SCAQMD Governing Board on December 1, 2017. The Mobile Source Air Pollution Reduction Review Committee Clean Transportation Funding program is responsible for removing as much as 8,000 tons of air pollution from the skies of Southern California, helping the region move closer to achieving smog standards and reducing residents' exposure to airborne toxics and other pollutants. SCAQMD will provide funding, on behalf of Mobile Source Air Pollution Reduction Review Committee, for the construction of hydrogen refueling stations within the SCAQMD jurisdiction to support the increasing number of zero-emission FCEVs being deployed in Southern California. Through the funding of hydrogen refueling stations, Mobile Source Air Pollution Reduction Review Committee's air pollution reduction goal intersects with the CEC's goal of increasing the availability of ZEV refueling infrastructure within California.

### **Volkswagen Infrastructure Investment Commitment**

On October 25, 2016, and May 17, 2017, the United States District Court for the Northern District of California approved the 2.0-liter and 3.0-liter, respectively, partial consent decrees (consent decrees) among CARB, the United States Environmental Protection Agency, the United States Department of Justice, and Volkswagen. The decrees partially resolve Clean Air Act and California claims against Volkswagen for the use of defeat devices in its 2.0-liter and 3.0-liter diesel vehicles. The 2.0-liter consent decree contains Appendix C, the Zero-Emission Vehicle (ZEV) Investment Commitment, and Appendix D, the Environmental Mitigation Trust both of which contain opportunities for funding hydrogen infrastructure.

Appendix C requires Electrify America, a Volkswagen subsidiary, to invest \$800 million in four 30-month cycles on eligible California projects that include ZEV Infrastructure, ZEV Awareness, ZEV Access and Green City initiatives. CARB's board approved Electrify America's proposed 30-month California ZEV Investment Plan: Cycle 1 (Cycle 1 Plan) at a public hearing on July 27, 2017. Approved Cycle 1 Plan investments in ZEV public education and awareness campaigns will include FCEVs. The Cycle 1 Plan did not allocate additional dollars to FCEVs and hydrogen refueling infrastructure projects but committed to considering these projects in future cycles.<sup>29</sup> Appendices D and D-2 of the 2.0-liter and 3.0-liter consent decrees create an environmental trust through which California is allocated about \$423 million to replace dirty engines with cleaner. Appendix D allows California to use up to 15 percent of its \$423 million on specified light-duty, ZEV equipment projects. CARB will develop through a public process a beneficiary mitigation plan that will determine how the funding will be spent. CARB is considering funding projects that pay for up to 33 percent of the cost to purchase, install, and maintain light-duty hydrogen FCEV supply equipment capable of dispensing at least 250 kg/day and that will be available to the public.<sup>30</sup>

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<sup>29</sup> [More information on Appendix C](https://www.arb.ca.gov/msprog/vw_info/vsi/vw-zevinvest/vw-zevinvest.htm). ([https://www.arb.ca.gov/msprog/vw\\_info/vsi/vw-zevinvest/vw-zevinvest.htm](https://www.arb.ca.gov/msprog/vw_info/vsi/vw-zevinvest/vw-zevinvest.htm) and <https://www.electrifyamerica.com/>)

<sup>30</sup> More information on [Appendix D](https://www.arb.ca.gov/msprog/vw_info/vsi/vw-mititrust/vw-mititrust.htm), [https://www.arb.ca.gov/msprog/vw\\_info/vsi/vw-mititrust/vw-mititrust.htm](https://www.arb.ca.gov/msprog/vw_info/vsi/vw-mititrust/vw-mititrust.htm) and "[Appendix D-2 to Partial Consent Decree](https://www2.arb.ca.gov/resources/documents/vw-settlement-consent-decrees)," <https://www2.arb.ca.gov/resources/documents/vw-settlement-consent-decrees>

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

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The CEC uses projections prepared by CARB<sup>31</sup> of the number of FCEVs expected on California roads to plan the solicitations for hydrogen refueling stations. As the early market has grown, the CEC is more closely evaluating not only the overall projected number of vehicles, but the distribution of those vehicles by California region. The CEC has begun evaluating the state in four regions (with connector and destination areas evaluated separately) to compare how the existing and planned station network meets anticipated regional demand for fuel from FCEV drivers. These four regions are the:

- Greater Los Angeles Area.
- San Francisco Bay Area.
- San Diego Area.
- Sacramento Area.

CARB's latest projections in the 2017 Annual Evaluation estimate that there will be 13,400 FCEVs in California by 2020 and 37,400 by 2023. The CEC is evaluating how the currently funded 65-station network meets this projected demand to help inform the next round of station funding. In doing so, the CEC uses the best available information from station developers to estimate when each station will be open. All the currently funded 65 stations should be open by 2020, with many from GFO-15-605 expected to open in 2019. The CEC translates each open station into the number of FCEVs it should be able to support and compares how the number of supported FCEVs grows over time, as stations open, in relation to the CARB vehicle projections through 2023.<sup>32</sup> This analysis provides the basis for understanding the minimum amount of fueling capacity needed, and by when, for each region if the State is to provide enough infrastructure to meet projected FCEV growth.

Before presenting this regional analysis, the CEC tracks the statewide rollout of stations. Figure 9 shows the progression of ARFVTP-funded stations from when the first station opened to the public in 2015. In 2017, the temporary refueler and the open non-retail station at California State University, Los Angeles were added to the station count, and three stations were not completed due to funds liquidation. These changes explain why the overall number of stations fell by one in the first quarter of 2017. As the CEC has approved stations for award under GFO-15-605, the overall number of stations has grown in the subsequent quarters: nine stations were approved at a CEC business meeting in June 2017, seven were approved in August 2017, and five were proposed for awards in November 2017. Three stations by

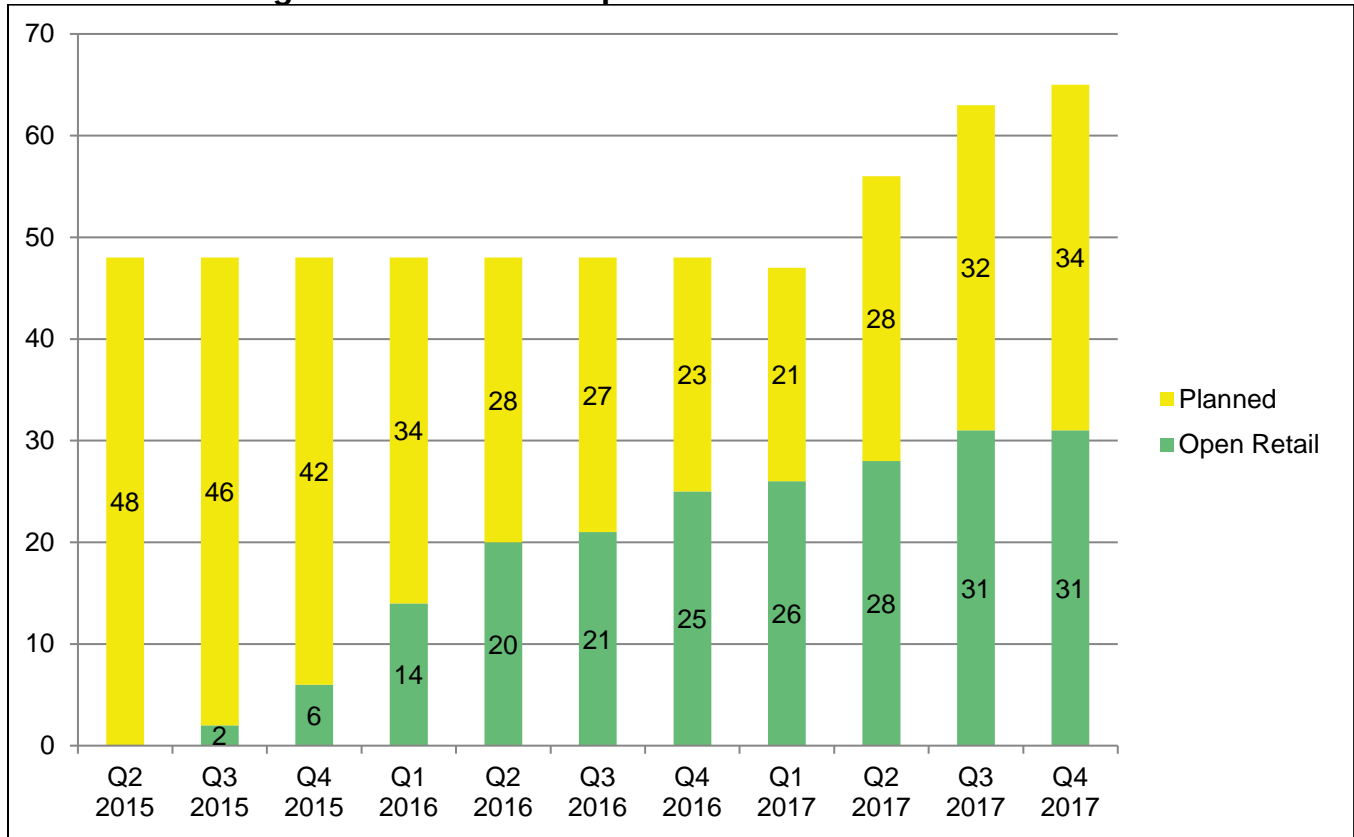
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<sup>31</sup> California Air Resources Board, [2017 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf). August 2017. [https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8\\_report\\_2017.pdf](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf)

<sup>32</sup> This analysis uses 0.7 kg as the typical FCEV fuel usage per day to convert station capacity into the number of FCEVs supported. This method is conservative because the 0.7 kg per day number assumes relatively high vehicle miles traveled per year. Source: Pratt, Joseph, Danny Terlip, Chris Ainscough, Jennifer Kurtz, and Amgad Elgowainy. [H2FIRST Reference Station Design Task, Project Deliverable 2-2](http://www.osti.gov/scitech/servlets/purl/1215215). National Renewable Energy Laboratory and Sandia National Laboratories, 2015. (<http://www.osti.gov/scitech/servlets/purl/1215215>)

developer HyGen Industries were removed from the station list in the fourth quarter. These 2017 changes are summarized in Table 4 in Chapter 2 of this report. As of November 15, 2017, there are 31 open retail stations (increased from 25 open retail stations reported in the 2016 Joint Report) and 34 that are planned and in some phase of development.

**Figure 9: Number of Open Retail and Planned Stations**



Source: CEC

## Market and Capacity Growth Analysis

The following four figures – one for each of the four evaluated regions – compare the estimated number of FCEVs that will be located in each region over time through 2023 with the number of FCEVs that would be supported by the region’s funded hydrogen refueling stations. The estimated number of FCEVs is expected to grow in all four regions. These figures, and the accompanying table, are meant to be planning tools for the CEC to use in its next funding cycle, along with California Hydrogen Infrastructure Tool and other market viability information, to assess regional station need.

This analysis estimates the need for hydrogen capacity in each of the four regions, which is in addition to the capacity provided by the 65 ARFVTP-funded stations. The estimates for the additional need by 2023 are presented in Table 9 at the end of this chapter followed by the graphs about network capacity and demand for fuel. They are meant to be minimum targets for adding capacity in the future. The shortfalls are calculated by comparing 80 percent of the funded network capacity to the amount of fuel that would be needed to support the 2023 FCEV projections.

This analysis is based on the assumption that the stations funded in the next several CEC funding cycles are operational by 2023. As station development becomes increasingly cost- and time-efficient and attracts private investors for additional money, there is the potential to greatly exceed these needs and support a much larger ramp-up of FCEV deployment.

The table is intended to reflect a minimum target of additional station capacity needed by 2023. Because stations take several years to develop, and because the State is working to provide stations before they are needed by FCEVs, the state's goal is to meet these minimum targets in its next rounds of funding.

Even though this analysis focuses on the capacity of stations (the kilograms per day of hydrogen needed in a region to support the population of FCEVs), this need is also about coverage. Only by strategically adding stations in key locations around each region – in other words, by adding coverage – will regions continue to have enough fuel to support the growing FCEV market. The ongoing need to provide more coverage is not intended to be understated, but rather to be underscored by the need for more capacity to fuel more FCEVs.

The following figures use the same template that CARB uses in Figure 33 in the 2017 Annual Evaluation.<sup>33</sup> That figure is a statewide figure analyzing projected hydrogen demand and fueling capacity, and these figures show results from a similar analysis at the regional level. As in the annual evaluation figure, the following figures show the projected number of FCEVs as vertical yellow bars. The bars represent the range of all the projections for FCEVs that CARB has received through auto manufacturer surveys for each year. The projections that were reported (meaning the actual numbers were published in an annual evaluation) at the end of the mandatory and optional survey periods are indicated in the figures by blue diamond symbols. For 2017 and past years, the actual FCEV numbers, as obtained from the California Department of Motor Vehicles each October, are shown by the blue diamonds.

The green shaded area indicates the potential number of FCEVs that could be fueled by the region's funded network of stations (based on projections of when each of the 65 funded stations will open to the public), with an assumed 0.7 kg/day of fuel consumption per FCEV. The width of the green shaded area reflects the difference between using as a basis either 100 percent of the nameplate capacity of the funded station network (the upper bound) or 80 percent of the nameplate capacity (the lower bound).<sup>34</sup> Because it is not realistic to assume stations operate at 100 percent of nameplate capacity, meaning they have zero kilograms left to dispense at the end of each day, the 80 percent number is presented in this analysis as something closer to actual sustainable operating conditions. This 80 percent number is the same one used in the financial scorecards presented later in this report to indicate when a station has reached maximum operational utilization.

Figure 10 shows that, in the Greater Los Angeles Area, a capacity shortfall may be experienced as early as 2018. The possible shortfall is small, however, and may or may not materialize, depending on station completion timelines and actual vehicle rollout. This period will be one to

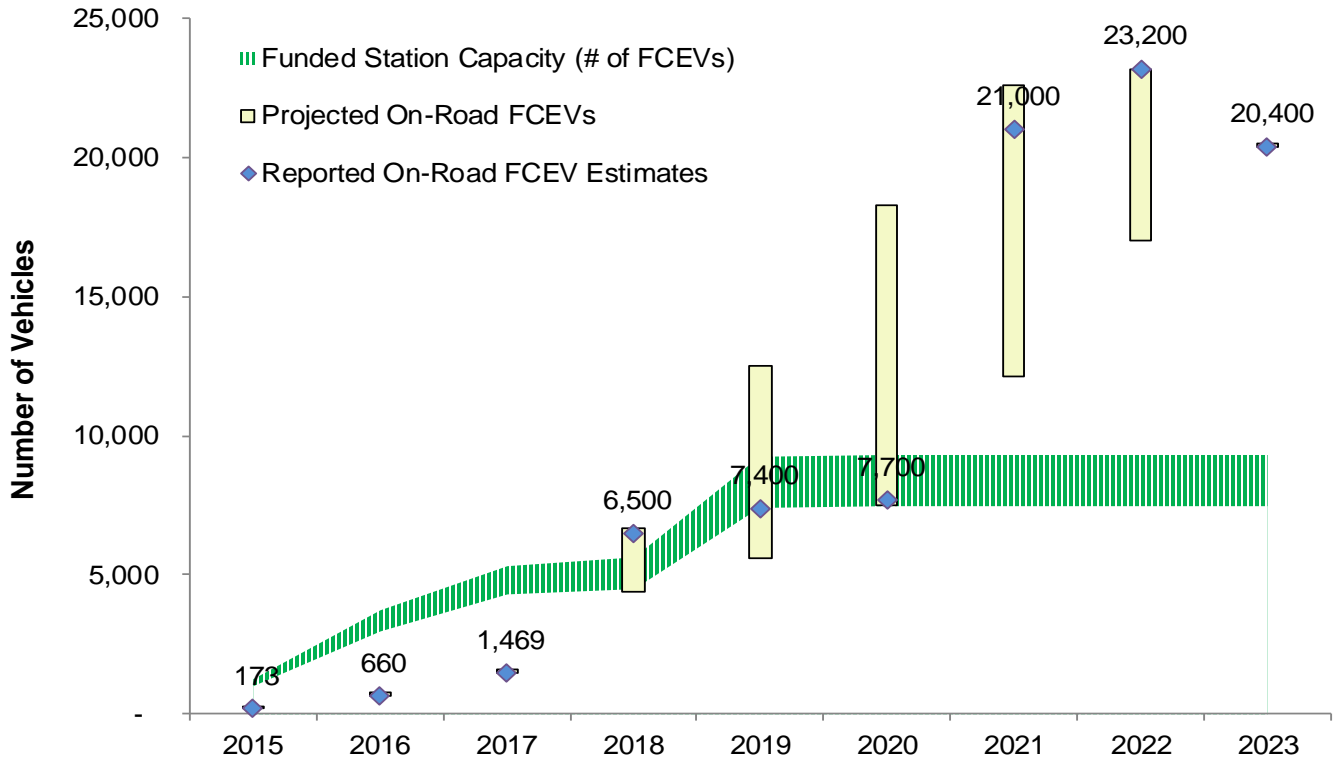
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<sup>33</sup> Figure 33 is also Figure ES5 in the [2017 Annual Evaluation](#). Explanatory text about this figure is on pages 66-67 of the 2017 Annual Evaluation. [https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8\\_report\\_2017.pdf](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf).

<sup>34</sup> The green shaded area is calculated somewhat differently in the CARB figure in the 2017 Annual Evaluation. Review the pages noted in the previous footnote for details on the method used in the Annual Evaluation.

closely monitor to evaluate if any kind of temporary fueling augmentation could be necessary. The longer-term, 2023 capacity need is roughly triple the current funded capacity. If the most recent estimate of 20,400 FCEVs in the region by 2023 holds true, and the sustainable number (based on 80 percent of the regional funded network nameplate capacity) of FCEVs supported is nearly 7,500, then converting these numbers back to nameplate capacity, nearly 9,100 kg/day of additional nameplate capacity, will be needed from yet-to-be-funded stations to meet the 2023 demand. This shortfall underscores the importance of CARB’s recommendation in the 2017 Annual Evaluation to focus the next round of station funding in Southern California.

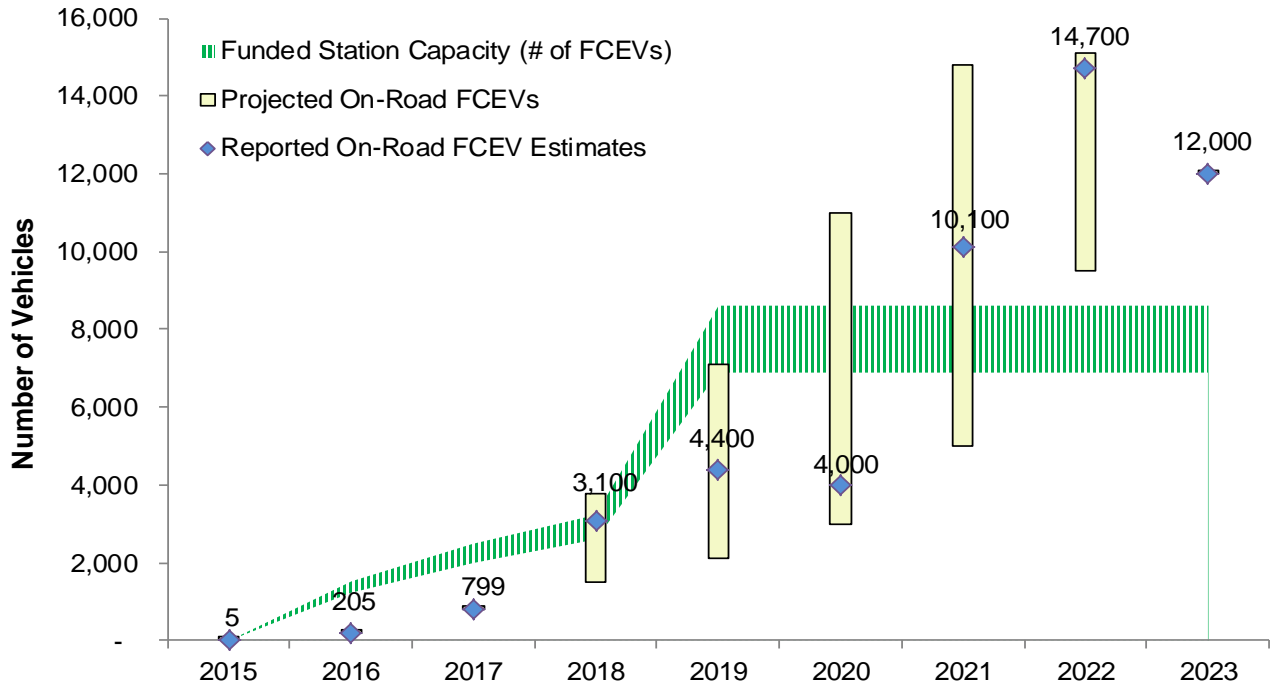
**Figure 10: Greater Los Angeles Area Station Network Capacity vs. Demand for Fuel**



Source: CEC

Figure 11 shows that, in the San Francisco Bay Area, the funded network capacity for the region is estimated to satisfy FCEV fueling needs until sometime post-2020. As in Los Angeles, but not quite to the same degree, it is possible that demand will approach supply in 2018 before the majority of newly funded stations open in 2019. By 2023, almost twice as much as today’s funded capacity will be needed to support the anticipated FCEV population (12,000 vehicles but only 7,000 supported with the funded network). In terms of nameplate capacity, that shortfall is nearly 3,600 kg/day, and it would be more if projected FCEV growth accelerates faster than the most recent survey results indicate.

**Figure 11: San Francisco Bay Area Station Network Capacity vs. Demand for Fuel**



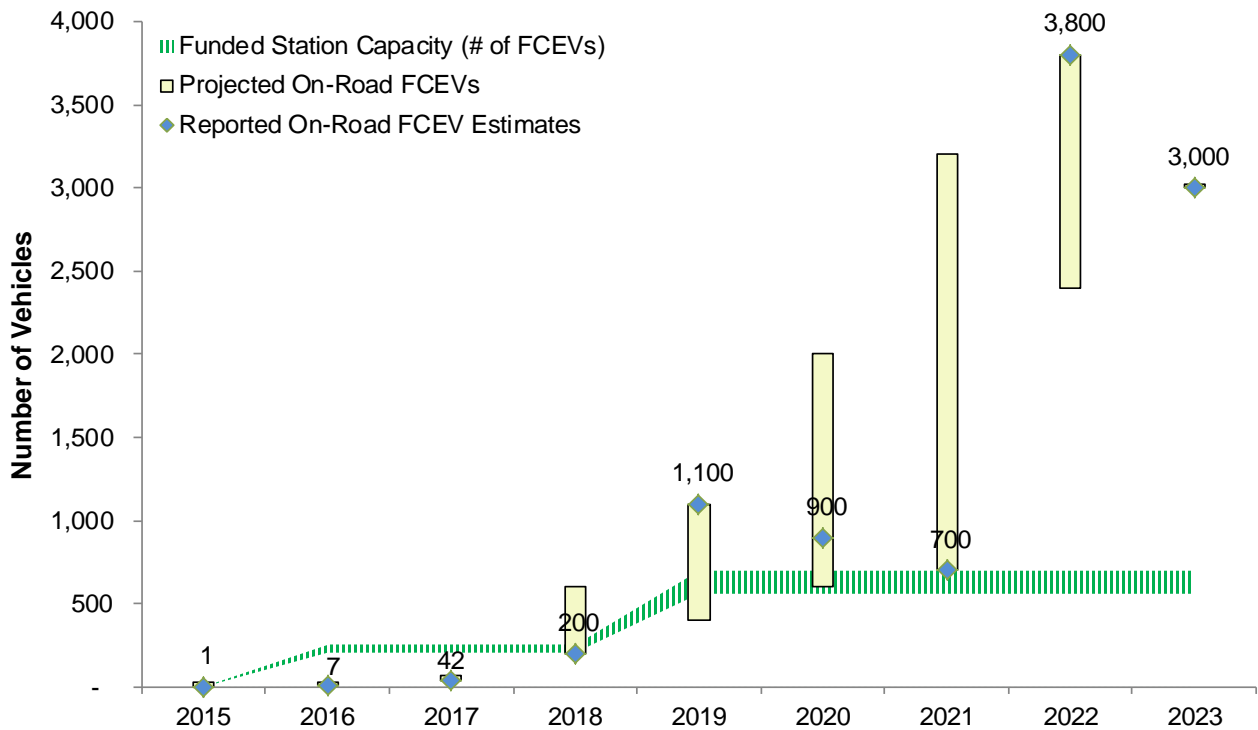
Source: CEC

Figure 12 demonstrates that the San Diego area has the earliest and most pronounced station network capacity shortfall when viewing the data graphically, but the actual magnitude of the shortfall is on a smaller scale than in the previous two areas. The region has one 180 kg/day station in Del Mar, and a second, higher-capacity station near Mission Valley is expected to open in early 2019. Before and after the second station opens, demand for fuel may outstrip what the regional network can provide. Additional capacity is needed relatively quickly to avoid any stifling of regional demand for FCEVs. Looking to 2023, when an estimated 3,000 FCEVs will be in the region, only 560 vehicles can be supported (again based on 80 percent of the funded network regional nameplate capacity). Nearly 1,700 kg/day of additional capacity would bridge this gap.

The FCEV market has been relatively slow to develop in the San Diego area compared to the other regions, and the existing Del Mar station more than satisfies the currently registered FCEVs in the area. The auto manufacturer survey results, however, indicate this potential regional market could grow quickly, and auto manufacturers listed several locations in the San Diego area as new priority market locations in their August 2017 letter to station developers and interested stakeholders.<sup>35</sup> If this region is to achieve the market growth anticipated, much more capacity than what is currently funded will be necessary.

<sup>35</sup> California Fuel Cell Partnership, [2017 CaFCP OEM Priority Hydrogen Station Location Recommendations](https://ww3.arb.ca.gov/msprog/mailouts/ecars1801/atc_8_cafcp_station_location_letter.pdf), [https://ww3.arb.ca.gov/msprog/mailouts/ecars1801/atc\\_8\\_cafcp\\_station\\_location\\_letter.pdf](https://ww3.arb.ca.gov/msprog/mailouts/ecars1801/atc_8_cafcp_station_location_letter.pdf)

**Figure 12: San Diego Area Station Network Capacity vs. Demand for Fuel**

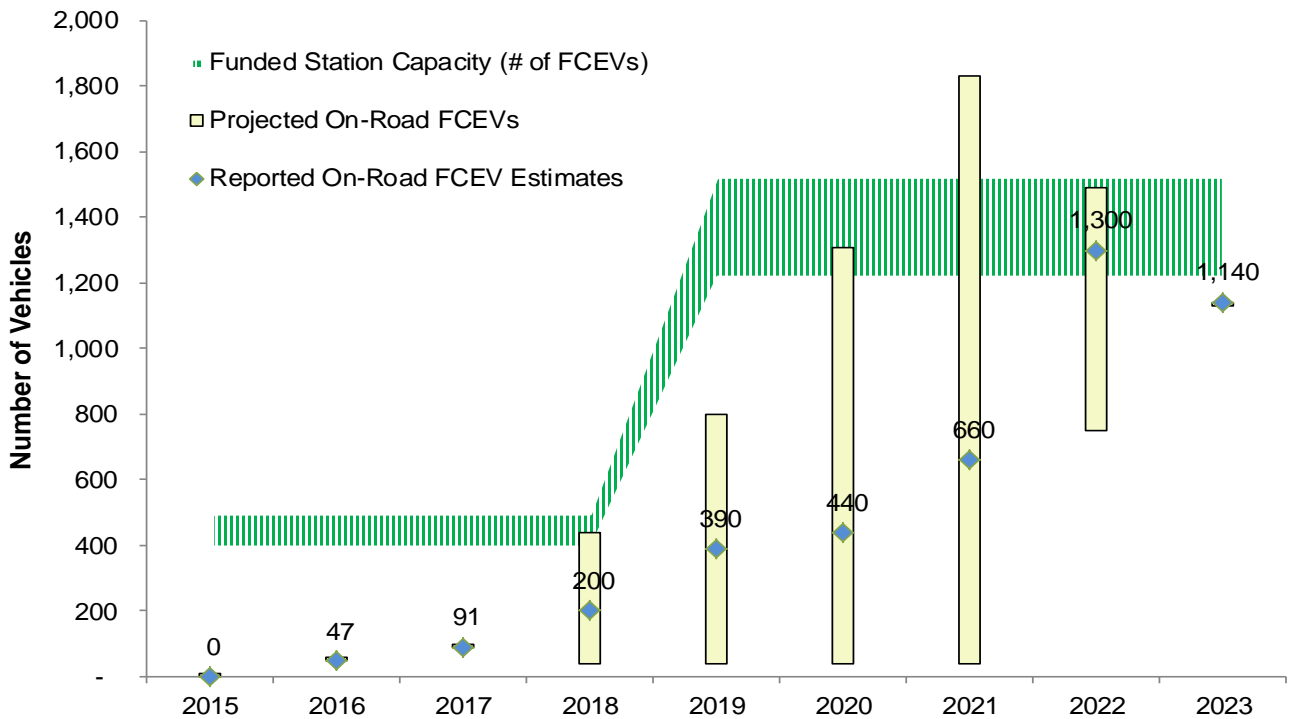


Source: CEC

Figure 13 presents perhaps the healthiest picture of funded station network capacity compared to projected FCEV demand for fuel. The Sacramento region has one 350 kg/day station in West Sacramento today, with two additional stations, one in Sacramento and one in Citrus Heights, expected to open in early 2019. The three stations combined will have just over 1,000 kg/day in nameplate capacity, which means they can support nearly 1,200 FCEVs (again based on 80 percent utilization). This supply will meet the anticipated demand for fuel from FCEVs in 2020 and 2023. The most critical time for the Sacramento region is likely to be in 2018 or early 2019, as the projected growth in the regional FCEV population approaches existing capacity prior to the two new stations opening. There is a relatively large burden on the one existing station to accommodate all regional FCEV fuel demand prior to more stations offering both the redundancy and the needed capacity to sustain a larger market. In addition, the regional outlook will need to be monitored closely post-2020. If regional demand exceeds recent projections, additional capacity could be needed sooner.



**Figure 13: Sacramento Area Station Network Capacity vs. Demand for Fuel**



Source: CEC

Even in regions where the funded stations appear to be sufficient to support anticipated regional FCEV growth, there can be more localized deficiencies within regions. For example, the 2017 Annual Evaluation indicates that, in the San Francisco Bay Area, Marin and Santa Cruz Counties may have deficits of hydrogen fueling capacity in 2020. In the Greater Los Angeles Area, there may be deficits in San Bernardino, Riverside, and Ventura Counties.<sup>36</sup> In Sacramento, locating stations in more outlying areas like Folsom or Davis could grow the regional market more quickly. As such, the analysis presented here is not the full story, and continued input from auto manufacturers and other stakeholders about market needs is vital to ensuring stations are funded in the most-needed locations.

<sup>36</sup> California Air Resources Board, [2017 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf). August 2017. [https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8\\_report\\_2017.pdf](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf) pages 65-66.

**Table 9: Comparison of Funded and Needed Capacity by Region**

| Region                   | 100% of Funded Capacity (kg/day) | 80% of Funded Capacity (kg/day) | FCEVs by 2023 | Nameplate Capacity Needed by 2023 (kg/day) | Shortfall Beyond 65 ARFVTP-Funded Stations by 2023 (kg/day) |
|--------------------------|----------------------------------|---------------------------------|---------------|--|---|
| Greater Los Angeles Area | 6,520                            | 5,200                           | 20,400        | 14,300                                     | 9,100   |
| San Francisco Bay Area   | 6,030                            | 4,800                           | 12,000        | 8,400                                      | 3,600   |
| San Diego Area           | 490                              | 400                             | 3,000         | 2,100                                      | 1,700   |
| Sacramento Area          | 1,070                            | 900                             | 1,140         | 800  | -   |

Source: CEC

The analysis presented in Table 9 is intended as a conservative estimate of the future capacity shortfall to plan for the “worst case” scenario; it compares the anticipated fuel demand to 80 percent of the funded station network capacity. The CEC and its partners are working to avoid these shortfalls through:

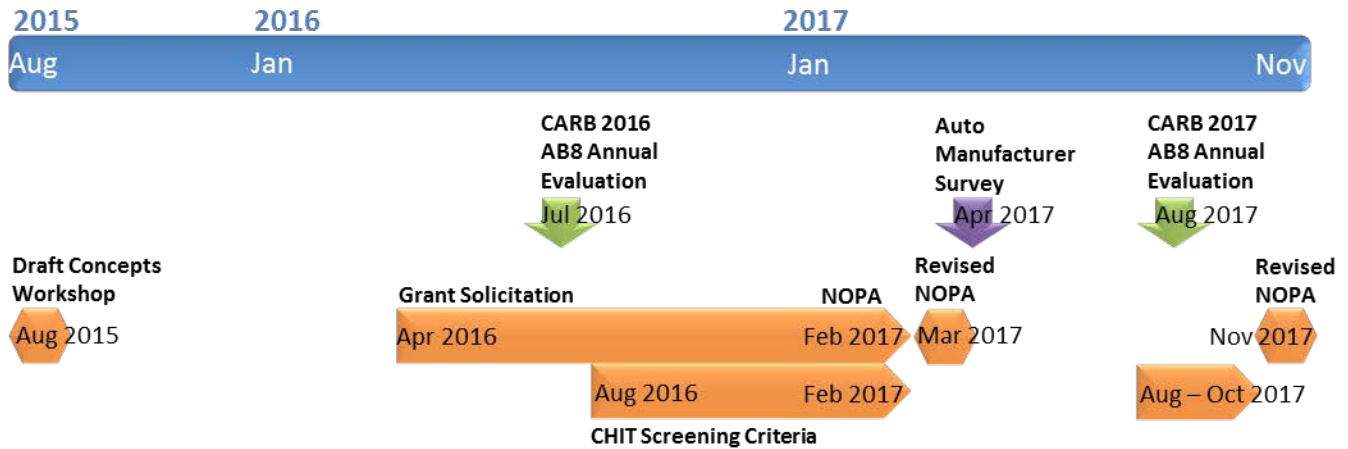
- Increasing the capacity of planned stations: Several planned stations may offer larger nameplate capacities than what is required in their grant funding agreements, thanks to the efforts of station developers to negotiate agreements for larger-scale equipment at reduced price.
- Expedited station development: As reviewed in Chapter 4, the CEC is closely evaluating the time it takes to develop stations and is taking concrete actions to reduce this time. The financial incentives in GFO-15-605 for achieving milestones and reaching operational status, coupled with the fact that many station developers now have greater experience, should result in the most recently funded stations being completed more quickly than those of past.
- Expedited funding: The CEC is pursuing a variety of ideas to increase the rate at which stations are funded, either through progressively planning for the use of future years’ allocations or pursuing new financing strategies to leverage additional private investment with the available ARFVTP funding. The financial outlook is discussed in Chapter 7.
- Investment in technology: The CEC, CARB, and other public agencies support research at NREL, Sandia National Laboratories, and the Pacific Northwest National Laboratory to advance technology that will improve the performance, reduce the cost, and ensure the safety of station equipment. Private partners are also investing in their own research and development efforts. With some technological breakthroughs comes the ability to expand station capacity with fewer ARFVTP dollars, and station developers report that they are beginning to see more efficient and lower-priced station equipment available in the market.

The CEC continuously reviews the use rates at open retail stations to evaluate how the current network capacity meets demand. Appendix D shows station dispensing and use information that supports FCEVs on California roads. Network use is growing, and a few stations are reaching the point where the need for additional capacity is fast approaching. This steady growth in utilization is evidence of the commercial demand for FCEVs.

# CHAPTER 6: Network Planning

Strategically planning California's network is imperative, and effective planning can lead to more FCEV adoption. Figure 14 shows the timeline of GFO-15-605. Process improvement for future solicitations, including increased stakeholder collaboration, is shown in Figure 15.

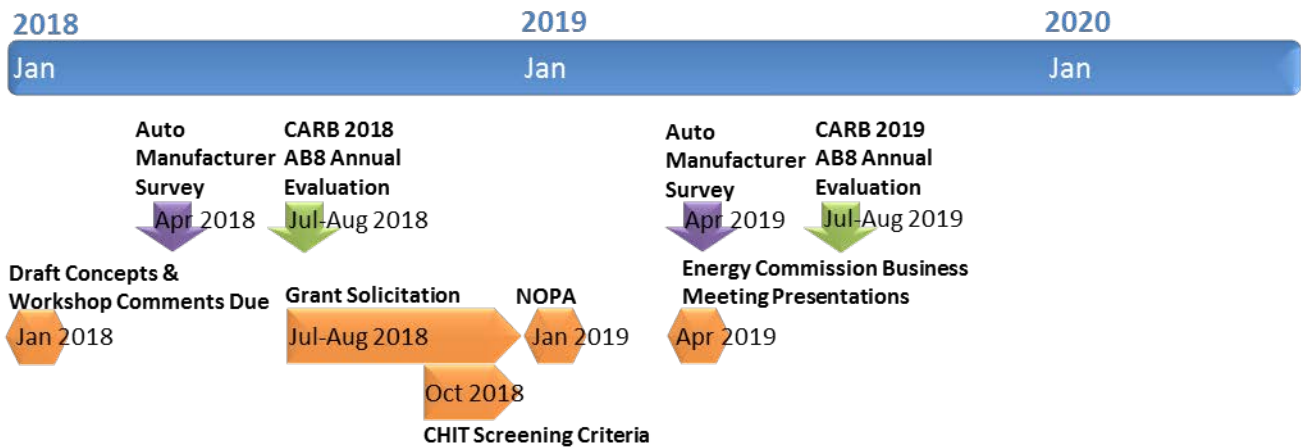
**Figure 14: GFO-15-605 Timeline**



Source: CEC

The plan is to release the solicitation with the 2018 Annual Evaluation to reflect the most current information in the solicitation about the need for station location and coverage of priority areas and the need for hydrogen refueling capacity.

**Figure 15: 2018-2020 Timeline**



Source: CEC

In planning the future network of hydrogen refueling stations in California, stakeholder feedback is critical. The CEC held several public workshops throughout 2017 to gather information and to discuss draft concepts of a future solicitation. The CEC also participates in various stakeholder partnership, working group, and consortium meetings to exchange information.

## Complementary Station Planning and Development Efforts

Network planning efforts are complemented by a long-term visioning process being led by CaFCP and by station development activities in the northeastern United States, which could inform future iterations of hydrogen infrastructure funding in California. Station development in the Northeast is funded by the private sector. Table 10 shows the sites in the Northeast and related status as of November 2017.

**Table 10: Planned Hydrogen Refueling Stations in the Northeast Region**

| Site Name        | Status as of November 2017         |
|------------------|------------------------------------|
| Hartford, CT     | Commissioning and testing complete |
| Providence, RI   | Commissioning and testing complete |
| Mansfield, MA    | Construction complete              |
| Hempstead, NY    | Construction stage                 |
| Lexington, MA    | Permit application stage           |
| Newton, MA       | Permit application stage           |
| Braintree, MA    | Permit application stage           |
| Lodi, NJ         | Permit application stage           |
| Brooklyn, NY     | Permit application stage           |
| Bronx, NY        | Permit application stage           |
| Whippany, NJ     | Permit application stage           |
| Farmingville, NY | Land Lease negotiations            |

Source: CEC with input from Air Liquide

### Planning to 2030

The state's financial support of hydrogen refueling stations is providing the infrastructure necessary to launch the early FCEV market, with the intention of building a sustainable market for this ZEV technology. Achieving a sustainable market means that stakeholders must look beyond the 100-station milestone to plan for what comes next. CaFCP is leading the effort to establish a consensus vision for commercial success in 2030 and identify high-level recommendations to achieve this vision. To reach the next level of a mature market, a faster and larger deployment of hydrogen refueling stations will be necessary to support rapid growth in FCEVs. Stakeholders are working to identify how to attract investment to enable development of large clusters of stations, enabling economies of scale that can reduce costs to a level where positive return on investment can be realized. The achievements thus far from the ARFVTP-funded hydrogen refueling infrastructure projects are being applied to set an aggressive but achievable vision for the future.

# CHAPTER 7: Remaining Cost and Time to Establish a Network of 100 Publicly Available Hydrogen Refueling Stations

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The current hydrogen refueling network consists of 65 ARFVTP-funded stations. The 2016 Joint Report assumed funding eight stations per year, each with a hydrogen fueling capacity of 180 kg/day, using the \$20 million allocation per year through fiscal year 2021-22 to yield 100 stations at a total estimated cost of \$225 million. In this case, the last set of stations funded with FY 2021-22 dollars will require time to build and reach open retail status. Some stakeholders express an urgent need for the 100 stations by 2020 so FCEV rollout can progress more quickly and contribute to Governor Edmund G. Brown Jr.'s goal of reaching 1.5 million ZEVs by 2025.

Technology has evolved rapidly, and the 2016 Joint Report assumptions are out of date. This Joint Report includes an updated business-as-usual scenario assumes that 10 larger stations, capable of at least 300 kg/day, can be funded with the \$20 million allocation per year. This includes capital expenses and O&M. This is possible due the decrease in the cost per kilogram of hydrogen capacity witnessed in the most recent GFO-15-605. As mentioned in the Capital Costs section below, the average request for CEC funding per kilogram of capacity was \$6,409.42 for GFO-15-605 funded stations, which is a significant drop from \$8,689 for stations funded under PON-13-607.

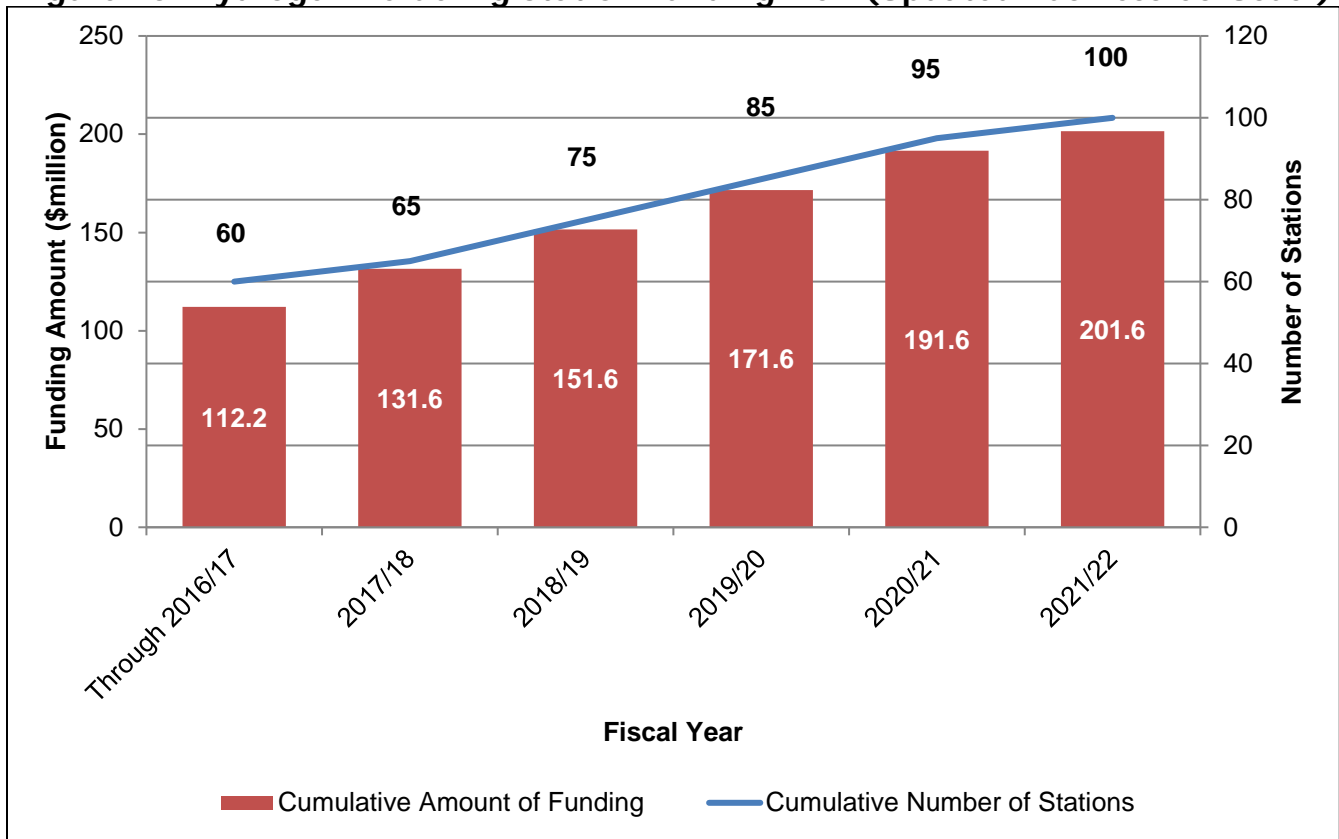
Table 11 and Figure 16 show the updated business-as-usual scenario, funding 10 stations per year. With this scenario, the 100-station milestone of open retail stations is anticipated to be achieved in 2024 with a cost of \$70 million (shown as five years of funding from FY 2018-19 to FY 2021-22) in addition to the \$131.6 million for infrastructure that has already been allocated to fund the first 65 stations.

**Table 11: Fiscal Years, Funding, and Calendar Years to Reach 100 Open Retail Stations (Updated Business-as-Usual)**

| <b>Funding Fiscal Years</b> | <b>Calendar Year for Stations to Be Open Retail</b> | <b>ARFVTP Funding (\$M)</b> | <b>Cumulative Open Retail Stations</b> |
|-----------------------------|---|-----------------------------|--|
| FY 2009-17                  | 2019  | 112.2                       | 60                                     |
| FY 2017-18                  | 2020  | 19.4                        | 65                                     |
| FY 2018-19                  | 2021  | 20                          | 75                                     |
| FY 2019-20                  | 2022  | 20                          | 85                                     |
| FY 2020-21                  | 2023  | 20                          | 95                                     |
| FY 2021-22                  | 2024  | 10                          | 100                                    |
| <b>Total</b>                |   | <b>201.6</b>                |  |

Source: CEC

**Figure 16: Hydrogen Refueling Station Funding Plan (Updated Business-as-Usual)**



Source: CEC

In the GFO-15-605 applications, proposed station development timelines were more aggressive than in previous years. Therefore, the 100-station milestone may be achieved even sooner than 2024. Compared to the 2016 Joint Report scenario, this updated scenario saves about \$25 million (\$200 million vs. \$225 million) in reaching the 100-station milestone, allowing the potential to fund stations beyond the 100-station goal.

The updated scenario still falls short of reaching 100 stations by 2020, which is the current request by some auto manufacturers. In an effort to accelerate station deployment, the CEC and CARB are analyzing costs and researching alternative funding mechanisms to identify ways that stations could be funded even more quickly and at reduced cost, which enables more stations to be funded with the same amount of money. Examples of alternative funding mechanisms explored include a solicitation that offers applicants a choice for requested funding to be used for either capital expenses or O&M or a combination of the two, a solicitation that allocates grant funds by kilogram of capacity on a regional basis for capital expenses or O&M or both, a loan loss reserve financing program, and other methods of competitively allocating funding that are different from the traditional grant funding process.

The alternative funding mechanisms that involve developing new financing programs are longer-term strategies. Many of these types of strategies would attempt to leverage additional outside investment to increase the number of stations funded per year. Other strategies, like the capital expenses and O&M flexibility, could be deployed in the short term and involve working within the current grant funding structure to advance available funds more efficiently. These short-term strategies could provide incremental improvements to the funding process to

enable station developers to choose the type of assistance that best fits their business models and available resources, and could enable them to plan more effectively a station network and achieve economies of scale.

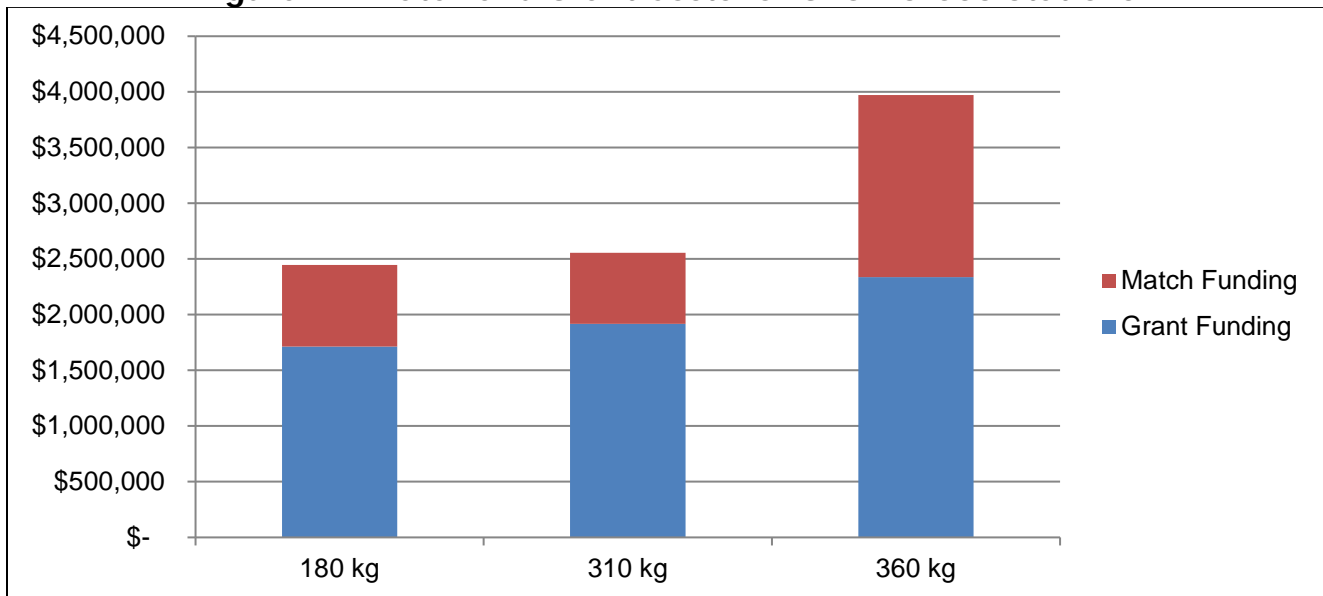
The CEC held a workshop on November 30, 2017, to discuss alternative funding mechanism options and gather stakeholders' feedback. Feedback received will be carefully reviewed and analyzed to develop the next solicitation. Cost-reduction potentials are described later in this chapter.

In addition, the CEC contracted with NREL to analyze the financial performance of two station designs funded by ARFVTP (180 kg gaseous and 350 kg liquid) using the Hydrogen Financial Analysis Scenario Tool model<sup>37</sup> with two patterns of utilization assumed: slow and fast growth in utilization. The results show that all the scenarios for these two station designs are favorable from the perspective of the entire project lifespan of 20 years, with the internal rate of return ranging from 13.7 percent to 34.7 percent. The details of the analyses are in Appendix B.

### Capital Costs of Hydrogen Refueling Stations

According to the budgets for the 21 awarded stations under GFO-15-605, the equipment, design, engineering, construction, project management, and overhead costs ("all-in costs" include match funding) for hydrogen refueling stations with delivered gas are nearly \$2.5 million for 310 kg/day stations (for main stations), nearly \$4.0 million for 360 kg/day stations (for main stations), and nearly \$2.4 million for a 180/day station (a connector station), as summarized in Figure 17.

**Figure 17: Match and Grant Costs for GFO-15-605 Stations**



Source: CEC

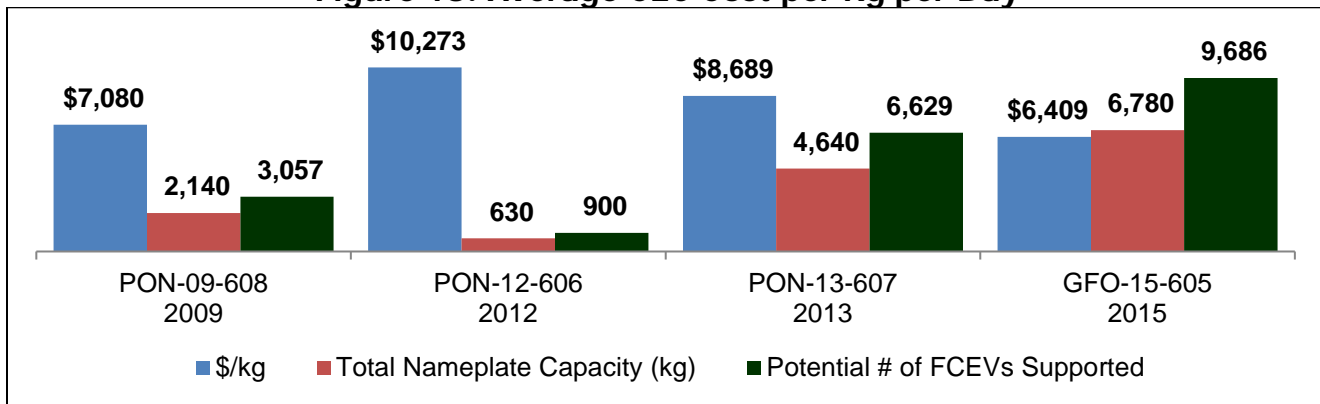
The 360 kg/day stations funded under GFO-15-605 provide two independent, redundant compressors, storage systems, and dispenser systems. This design allows FCEV drivers to

<sup>37</sup> [Hydrogen Financial Analysis Scenario Tool Model](https://www.nrel.gov/hydrogen/h2fast.html), <https://www.nrel.gov/hydrogen/h2fast.html>

refuel even if one dispenser goes off-line, meaning the station provides redundancy and backup to itself. Although the total cost for the 360 kg/day stations funded under GFO-15-605 is \$4 million, each of these stations is analogous to two 180 kg/day stations for \$2 million each, which is a savings compared to the cost of one 180 kg/day station at \$2.4 million. The decreases in station costs are also reflected in the CEC cost per kilogram of nameplate capacity, as shown in Figure 18.

The average CEC cost per kg per day has decreased for stations funded under GFO-15-605. Figure 18 shows average CEC cost per kg per day for the four past solicitations, along with the total nameplate capacity for the stations funded under each solicitation and potential number of FCEVs that can be supported by the total nameplate capacity.

**Figure 18: Average CEC Cost per Kg per Day**



Note: Does not include California State University, Los Angeles

Source: CEC

Table 12 summarizes the budgeted station costs (both the CEC share and match share) for each of the 65 ARFVTP-funded stations. Station costs can range anywhere between \$1.5 million to \$4.6 million, depending on the type and capacity of the station. The funding amounts listed in Table 12, however, do not take into account other costs that developers might incur such as permitting fees, compliance with local aesthetics requirements, and civil engineering costs.

**Table 12: Budgeted Cost Range of Various Station Designs**

|                     | Capacity < 200 kg/day | Capacity 200 – 400 kg/day |
|---------------------|-----------------------|---------------------------|
| <b>Gaseous</b>      | \$1.5M to \$3.3M      | \$2.5M to \$4.0M          |
| <b>Liquid</b>       | N/A                   | \$2.5M to \$2.7M          |
| <b>Electrolysis</b> | \$2.5M to \$4.6M      | N/A                       |

Note: Does not include California State University, Los Angeles or temporary refueler.

Source: CEC

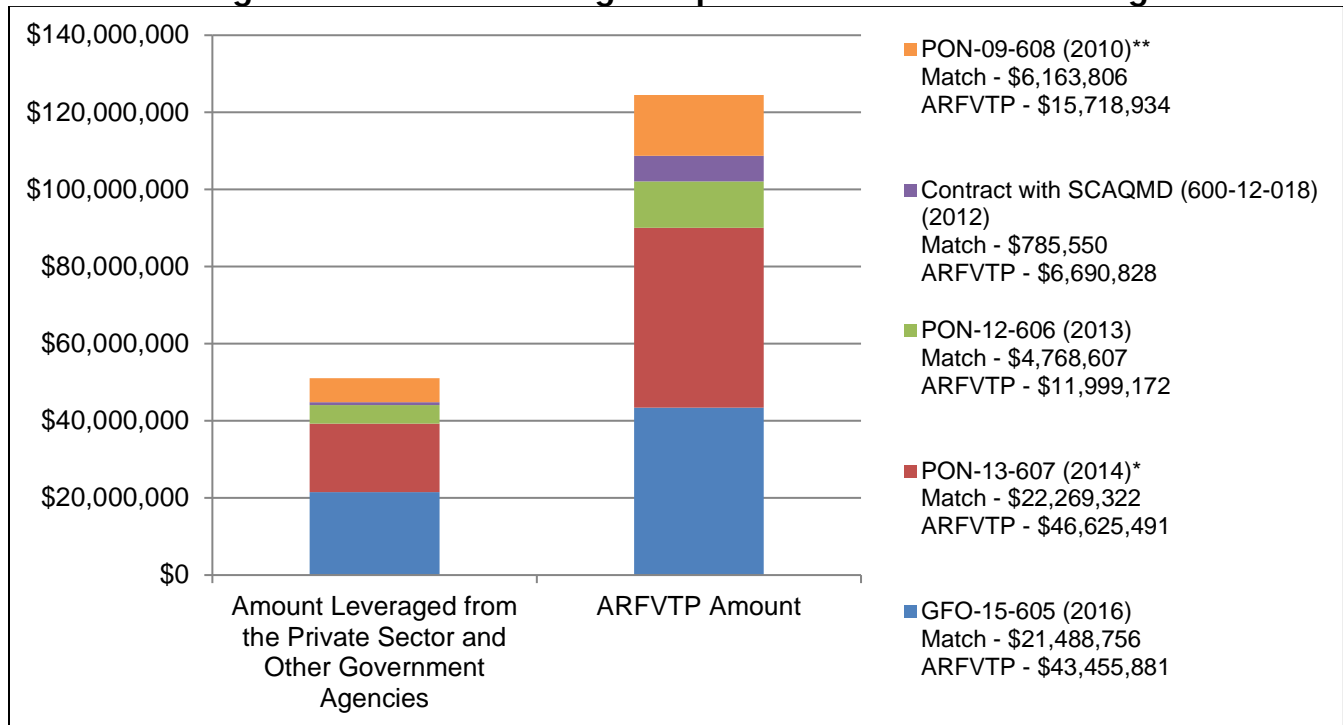
The CEC and CARB are carefully evaluating the market based on the feedback received on the funded stations and on future stations and studies conducted by stakeholders to determine appropriately sized capacity for future stations.



## Match Funding for Hydrogen Refueling Stations

About \$54 million has been committed as match funding under hydrogen refueling infrastructure grant agreements. Solicitations require match funding for grants, and as stated earlier, some station developers absorb additional costs in excess of the match. Figure 19 shows the match funding compared with ARFVTP funding. Match funding combined with capital expenditure funding is the total station cost.

**Figure 19: Match Funding Compared With ARFVTP Funding**



\*Includes temporary refueler

\*\*Includes hydrogen delivery trailers and central fill system

Source: CEC

## Other Strategies for Cost Reduction

Besides the above-mentioned efforts to develop alternative funding mechanisms that would attract larger-scale investment in hydrogen refueling stations and drive down costs, the CEC is pursuing other strategies to reduce costs. The CEC continues to support station O&M during this early market phase to reduce the out-of-pocket costs to station operators as they work to build efficiencies in their operational staffing and supply chains. Furthermore, the CEC has begun to address the anticipated need for more hydrogen production, and in particular renewable hydrogen production, in California, with the intent of lowering the cost for the hydrogen molecule and greening the fuel production. Finally, the CEC has been reaching out to other state agencies, local governments, and private sector stakeholders to understand what opportunities might exist to reduce costs associated with station siting and operation.

## Operation and Maintenance (O&M) Support Grants

Under PON-13-607, Hydrogen Refueling Infrastructure, grant recipients received funding to develop the infrastructure necessary to dispense hydrogen transportation fuel. PON-13-607

provided incentive funding for those stations that became operational by specific dates, and some developers missed the incentive funding dates.

CEC staff analyzed the impacts on stations not receiving the full \$300,000 O&M funding support under PON-13-607. Staff concluded that this support is critical to ensure hydrogen refueling stations become operational and remain operational while FCEVs are being deployed in California. As such, the CEC released GFO-17-601 Light Duty Vehicle Hydrogen Refueling Infrastructure Operation and Maintenance Support Grants, offering up to \$7.3 million in funding for hydrogen refueling station O&M support for qualifying stations that did not previously receive the maximum \$300,000 under PON-13-607 and become operational before June 30, 2018.

The maximum award amount for each of the 34 eligible hydrogen refueling stations listed in GFO-17-601 was determined by subtracting any previous O&M support funding provided through PON-13-607, if any, from the maximum allowable \$300,000 in total O&M support offered in GFO-17-601. Hydrogen refueling stations with less than full funding O&M agreements are eligible to apply for the remainder to receive full O&M funding by submitting a reasonable plan for the station to become operational within 90 days from the date of application or June 30, 2018, whichever comes first. This approach allows stations to have O&M agreements as quickly as possible for the nonoperational stations, in some cases, as soon as the stations come on-line and are eligible to receive reimbursement for eligible O&M costs. The additional O&M funds from GFO-17-601, giving stations the opportunity to receive the maximum \$300,000 in O&M support, will ensure the hydrogen refueling stations remain operating during the initial rollout of FCEVs.

## **Renewable Hydrogen**

The CEC plans to release a competitive grant solicitation (GFO-17-602) to fund the installation of a cost-effective facility in California that will produce 100 percent renewable hydrogen from in-state renewable resources dedicated for distribution and delivery to public hydrogen refueling stations that serve light-duty FCEVs. Development of the solicitation included input from stakeholders received at staff workshops held January 30, 2017, and July 31, 2017, and is targeted for new renewable hydrogen production with a nameplate capacity of at least 1,000 kilograms per day of 100 percent renewable hydrogen from feedstocks sourced in California. Electricity costs to operate hydrogen production systems will comprise a significant portion of the facilities costs, which, in turn, affect the price of hydrogen charged to FCEV drivers.

Based on the projected fueling capacity of open and planned stations, 5,500 kg/day of renewable hydrogen will be needed by 2022. This includes the need to meet the 33.3 percent renewable content intended by Senate Bill 1505 for the hydrogen produced for or dispensed by fueling stations that receive state funds. Some station developers have informed CEC staff that their mission is to dispense more than the required minimum renewable hydrogen content. Higher hydrogen demand implies there will be increasing opportunities to produce renewable hydrogen at larger scales, bringing down costs.

The addition of new 100 percent renewable hydrogen production will strengthen the sustainability of California's network of hydrogen refueling stations that support the state's carbon reduction and air quality goals. Renewable hydrogen production will also contribute to

the mix of alternative fuels needed to implement the LCFS, which is designed to reduce the carbon intensity of transportation fuels by 10 percent by 2020.

### **Siting Stations at Government Properties and Other Locations/Options**

Station location is a challenge in project development and in operation. For project development, station developers could spend a significant amount of time and effort in identifying potential sites, negotiating with property owners, and meeting with AHJs to determine if a site is viable. Even then, site agreements are not guaranteed. In operation, a high price of monthly rent/lease of the site increases the O&M costs. As of July 2017, monthly rent for hydrogen stations ranged from \$2,500 to \$6,000, excluding two with rent less than \$400, with an average rent of \$3,700 per month. The two stations with the highest rent have electricity included in the fixed rent payments. This arrangement has probably not yet reduced expenses for those two stations, since the latest average monthly electricity bill was \$1,400.

The CEC is exploring opportunities with other government agencies and private sector organizations to identify alternative strategies for station siting to alleviate these difficulties and costs.

# CHAPTER 8: Conclusions

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The CEC's ARVFTP has provided \$131.6 million in funding for capital expenses and O&M support for 65 hydrogen refueling stations, of which 31 are open retail and 34 planned. Leading America in hydrogen refueling station rollout, California joins nations in Europe and Asia in the internationally growing network of hydrogen refueling stations.

The most recent number of FCEVs reported by industry is 3,234 through December 1, 2017. Comparing California Department of Motor Vehicles FCEV registrations, which were 925 in October 2016 and 2,473 in October 2017, the number of FCEVs increased by nearly 170 percent in the last year.

To keep this strong momentum alive, the CEC will offer incentives for expedited station deployment through funding mechanisms. Together, the stations and the vehicles will yield an effective network.

Supporting hydrogen FCEVs and hydrogen refueling stations aligns with Governor Brown's vision to encourage and increase the adoption of ZEVs to reach 1.5 million by 2025. The CEC and CARB should stay the course on hydrogen FCEVs and hydrogen refueling stations.

## **Time and Cost Needed to Reach 100 Hydrogen Refueling Stations in California With Business-as-Usual Will Need Additional \$70 Million and Will Reach 100 Open Retail Hydrogen Refueling Stations by 2024**

This report estimates that \$70 million, in addition to the \$131.6 million allocated, for a total of \$201.6 million, is needed to reach the 100 station milestone. This is a savings of nearly \$25 million over the \$225 million estimated in the 2016 Joint Report. The savings are anticipated because of the lower station development costs reflected in the applications for GFO-15-605.

Under the updated business-as-usual scenario, 100 open stations are expected to be achieved in 2024. Public and private sector stakeholders continue to work together to reduce the cost and time of achieving this milestone through innovation, alternative funding mechanisms, process improvements, and commitment to the shared vision and course of action.

## **Station Coverage and Capacity Is Sufficient to Support Current FCEV Market but Will Need More for Increasing FCEV Deployment**

With ARVFTP funding, the CEC is working to supply the station coverage and capacity to support the growing number of FCEVs in California in the Greater Los Angeles Area and San Francisco Bay Area, where most open retail stations are located, in addition to stations in the Sacramento and San Diego areas. Evaluating coverage and capacity in these four core regions, today's open retail stations are meeting the fuel demand of the current population of 3,234 FCEVs. FCEV drivers can drive to and from any of these areas fueling at the Coalinga connector station. The destination areas of Lake Tahoe and Santa Barbara are also being served.

The state's *ZEV Action Plan* articulates the need to keep station development ahead of vehicle deployment to allow for market growth. In 2017, funding awards for 16 new stations were approved by the CEC, and 5 new stations were proposed for awards, adding stations to all four

market areas and 1 connector station in Santa Nella. These new stations will be larger than most of today's open retail stations, offering more fueling capacity and more fueling positions to support more FCEVs. These stations are expected to be developed quickly with requirements for upfront permitting work and site control and with incentive funding provided on a sliding scale based on the operational date of the station.

CARB projects that there will be 37,400 FCEVs deployed in California by 2023, and that this number could possibly be higher if there were the station coverage and capacity to support it. A few stations are already experiencing high sales volume of hydrogen and will most likely need backup stations nearby to support and complement them. To provide sufficient fuel for the FCEVs in high-demand areas and to support the projected number of FCEVs in future years, the CEC and CARB are exploring alternative funding mechanisms to accelerate station deployment. Input is being collected from industry stakeholders at public workshops.

The CEC and CARB work to coordinate the findings of CARB's annual evaluations with the CEC solicitations. The 2017 Annual Evaluation reports that larger station capacities (300 kg/day minimum and 600+ kg/day in certain areas) are needed in priority areas to avoid a projected hydrogen shortfall. The first 100 stations need to be in the right places with appropriate design features to maximize market impact. Attention to details such as the number of fueling positions and possible integration "under the canopy" with other fuel types is important to ensuring station availability and user-friendliness, which are both critical to get right in the early commercial FCEV market. Industry stakeholders provide vital feedback about station locations and technical requirements through forums like CaFCP and public workshops.

## **Alternative Funding Strategies Under Exploration**

This 2017 Joint Report presents an updated business-as-usual scenario that assumes funding 10 stations per year instead of a scenario that assumes 8. By analyzing the cost per kilogram of stations provided in applications for solicitations, considering 12 out of 21 awarded stations under GFO-15-605 budgeted less than the maximum available funding amount, and given the large number of applications, funding 10 stations per year should be achievable and realistic. The applications to GFO-15-605 indicate that the market for developing and operating hydrogen stations is strong enough for the CEC to incrementally lower the maximum available funding amount per station in future solicitations to fund more stations per fiscal year.

To implement the updated business-as-usual scenario, and with the vision of pursuing alternative funding mechanisms that will expedite station deployment, the CEC plans process improvement described in Chapter 6. This plan is intended to provide certainty to station developers that stations will have a greater chance of financial viability due to the auto manufacturers' survey input reflected in the CARB 2018 Annual Evaluation and future CEC solicitations.

To ensure stations are sustainable in the early market, and to improve the long-term market outlook, the CEC offers O&M support grants and is supporting the production of renewable hydrogen. Moreover, the CEC and CARB have been reaching out to stakeholders to assess how and when the business case for station development and operation will be self-sufficient. California must keep the momentum alive.

# GLOSSARY

**ASSEMBLY BILL (AB)**—A proposed law, introduced during a session for consideration by the Legislature, and identified numerically in order of presentation; also, a reference that may include joint, concurrent resolutions, and constitutional amendments, by Assembly, the house of the California Legislature consisting of 80 members, elected from districts determined on the basis of population. Two Assembly districts are situated within each Senate district.

**AUTHORITY HAVING JURISDICTION (AHJ)**—An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

**ALTERNATIVE AND RENEWABLE FUELS AND VEHICLE TECHNOLOGY PROGRAM (ARFVTP)**—Now known as the Clean Transportation Program, created by Assembly Bill 118 (Nunez, Chapter 750, Statutes of 2007), with an annual budget of about \$100 million. Supports projects that develop and improve alternative and renewable low-carbon fuels, improve alternative and renewable fuels for existing and developing engine technologies, and expand transit and transportation infrastructures. Also establishes workforce training programs, conducts public education and promotion, and creates technology centers, among other tasks.

**BAY AREA AIR QUALITY MANAGEMENT DISTRICT (BAAQMD)**—Tasked with regulating stationary sources of air pollution in the nine counties that surround San Francisco Bay: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, southwestern Solano, and southern Sonoma counties. It is governed by a 24-member Board of Directors composed of locally elected officials from each of the nine Bay Area counties, with the number of board members from each county being proportionate to its population.

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

**CALIFORNIA CODE OF REGULATIONS (CCR)**—The official compilation and publication of the regulations adopted, amended, or repealed by state agencies pursuant to the Administrative Procedure Act (APA). Properly adopted regulations that have been filed with the Secretary of State have the force of law. The CCR is compiled into Titles and organized into Divisions containing the regulations of state agencies.<sup>38</sup>

**CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE (CDFA)**—A cabinet-level agency in the California government responsible for the regulation of food, protecting agriculture from from pests, promoting California's agricultural industry, and enforcing standards for most petroleum products.<sup>39</sup>

**CARBON DIOXIDE EQUIVALENT (CO<sub>2</sub>e)**—A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated

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<sup>38</sup> [California Office of Administrative Law](https://oal.ca.gov/) (https://oal.ca.gov/)

<sup>39</sup> [California Department of Food and Agriculture](https://www.cdfa.ca.gov/CDFA-Mission.html) (https://www.cdfa.ca.gov/CDFA-Mission.html)

radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

**CALIFORNIA DIVISION OF MEASUREMENT STANDARDS (DMS)**—Enforcer of California weights and measures laws and regulations. The Division works closely with county sealers of weights and measures who, under the supervision and direction of the Secretary of Food and Agriculture, carry out the vast majority of weights and measures enforcement activities at the local level. Ensuring fair competition for industry and accurate value comparison for consumers are the primary functions of the county/state programs.

**CALIFORNIA FUEL CELL PARTNERSHIP (CaFCP)**—The California Fuel Cell Partnership is an industry/government collaboration aimed at expanding the market for fuel cell electric vehicles powered by hydrogen to help create a cleaner, more energy-diverse future with no-compromises to zero emission vehicles.

**CARBON INTENSITY (CI)**—The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

**ENVIRONMENTAL JUSTICE (EJ)**—The fair treatment and meaningful involvement of all people with respect to the development, implementation, and enforcement of laws, regulations, and policies.

**FACTORY ACCEPTANCE TEST (FAT)**—The functional test that is performed by the vendor upon completion of the manufacturing process to prove the equipment has the same specification and functionality that indicated in the datasheet, specification and purchase order. The third party inspector and customer representative (purchaser) typically witnesses the test.

**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.

**GREENHOUSE GAS (GHG)**—Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (NO<sub>x</sub>), halogenated fluorocarbons (HCFCs), ozone (O<sub>3</sub>), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

**GOVERNOR'S OFFICE OF BUSINESS AND ECONOMIC DEVELOPMENT (GO-Biz)**—Serves as the State of California's leader for job growth and economic development efforts. They offer a range of services to business owners including: attraction, retention and expansion services, site selection, permit assistance, regulatory guidance, small business assistance, international trade development, and assistance with state government.

**HYDROGEN STATION EQUIPMENT PERFORMANCE (HyStEP)**—The primary purpose of the HyStEP Device is to be used by a certification agency to measure the performance of hydrogen dispensers with respect to the required fueling protocol standard.<sup>40</sup>

**KILOWATT (kW)**—One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home—with central air conditioning and other equipment in use—might have a demand of 4 kW each hour.

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

**MEGAJoule (MJ)**—A joule is a unit of work or energy equal to the amount of work done when the point of application of force of one newton is displaced one meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about one million joules to make a pot of coffee. A megajoule itself totals one million joules.

**NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)**—A global self-funded nonprofit organization, established in 1896, devoted to eliminating death, injury, property, and economic loss due to fire, electrical, and related hazards.

**NATIONAL RENEWABLE ENERGY LABORATORY (NREL)**—The United States' primary laboratory for renewable energy and energy efficiency research and development. NREL is the only Federal laboratory dedicated to the research, development, commercialization, and deployment of renewable energy and energy efficiency technologies. Located in Golden, Colorado.<sup>Error! Bookmark not defined.</sup>

**OPERATION AND MAINTENANCE (O&M)**—Maintenance and repair of real property, operation of utilities, and provision of other services such as refuse collection and disposal, entomology, snow removal, and ice alleviation.<sup>41</sup>

**SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)**—A global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries. The leader in connecting and educating mobility professionals to enable safe, clean, and accessible mobility solutions.<sup>42</sup>

**SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT (SCAQMD)**—The air pollution control agency for all of Orange County and the urban portions of Los Angeles, Riverside, and San Bernardino counties. This area of 10,740 square miles is home to over 17 million people—about half the population of the whole state of California. It is the second most populated

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<sup>40</sup> Sandia National Laboratories [HyStEP](https://www.sandia.gov/news/publications/labnews/articles/2016/08-01/hystep.html) (https://www.sandia.gov/news/publications/labnews/articles/2016/08-01/hystep.html)

<sup>41</sup> [Operation and Maintenance](https://www.thefreedictionary.com/operation+and+maintenance) Definition (https://www.thefreedictionary.com/operation+and+maintenance)

<sup>42</sup> [Society of Automotive Engineers](https://www.sae.org/about/) (https://www.sae.org/about/)



urban area in the United States and one of the smoggiest. Its mission is to clean the air and protect the health of all residents in the South Coast Air District through practical and innovative strategies.

**UNITED STATES DEPARTMENT OF ENERGY (U.S. DOE)**—The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

**ZERO EMISSION VEHICLE (ZEV)**—Vehicles that produce no emissions from the on-board source of power (e.g., an electric vehicle).

# APPENDIX A: Self-Sufficiency Framework

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CARB and the CEC (referred to collectively as “the agencies” in this appendix) have initiated an effort to understand and quantify financial opportunity-based decisions within the hydrogen infrastructure industry that lead to development and expansion of the hydrogen refueling station network. The primary goal of the effort is to quantify the market conditions necessary to enable potential hydrogen refueling station developers to fully self-fund ongoing development without additional state investment. In combination with projections for FCEV deployment growth, this information will help the State identify the potential timing and state expenditure required until the market achieves this self-sufficiency. To accomplish this goal, the agencies have developed an analysis framework, first presented in the 2016 Joint Report, which assumes there is some metric(s) that an entity uses to determine the degree to which it can fully self-fund development of a new hydrogen refueling station. That decision is potentially affected by the assumed current and future status of FCEV deployment, the development status of the existing hydrogen refueling network, the robustness of the necessary material and equipment supply chain, the availability of hydrogen supply sources, and the availability of station equipment with the appropriate technical performance capabilities. The framework further assumes that there is some threshold value for that metric(s) at which a new refueling station could be fully self-funded by that potential developer. For example, if the metric used were return on investment, once the return on investment reached a certain value, the developer would choose to proceed with self-funding the station.

These metrics and the related values that indicate favorable conditions for fully self-sufficient hydrogen refueling station development are largely unknown. Moreover, by surveying the existing hydrogen refueling industry, it is clear that there are (and likely will be in the future) several types of private entities evaluating the prospect for investment in hydrogen refueling station development. Because of the wide variation in these entities, the framework has been established with flexibility to consider each type of potential station developer separately; they may each have different motivations and expectations for investment in California’s hydrogen refueling network and may evaluate the prospect of continued investment into hydrogen refueling against factors unique to their business or industry. Thus, the framework assesses opportunities from various perspectives to answer the overall question: “When will California’s hydrogen refueling stations be self-sufficient?”

In the 2016 Joint Report, eight types of entities were identified as potential unique perspectives to be included in the self-sufficiency analysis. These were existing independent gas station owners, industrial gas companies, independent hydrogen refueling developers, auto manufacturers, fleet operators, station equipment providers, energy and fuel companies, and public agencies. These entities and examples of potential value proposition metrics are shown in Table A-1. In addition, to maintain a consumer perspective in the analysis, early market and mass-market FCEV drivers’ prospective needs will be analyzed and modeled.

**Table A-1: Self-Sufficiency Framework**

| <b>Value Proposition Entity</b> | <b>Value Proposition Metric</b>  | <b>Previous Study?</b>                  | <b>Value Proposition Threshold</b>  | <b>Affected by Fuel Cost Difference?</b> | <b>Candidate Entities</b>   | <b>Study Round</b> |
|---------------------------------|--|---|---|--|---|--------------------|
| Gas Station Owner               | Revenue-opportunity costs (gasoline pump or other station services)  | -                                       | >\$0, in X yrs.; X may be considered long-term                              | Yes                                      | Costco, Harbor City Chevron, Noble, Ontario CNG, Safeway, Walmart   | 2nd                |
| Industrial Gas Company          | Revenue-opportunity costs (other hydrogen related ventures)  | -                                       | >\$0, in X yrs.; X may be considered long-term                              | Indirect                                 | Air Liquide, Air Products and Chemicals, Linde, Praxair, United Hydrogen  | 1st                |
| Independent Operator            | Traditional investment metrics, i.e., return on investment, and payback period                                     | December 2015 AB 8 report               | X yrs.  | No                                       | FirstElement Fuel, H2 Frontier, HydrogeNXT, HyGen Industries, HTEC, StratosFuel   | 1st                |
| Auto Manufacturer               | Cost differential of infrastructure investment vs. other sales-driving options to achieve target FCEV sales volume | -                                       | $X \leq \$0$  | No                                       | Daimler, General Motors, Honda, Hyundai, Toyota   | 1st                |
| Fleet Operator                  | Total cost of ownership parity w/gasoline  | -                                       | Equivalence or X% premium, including incentives available to fleet operator | Yes                                      | A3 Labs, FedEx, Lyft, Maven, StratosFuel, Uber, UPS, Zipcar   | 2nd                |
| Station Equipment Provider      | Traditional investment metrics, like return on investment, and payback period                                      | Variation on December 2015 Joint Report | X yrs.  | No                                       | Air Liquide, Air Products and Chemicals, FASTECH, Greenlight Innovation, Hydrogenics, ITM Power, Kobelco, Linde, McPhy, Nel Hydrogen, Next Hydrogen, Nuvera, PowerTech Labs | 1st                |
| Energy/Fuel Company             | Revenue-opportunity costs (other fuel product ventures)  | -                                       | >\$0, in X yrs.; X may be considered long-term                              | Yes                                      | ENGIE, PG&E, Shell, SoCalGas, Total   | 1st                |
| Public Agency                   | Monetary value of achieving policy goals, including quantified public health-benefits                              | National Academy of Sciences Report(s)  | Within +/- X% of other state-funded options with similar goals              | Indirect                                 | AC Transit, BAAQMD, California Department of General Services, Caltrans, San Francisco Department of the Environment, SCAQMD, SunLine Transit Agency                        | 2nd                |

Source: CARB

Over the past year, the agencies have begun the fact-finding stage to quantify the market conditions necessary for self-sufficient growth, identify the value proposition metric(s) that companies within each entity group evaluate for their decision-making processes, and the threshold values above which companies perceive investment as fully self-sufficient. The agencies have adopted a survey-based approach for this information-gathering phase and have begun contacting companies for participation in the effort. Completion of the project has also been divided into two “waves.” In the current first wave, the agencies are focusing on characterizing five of the entities in Table A-1: industrial gas companies, independent operators, auto manufacturers, station equipment providers, and energy and fuel companies. When appropriate, the surveys have been structured to ask these entities about their business case evaluations in a role as a potential station developer, as well as their assessments in a role as a participant in the hydrogen refueling industry supply chain. The following narratives provide an overview of the considerations that CARB and the CEC understand each entity might evaluate, which form the basis of the agencies’ information gathering.

## **Industrial Gas Companies**

**Example Companies:** Air Liquide, Air Products and Chemicals, Linde, Praxair, United Hydrogen

**Overview:** Industrial gas companies are companies whose primary business is the production, transportation, distribution, and sales of one or more gases for industrial and other purposes. For example, industrial gas companies may supply helium, hydrogen, neon, and other gases to laboratories, oxygen to hospitals, or nitrogen for electronics processing, among other products and end uses. Industrial gas companies also often provide equipment and services to produce or use gases on-site or both. The industrial gas companies listed here as examples all participate in the production of hydrogen as an industrial gas and have had roles in developing California’s current hydrogen refueling infrastructure. These companies may act as a provider of station equipment, a provider of gaseous or liquefied hydrogen, a station developer, a station operator, or several of these roles at once.

**In a station developer role:** Based on participation in the state’s current hydrogen refueling network, it is clear that industrial gas companies are potentially interested in continuing their roles as key players in the hydrogen refueling market. As a potential station developer and owner/operator, the agencies hypothesize that industrial gas companies weigh the potential for investments in hydrogen refueling stations against the potential investments and returns in the companies’ other business ventures. However, the agencies do not know for certain which metrics are used in these decision-making processes, or what other ventures the companies compare to hydrogen refueling infrastructure investments. For example, the agencies hypothesize that self-sufficient hydrogen refueling station investments may be judged based on an expectation of a given internal rate of return. Those investments may be considered strictly in comparison to other potential hydrogen-related ventures within the company, or they could be compared against all possible ventures pursued by the company. In addition, for many industrial gas companies, operating a refueling station and potentially other services on-site is a new type of business venture. It is important to understand how these new competencies are viewed in the companies’ overall assessment of needs for investment in hydrogen refueling infrastructure.

**In a supply chain role:** Industrial gas companies provide gases and equipment for production, storage, and use of gases across varied industries, including hydrogen refueling stations. Even if industrial gas companies do not envision a future role as station owners/operators, they remain potentially significant participants in the overall supply chain for hydrogen refueling stations. To get a clear picture of the industrywide needs for self-funded hydrogen refueling station network expansion, it is also important to understand the market conditions necessary to enable companies within the refueling supply chain to make complementary investments and growth. For example, if hydrogen refueling stations multiply but hydrogen production capacity does not grow commensurate to the network fueling capacity, then the hydrogen supply will act as a bottleneck to the overall growth of hydrogen refueling stations and the FCEV population in the state. Therefore, the agencies developed the self-sufficiency survey to understand the needs of industrial gas companies to develop a self-sufficient business for growth in hydrogen production and distribution, as well as hydrogen refueling station equipment.

### **Independent Operators**

**Example Companies:** FirstElement Fuel, H2 Frontier, HydrogeNXT, HyGen Industries, HTEC, StratosFuel

**Overview:** *Independent operators* are defined in the self-sufficiency effort as organizations whose primary, or possibly sole, business venture is the ownership and operation of hydrogen refueling equipment. These operators do not have existing business ventures in the ownership or operation of conventional gasoline stations or both. Several of these entities are recently formed businesses and may, in some cases, be considered similar to start-ups within the hydrogen refueling industry. For the most part, these companies do not have secondary potential roles as participants in the hydrogen refueling station supply chain.

**In a station developer role:** For these entities, the agencies assume the evaluations of market participation are considered more independently than for other entities. Because ownership and operation of hydrogen refueling stations are their primary or sole business, it is not assumed that the potential for that business is compared to any other venture for these entities. While there may be several similarities in the approaches these companies take to approaches adopted by other types of entities, the fundamental difference of these companies' singular focus has the potential to significantly alter the importance of factors considered in the business decision-making process.

### **Auto Manufacturers**

**Example Companies:** Daimler, General Motors, Honda, Hyundai, Toyota

**Overview:** Auto manufacturers inherently have an interest in the success of the state's hydrogen refueling network, as the launch of a station network is necessary for the launch and growth of FCEV deployments. To this end, auto manufacturers have not only participated in public-private partnerships and collaborative efforts, but have made direct financial investments in California's hydrogen refueling network. Although they do not have a direct role as a station developer or operator, their financial investment and the business decisions motivating that investment can still help the state agencies gain a clear understanding of

necessary market conditions for the hydrogen refueling network to expand on its own, as well as the complementary FCEV deployment expansion that will be necessary.

**In a station developer role:** Auto manufacturers do not have a direct role as station developers and are not expected to have such a role in the future. However, the financial commitment of auto manufacturers to station developers' efforts reveals that some analysis or determination was made of the market conditions and potential progress toward a fully self-sufficient hydrogen refueling network. This perspective is equally valuable to the state's efforts to characterize market needs. It may be possible that the auto manufacturers weigh the potential effect of direct financial support against other methods that may also grow the potential FCEV adopter market. For example, investment in hydrogen stations may be weighed against the market gain that could be made through expanded advertising, expanded driver incentives (auto manufacturers already offer up to \$15,000 of fuel to FCEV adopters), dealer incentives, or other mechanisms common to their broader retail sales and marketing efforts. It is important for the State to understand this evaluation and be able to identify the market conditions that may free up those funds for other market-building efforts.

## Station Equipment Providers

**Example Companies:** Air Liquide, Air Products and Chemicals, FASTECH, Greenlight Innovation, Hydrogenics, ITM Power, Kobelco, Linde, McPhy, Nel Hydrogen, Next Hydrogen, Nuvera, PowerTech Labs

**Overview:** Hydrogen refueling station equipment providers represent a wide array of business structures, proficiencies, and expected roles in the overall hydrogen refueling industry. Several equipment providers participate only in the supply chain for California's hydrogen refueling stations. Some may envision continuing only in this role, while others may envision expansion into station ownership and operation. In addition, some station equipment providers already participate in both roles, as both supply chain participants and refueling station owner/operators. Equipment offerings from these companies include items required for station operation (hydrogen storage, compressors, chillers, dispensers, and so forth), as well as items required for on-site production of hydrogen (most commonly electrolyzers, which use electricity to split water into hydrogen and oxygen).

**In a station developer role:** Similar to industrial gas companies, station equipment providers likely have parallel business ventures outside the hydrogen refueling industry. For example, a company that builds electrolyzers may offer them as a product for station developers to integrate on-site at a hydrogen refueling station and offer them to the petrochemical industry for production of fuel-processing gases or to utilities for renewable energy storage applications, among other potential applications. Similarly, a company that builds compressors may develop products for a wide array of end uses and operation on a similarly wide array of product gases. Thus, it is important to understand the metrics against which the prospects presented by hydrogen refueling station development, ownership, and operation are evaluated for these companies and how these considerations are made with respect to their other potential business ventures.

**In a supply chain role:** Station equipment providers also have a very clear role in the overall supply chain for hydrogen refueling station network expansion. As is the case with industrial gas companies, station equipment providers will likely need to see certain market conditions

become apparent to justify expansion of production facilities to keep pace with the potential demand of hydrogen refueling station developers. It will also be necessary to assess whether the visions of future hydrogen refueling station technical performance expressed by the several types of station developers match with the designs the equipment providers anticipate needing or providing through their product offerings.

## **Energy and Fuel Companies**

**Example Companies:** ENGIE, PG&E, Shell, SoCalGas, Total

**Overview:** Energy and fuel companies are those that have had a long-standing history as providers of conventional gases and/or liquids intended for retail sale as fuel and expressed an interest in adding hydrogen as one of their product offerings. These companies differ from the industrial gas companies in many ways, including the key differences between a history of developing products for industrial use and developing products for retail sale. In addition, the sourcing of materials and chemicals for production may vary significantly between these types of companies.

**In a station developer role:** Companies in this group have participated in California's hydrogen refueling network efforts since the research and demonstration phase and are participating as developers of retail hydrogen refueling stations. California's zero-emission transportation goals will have clear effects on these companies' traditional business ventures and strategies, and it is important to understand these companies' vision for participation in the development of the hydrogen refueling industry. It is likely that continued investments by these companies will involve analysis of the tradeoff between continuing and expanding business in conventional fuels and establishing and growing business in hydrogen or other alternative fuel. In addition, direct ownership and operation of retail hydrogen refueling facilities represent a departure from today's refueling market structure in California, where the vast majority of vehicle refueling stations are owned by independent operators rather than the fuel companies themselves. Finally, these companies bring a unique perspective in terms of the decades of experience gained through participation in the retail sale of fuels in general. The market conditions and evaluations that these companies may be able to share could bring valuable insights to the state's self-sufficiency evaluation.

**In a supply chain role:** With hydrogen production, distribution, and sale traditionally handled more by the industrial gas companies industry, it is not entirely clear how conventional energy and fuel providers may respond or envision their future role in the supply chain. Refineries today are the largest producers and consumers of hydrogen (used for several steps in the process of refining crude oil into gasoline, diesel, and other fuels), and these companies may eventually find value in shifting their product offerings toward hydrogen. However, the industrial gas companies often own and operate the on-site hydrogen equipment at refineries, with the fuel company simply acting as the host site and ultimate customer of the product hydrogen. In addition, as they would be new entrants in the retail sale of hydrogen, there are several unknowns about energy and fuel companies' vision for this potential transition and their evaluation of the enabling market conditions.

# APPENDIX B: Hydrogen Refueling Station Evaluation Scorecards

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The following financial assessments, or “scorecards,” as of November 15, 2017, are output from the Hydrogen Financial Analysis Scenario Tool for hydrogen refueling stations.<sup>43</sup> The Hydrogen Financial Analysis Scenario Tool model was used to describe the financial performance of two station designs (one using gaseous truck delivery and one using delivered liquid) funded by ARFVTP. Each station was considered under two utilization growth trajectories (“slow” and “fast”) and two sizes (180 kg/day and 350 kg/day). An additional hypothetical station was analyzed to provide an outlook of the impact of station scale to 600 kg/day. In total, five Hydrogen Financial Analysis Scenario Tool scenarios are described below:

- 180 kg/day gaseous truck delivery station experiencing slow (seven-year) growth in utilization
- 180 kg/day gaseous truck delivery station experiencing fast (three-year) growth in utilization
- 350 kg/day delivered liquid station experiencing slow (10-year) growth in utilization
- 350 kg/day delivered liquid station experiencing fast (five-year) growth in utilization
- 600 kg/day delivered liquid station experiencing fast (eight-year) growth in utilization

In this evaluation, the different station sizes are given different time durations associated with slow and fast utilization growth because a larger station is likely to take longer to reach a high utilization (defined as 80 percent of capacity) than a smaller station. However, the analysis assumes that larger stations are larger because they are in higher-demand areas, and so the associated sales growth trajectory is higher than that of a smaller station. As such, a 350 kg/day fast-growth station could reach 80 percent utilization in five years instead of six years, which would have been the case if the performance of the 180 kg/day fast-growth station was applied linearly to the 350 kg/day station.

The rate of growth for the average station in the currently open retail station network is five years to reach 80 percent utilization. Some stations are on a trajectory to achieve 80 percent utilization in roughly a year, and some stations have trajectories of more than 10 years. Each scorecard has an assumed length of time for reaching the 80 percent utilization benchmark. As described earlier, and based on the operating data collected thus far, larger stations are anticipated to experience a slower demand ramp to 80 percent utilization than smaller stations because more throughput is needed to reach 80 percent of the higher capacity.

The scorecards articulate the overall financial performance and detailed cash flows on a per-kilogram of hydrogen basis. The scorecards account for station capital equipment costs, O&M costs, upfront financing by source, and key financial parameters. The assessments are based on input from conversations with station developers, CEC grant agreement budgets and

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<sup>43</sup> Information on [Hydrogen Financial Analysis Scenario Tool](https://www.nrel.gov/hydrogen/F.html) is available online. (<https://www.nrel.gov/hydrogen/F.html>)



invoices, and the station developers' input to the NREL Data Collection Tool, which is required for reimbursement of eligible expenses.

The CEC works in collaboration with the NREL National Fuel Cell and Technology Evaluation Center to collect, quantify, and analyze hydrogen station throughput data and O&M costs.<sup>44</sup> In some cases, station developers pay for maintenance themselves, and this includes direct labor and parts, when O&M costs exceed the amount of O&M grant funding. The two station designs of delivered gaseous hydrogen and delivered liquid hydrogen evaluated here are among the many possible design approaches.

The scorecards present financial analysis inputs and results for each station in the following sections:

- Upfront financing estimate by source
- Key financial parameters
- Key assumptions
- Financial performance and break-even retail price
- Real levelized value contributions (\$/kg H<sub>2</sub>)
- Annual cost of goods sold (\$/kg)

A few important metrics shown on these scorecards are the levelized break-even price of hydrogen, first-year retail price of hydrogen, project net present value, and leveraged after-tax nominal internal rate of return (IRR).

There are two important operating expenses associated with dispensing hydrogen: fixed and variable. *Fixed operating expenses* are ones that are incurred regardless of the volume of hydrogen sales. Below are the values that are modeled as fixed operating expenses:

- Rent at the retail location typically varies between \$4,000 and \$6,000 per month.
- Fixed electricity energy expense is the electricity used for keeping chillers cold, for lighting, and for powering control systems.
- Utility demand charges and service charges are the expenses passed on by the utility to the station operator based on the peak power (kW) drawn by the retail station, and the utility's administrative charges, which are independent of energy use.
- Maintenance expenses are treated as a fixed cost independent of actual hydrogen throughput.
- Purity testing is a mandated expense incurred a fixed number of times per year of operation.
- Internet connection expenses are for system control and data collection.

Fixed operating expenses are especially important in the context of low station utilization during the first years of operation. Such expenses must be paid even if few kilograms of hydrogen are sold and greatly magnify the station annual cost of hydrogen. During the first years of operation, such expenses dominate the cost of hydrogen. Over time, as demand

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<sup>44</sup> Information on the [National Fuel Cell and Technology Evaluation Center](https://www.nrel.gov/hydrogen/nfctec.html) is available online. <https://www.nrel.gov/hydrogen/nfctec.html>

grows, fixed operating expenses diminish in cost on a per-kilogram basis and are displaced in importance by variable operating expenses. These expenses are incurred only when hydrogen is sold. Below are some examples of variable operating expenses:

- Cost of delivered hydrogen that is correlated with the amount of hydrogen sold (more kilograms must be delivered more frequently as the demand for hydrogen grows)
- Cost of electricity used for compression and cooling of gas
- Sales taxes
- Credit card fees

The contributions of expenses as well as the value of financing cash flows are summarized in the scorecards' chart of real levelized value breakdown of hydrogen (\$/kg).

Figure B-1 shows the scorecard for a 180 kg/day delivered gaseous station installed with \$1,450,000 in CEC capital expenditure grant funding and a station developer match of \$633,333 along with debt financing of \$316,667, for a total capital cost of \$2,400,000, as well as \$300,000 in O&M funding. Demand growth for this station is modeled to achieve 80 percent utilization in seven years, which is consistent with slower demand growth station data from field analysis. The results show a levelized break-even hydrogen price would be \$10.77 per kilogram, while the levelized retail price of hydrogen is \$10.65 per kilogram. The internal rate of return for an equity investor over the 20-year life of the project is estimated at 13.7 percent. Note that 20-year project life is an industry-accepted estimate for hydrogen fueling stations. While all components are not expected to perform continuously for 20 years, regular maintenance, component replacements, and overhauls are expected to allow installations to achieve such a project span.<sup>45</sup>

In this analysis, the lifetime assumption of 20 years is used. Furthermore, station analysis is calibrated with operating expenses incurred by stations in the field. Maintenance expenses may not fully reflect longer-term maintenance cost items. For example, overhaul expenses may become necessary throughout the life span of stations, and such costs have yet to be incurred. In the subsequent scorecards, analysis assumes that no capacity upgrades are performed throughout the life of the project. This assumption will likely prove inaccurate as early stations are placed in some of the best market locations, and market growth would be expected to outpace initial capacity. It is thus likely that operators would take advantage of improved economies of scale stations via capacity upgrades. Such upgrades are, however, not modeled due to low certainty of cost, technology choices, performance impacts, and timing.

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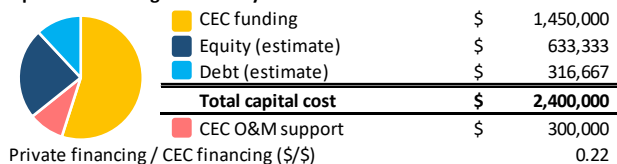
<sup>45</sup> Peer-reviewed Department of Energy station models use the following as overall station life span:

- [Hydrogen Analysis Model](https://www.hydrogen.energy.gov/h2a_production.html) (H2A): 20 years: ([https://www.hydrogen.energy.gov/h2a\\_production.html](https://www.hydrogen.energy.gov/h2a_production.html))
- [Hydrogen Delivery Scenario Model](https://www.hydrogen.energy.gov/h2a_delivery.html) (HDSAM): 30 years ([https://www.hydrogen.energy.gov/h2a\\_delivery.html](https://www.hydrogen.energy.gov/h2a_delivery.html))
- [Hydrogen Refueling Station Analysis Model](https://www.hydrogen.energy.gov/h2a_delivery.html) (HRSAM): 10 years ([https://www.hydrogen.energy.gov/h2a\\_delivery.html](https://www.hydrogen.energy.gov/h2a_delivery.html))

# Figure B-1: Scorecard, 180 Kg/Day Gaseous Truck Delivery Station Experiencing Slow Growth

## (1) Delivered Gaseous Hydrogen - Low Utilization Growth

### Up-front financing estimate by source



### Key financial parameters

|   |    |        |
|---|----|--------|
| First year retail price of H2 (\$/kg)                     | \$ | 15.31  |
| Levelized retail price of H2 (\$/kg)                      | \$ | 10.65  |
| First year cost of delivered H2 (\$/kg)                   | \$ | 8.94   |
| Levelized cost of delivered H2 (\$/kg)                    | \$ | 6.65   |
| Variable electricity use (kWh/kg)                         |    | 4.00   |
| Fixed electricity use (kW)                                |    | 2.00   |
| First year electricity demand & service charges (\$/year) | \$ | 2,100  |
| Levelized cost of electricity (\$/kWh)                    | \$ | 0.233  |
| First year rent (\$/year)                                 | \$ | 46,000 |
| First year maintenance (\$/year)                          | \$ | 42,800 |
| Purity testing (\$/year)                                  | \$ | 8,100  |
| Internet connection (\$/year)                             | \$ | 2,300  |

### Key assumptions

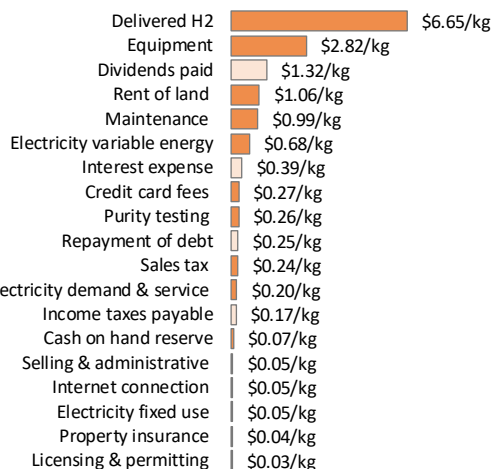
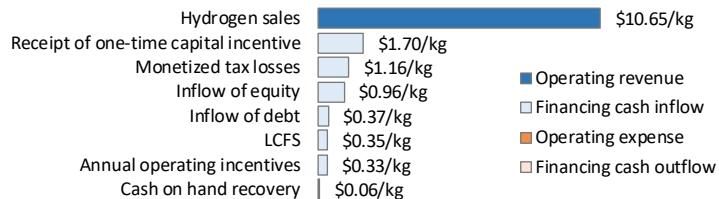
|                                    |      |
|------------------------------------|------|
| Nameplate capacity (kg/day)        | 180  |
| Project initiation year            | 2017 |
| Equipment operational life (years) | 20   |
| Long term equipment utilization    | 80%  |
| Demand ramp-up period (years)      | 7.0  |

### Financial performance and break-even retail price

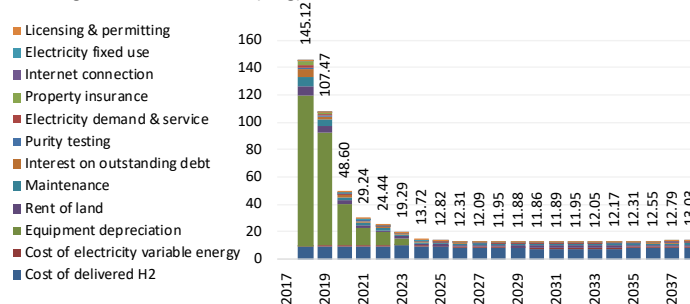
|  |           |
|--|-----------|
| Levelized break-even price of hydrogen (\$/kg) | \$10.77   |
| Levelized retail margin (\$/kg)                | \$ 3.33   |
| Levelized break-even margin (\$/kg)            | \$ 3.45   |
| Project NPV                                    | \$ 84,000 |
| Profitability index                            | 1.48      |
| Leveraged after-tax nominal IRR                | 13.7%     |

Source: NREL

### Real levelized value breakdown of hydrogen (\$/kg)



### Cost of goods sold breakdown (\$/kg)



The financial performance of this station is favorable from the perspective of the entire project life span. The 13.7 percent internal rate of return outperforms many investment opportunities, and the scorecard reflects the performance of a poor performing station based on the demand growth seen in the field. That said, the cost of goods sold, seen in the lower right of the chart, shows that cost of hydrogen sold in the early years of station operation is much higher than the price that the market can bear. This is indeed the case for all scorecard analysis in this report. This is largely due to low throughput in the early years compounded with accelerated capital depreciation. Besides depreciation during the first years, financial performance is especially stressed by fixed operating expenses ranked in importance as follows:

- Rent
- Maintenance
- Purity testing
- Electricity demand charges
- Internet connection
- Fixed electricity use (electricity needed to keep cooling heat exchangers to -40°C)

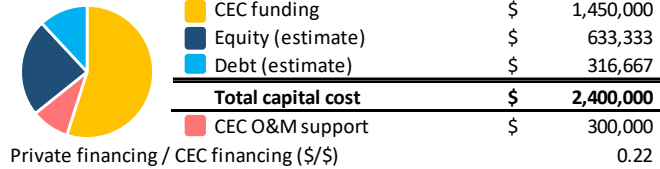
Variable operating expenses such as cost of delivered hydrogen and energy cost of electricity are not as important in the early years since low station utilization implies small quantities of these incurred expenses. As projected, demand growth is realized, and fixed operating expenses become less important and are overtaken in cost contribution by variable expenses. As such, pressure on the cost-competitive price of delivered hydrogen is expected to be more substantial in later years of operation and will drive the overall financial profitability of stations in the long term. The cost of goods sold chart does not reflect the financial performance for an equity investor as depreciation spans the entire station cost – including portions subsidized by CEC grants. Furthermore, a significant portion of operating expenses is subsidized by CEC O&M grants.

Figure B-2 shows the scorecard for a 180 kg/day delivered gaseous station installed with \$1,450,000 in CEC capital expenditure grant funding and a station developer match of \$633,333 along with debt financing of \$316,667 for a total capital cost of \$2,400,000, as well as \$300,000 in O&M funding. Demand growth for this station is modeled to achieve 80 percent utilization in three years, which is consistent with faster demand growth station data from field analysis. The results show a levelized break-even hydrogen price would be \$10.58 per kilogram, while the levelized retail price of hydrogen is \$10.96 per kilogram. In the price profile, there is a built-in downward trajectory – hydrogen becomes cheaper over time. As the faster demand growth station sells more hydrogen sooner, it also takes in more sales of the early and more expensive hydrogen. Thus, when the revenue stream is levelized, it yields a sales price of hydrogen that is higher. However, the faster growth station also ends up buying more expensive delivered hydrogen early on than the slower growth station. The internal rate of return for an equity investor over the 20-year life of the project is estimated at 19.1 percent.

**Figure B-2: Scorecard, 180 Kg/Day Gaseous Truck Delivery Station Experiencing Fast Growth**

(2) Delivered Gaseous Hydrogen  
- High Utilization Growth

**Up-front financing estimate by source**



**Key financial parameters**

|   |    |        |
|---|----|--------|
| First year retail price of H2 (\$/kg)                     | \$ | 15.31  |
| Levelized retail price of H2 (\$/kg)                      | \$ | 10.96  |
| First year cost of delivered H2 (\$/kg)                   | \$ | 8.94   |
| Levelized cost of delivered H2 (\$/kg)                    | \$ | 6.87   |
| Variable electricity use (kWh/kg)                         |    | 4.00   |
| Fixed electricity use (kW)                                |    | 2.00   |
| First year electricity demand & service charges (\$/year) | \$ | 2,100  |
| Levelized cost of electricity (\$/kWh)                    | \$ | 0.226  |
| First year rent (\$/year)                                 | \$ | 46,000 |
| First year maintenance (\$/year)                          | \$ | 42,800 |
| Purity testing (\$/year)                                  | \$ | 8,100  |
| Internet connection (\$/year)                             | \$ | 2,300  |

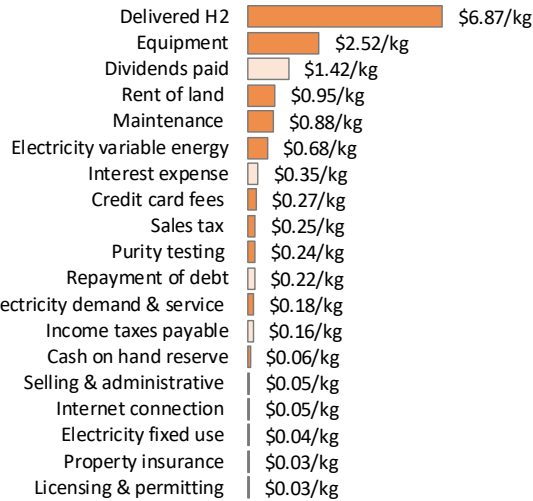
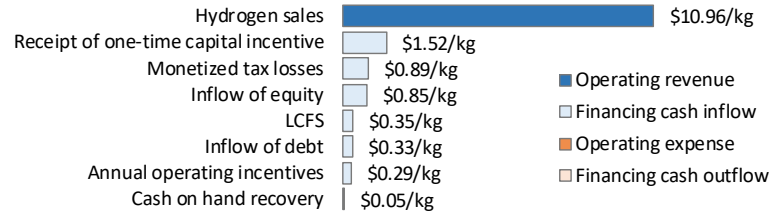
**Key assumptions**

|                                    |      |
|------------------------------------|------|
| Nameplate capacity (kg/day)        | 180  |
| Project initiation year            | 2017 |
| Equipment operational life (years) | 20   |
| Long term equipment utilization    | 80%  |
| Demand ramp-up period (years)      | 3.0  |

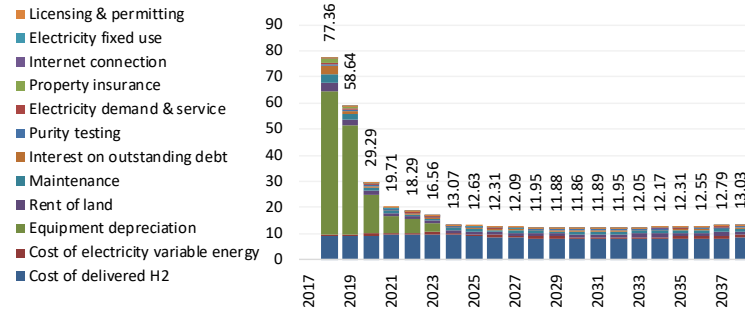
**Financial performance and break-even retail price**

|  |            |
|--|------------|
| Levelized break-even price of hydrogen (\$/kg) | \$10.58    |
| Levelized retail margin (\$/kg)                | \$ 3.41    |
| Levelized break-even margin (\$/kg)            | \$ 3.03    |
| Project NPV                                    | \$ 239,000 |
| Profitability index                            | 1.86       |
| Leveraged after-tax nominal IRR                | 19.1%      |

**Real levelized value breakdown of hydrogen (\$/kg)**



**Cost of goods sold breakdown (\$/kg)**



Source: NREL

In contrast to the financial performance shown in Figure B-1, this station is able to distribute the fixed operating costs across a higher volume of hydrogen sold in the early years. As such, it is able to provide a lower cost of goods sold in the early years of operation, yielding a higher project IRR. Once the station demand is saturated, the associated annual financial performance will resemble the financial performance of the lower growth station shown in Figure B-1.


Figure B-3 shows the scorecard for a 350 kg/day delivered liquid station installed with \$2,100,000 in CEC capital expenditure grant funding and a station developer match of \$466,667, along with debt financing of \$233,333 for a total capital cost of \$2,800,000, as well as \$300,000 in O&M funding. Demand growth for this station is modeled to achieve 80 percent utilization in 10 years, which is consistent with slower demand growth station data from field analysis. The results show a levelized break-even hydrogen price of \$9.40 per kilogram, while the levelized retail price of hydrogen is \$10.47 per kilogram. The internal rate of return for an equity investor over the 20-year life of the project is estimated at 27.9 percent.

## Figure B-3: Scorecard, 350 Kg/Day Delivered Liquid Station Experiencing Slow Growth

### (3) Delivered Liquid Hydrogen

#### - Low Utilization Growth

#### Up-front financing estimate by source

|   |   |           |                  |
|---|---|-----------|------------------|
|  | CEC funding                               | \$        | 2,100,000        |
|   | Equity (estimate)                         | \$        | 466,667          |
|   | Debt (estimate)                           | \$        | 233,333          |
|   | <b>Total capital cost</b>                 | <b>\$</b> | <b>2,800,000</b> |
|   | CEC O&M support                           | \$        | 300,000          |
|   | Private financing / CEC financing (\$/\$) |           | 0.11             |

#### Key financial parameters

|   |    |        |
|---|----|--------|
| First year retail price of H2 (\$/kg)                     | \$ | 15.31  |
| Levelized retail price of H2 (\$/kg)                      | \$ | 10.47  |
| First year cost of delivered H2 (\$/kg)                   | \$ | 8.94   |
| Levelized cost of delivered H2 (\$/kg)                    | \$ | 6.51   |
| Variable electricity use (kWh/kg)                         |    | 4.00   |
| Fixed electricity use (kW)                                |    | 2.00   |
| First year electricity demand & service charges (\$/year) | \$ | 2,100  |
| Levelized cost of electricity (\$/kWh)                    | \$ | 0.205  |
| First year rent (\$/year)                                 | \$ | 46,000 |
| First year maintenance (\$/year)                          | \$ | 90,900 |
| Purity testing (\$/year)                                  | \$ | 8,100  |
| Internet connection (\$/year)                             | \$ | 2,300  |

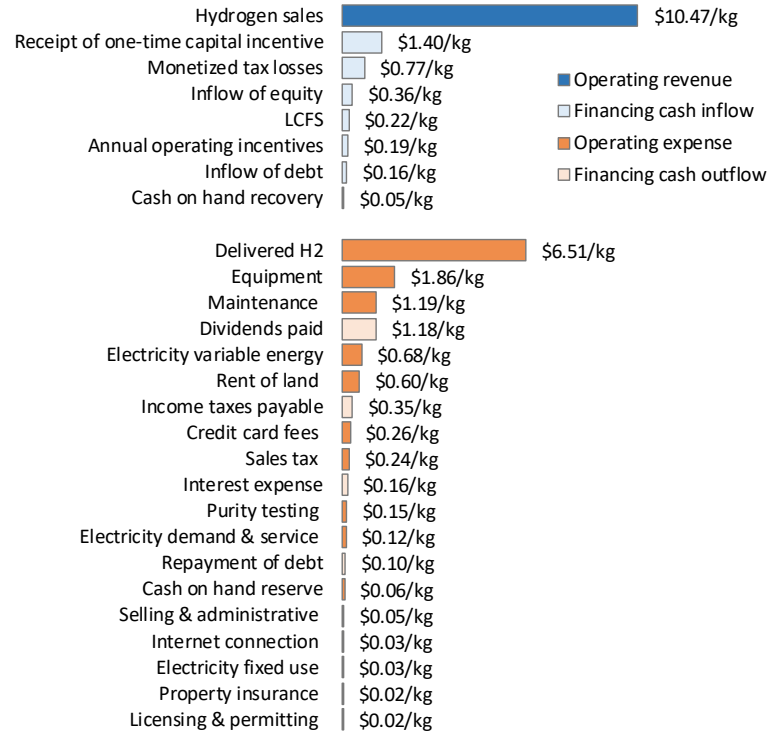
#### Key assumptions

|                                    |      |
|------------------------------------|------|
| Nameplate capacity (kg/day)        | 350  |
| Project initiation year            | 2017 |
| Equipment operational life (years) | 20   |
| Long term equipment utilization    | 80%  |
| Demand ramp-up period (years)      | 10.0 |

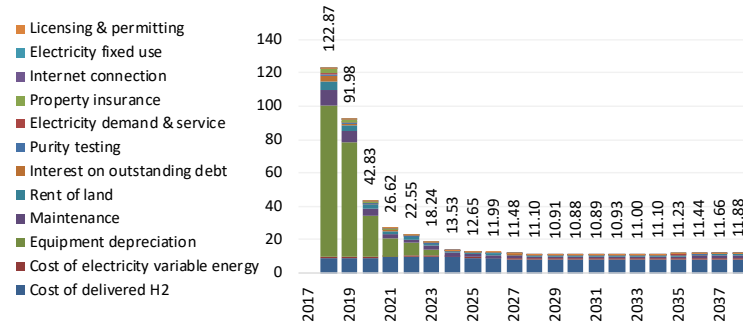
#### Financial performance and break-even retail price

|  |    |         |
|--|----|---------|
| Levelized break-even price of hydrogen (\$/kg) | \$ | 9.40    |
| Levelized retail margin (\$/kg)                | \$ | 3.29    |
| Levelized break-even margin (\$/kg)            | \$ | 2.22    |
| Project NPV                                    | \$ | 507,000 |
| Profitability index                            |    | 3.65    |
| Leveraged after-tax nominal IRR                |    | 27.9%   |

#### Real levelized value breakdown of hydrogen (\$/kg)



#### Cost of goods sold breakdown (\$/kg)



Source: NREL

The station capacity experiences slower demand growth than those of smaller peers (Figures B-1 and B-2). This is largely because stations exhibit low product differentiation. Fuel cell vehicle users benefit from subsidized fuel costs and are not motivated to price shop for their fuel. Since this station has an economy of scale advantage, it could realize a lower retail price that could attract more consumers. This advantage can materialize at a time when consumers begin paying out of pocket for fuel. At this time, such stations need to be carefully placed in the highest-demand growth areas to realize more competitive demand growth and to better serve the emerging market demand growth. Alignment of high-demand locations with larger station capacities would provide better financial performance for station owners, as well as improve satisfaction of vehicle drivers by having larger capacity stations where they want to refuel.

In this station scorecard, LCFS credits are estimated to be \$0.22/kg, while in the prior gaseous delivery stations, LCFS was estimated to be \$0.35/kg. This difference exists because liquid hydrogen exhibits more carbon emissions as more electricity is used in liquefaction compared to gaseous hydrogen. As such, carbon emission reductions from liquid hydrogen pathway yield a lower LCFS benefit.

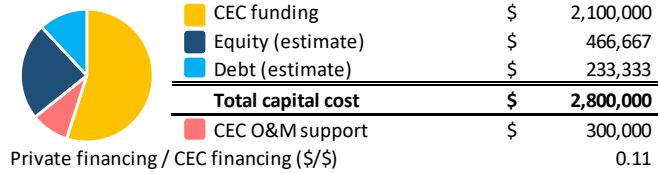
Figure B-4 shows the scorecard for a 350 kg/day delivered liquid station installed with \$2,100,000 in CEC capital expenditure grant funding and a station developer match of \$466,667, along with debt financing of \$233,333 for a total capital cost of \$2,800,000, as well as \$300,000 in O&M funding. Demand growth for this station is modeled to achieve 80 percent utilization in five years, which is consistent with faster demand growth station data from field analysis. The results show a levelized break-even hydrogen price would be \$9.41 per kilogram, while the levelized retail price of hydrogen is \$10.79 per kilogram. The internal rate of return for an equity investor over the 20-year life of the project is estimated at 34.7 percent.



## Figure B-4: Scorecard, 350 Kg/Day Delivered Liquid Station Experiencing Fast Growth

**(4) Delivered Liquid Hydrogen  
- High Utilization Growth**

**Up-front financing estimate by source**



**Key financial parameters**

|   |    |        |
|---|----|--------|
| First year retail price of H2 (\$/kg)                     | \$ | 15.31  |
| Levelized retail price of H2 (\$/kg)                      | \$ | 10.79  |
| First year cost of delivered H2 (\$/kg)                   | \$ | 8.94   |
| Levelized cost of delivered H2 (\$/kg)                    | \$ | 6.76   |
| Variable electricity use (kWh/kg)                         |    | 4.00   |
| Fixed electricity use (kW)                                |    | 2.00   |
| First year electricity demand & service charges (\$/year) | \$ | 2,100  |
| Levelized cost of electricity (\$/kWh)                    | \$ | 0.200  |
| First year rent (\$/year)                                 | \$ | 46,000 |
| First year maintenance (\$/year)                          | \$ | 90,900 |
| Purity testing (\$/year)                                  | \$ | 8,100  |
| Internet connection (\$/year)                             | \$ | 2,300  |

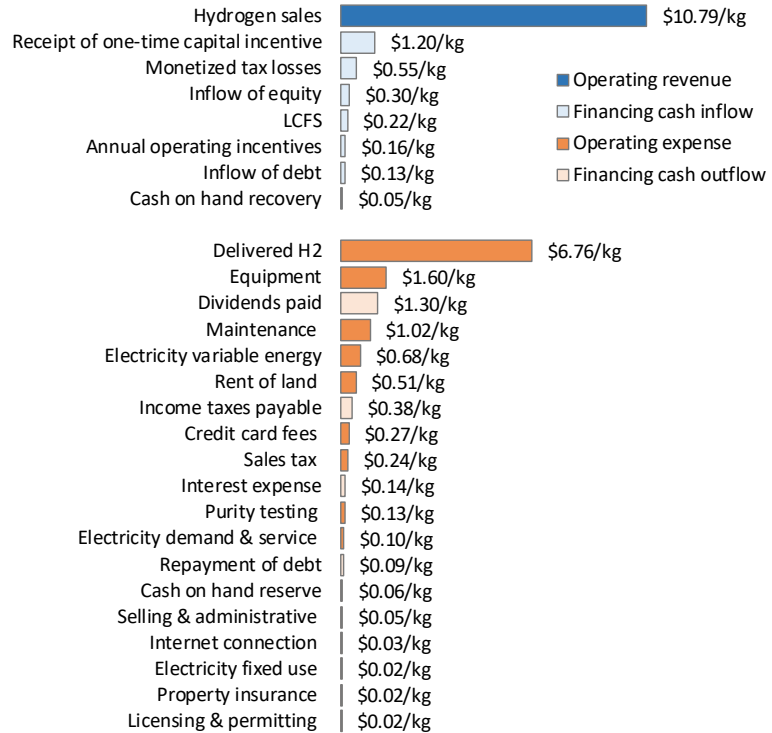
**Key assumptions**

|                                    |      |
|------------------------------------|------|
| Nameplate capacity (kg/day)        | 350  |
| Project initiation year            | 2017 |
| Equipment operational life (years) | 20   |
| Long term equipment utilization    | 80%  |
| Demand ramp-up period (years)      | 5.0  |

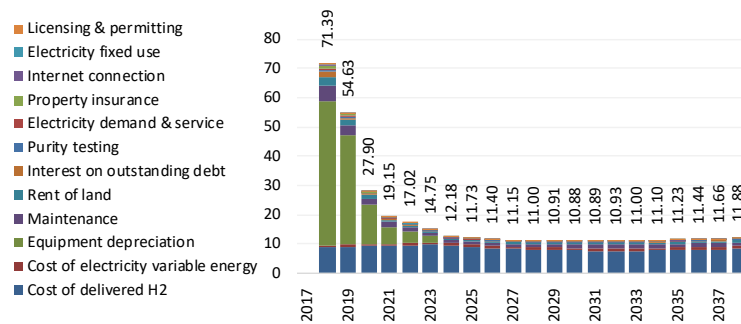
**Financial performance and break-even retail price**

|  |    |         |
|--|----|---------|
| Levelized break-even price of hydrogen (\$/kg) | \$ | \$9.41  |
| Levelized retail margin (\$/kg)                | \$ | 3.36    |
| Levelized break-even margin (\$/kg)            | \$ | 1.97    |
| Project NPV                                    | \$ | 804,000 |
| Profitability index                            |    | 4.74    |
| Leveraged after-tax nominal IRR                |    | 34.7%   |

**Real levelized value breakdown of hydrogen (\$/kg)**



**Cost of goods sold breakdown (\$/kg)**



Source: NREL

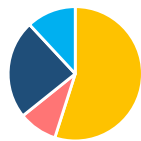
Larger-capacity stations with faster utilization show even better financial performance projections. The above station scenario shows an IRR of 34.7 percent, which is very attractive but is subject to achieving the specified demand growth. As fuel cell vehicle penetration rate increases, it is likely that station utilization growth may become faster and that financial performance of this type may be achieved more frequently. With current costs, such stations still require financial incentives. While the total incentives amounting to \$2.4 million (\$2.1 million for capital and \$300,000 for O&M), the net present value of the project is only \$900,000. Thus, without incentives, this station and utilization characteristics will not achieve 10 percent IRR and may not be attractive to investors. The project net present value would still be robustly positive even without any O&M incentives. This implies that the station has enough incentives from opening day and hydrogen demand follows the assumed trajectory.

Figure B-5 shows the scorecard for a 600 kg/day delivered liquid station installed with \$2,100,000 in CEC capital expenditure grant funding and a station developer match of \$1,333,333, along with debt financing of \$666,667 for a total capital cost of \$4,100,000, as well as \$300,000 in O&M funding. Demand growth for this station is modeled to achieve 80 percent utilization in eight years, which is consistent with faster demand growth station data from field analysis. The results show a levelized break-even hydrogen price would be \$10.37 per kilogram, while the levelized retail price of hydrogen is \$10.58 per kilogram. The internal rate of return for an equity investor over the 20-year life of the project is estimated at 14.9 percent. This station capacity is larger than any ARFVTP-funded stations, and the related cost is estimated based on the liquid 350 kg/day stations assuming a scaling factor of 0.707.

## Figure B-5: Scorecard, 600 Kg/Day Delivered Liquid Station Experiencing Fast Growth

### (5) Delivered Liquid Hydrogen - High Utilization Growth

#### Up-front financing estimate by source



|                           |           |                  |
|---------------------------|-----------|------------------|
| CEC funding               | \$        | 2,100,000        |
| Equity (estimate)         | \$        | 1,333,333        |
| Debt (estimate)           | \$        | 666,667          |
| <b>Total capital cost</b> | <b>\$</b> | <b>4,100,000</b> |
| CEC O&M support           | \$        | 300,000          |

Private financing / CEC financing (\$/\$) 0.32

#### Key financial parameters

|   |    |         |
|---|----|---------|
| First year retail price of H2 (\$/kg)                     | \$ | 15.31   |
| Levelized retail price of H2 (\$/kg)                      | \$ | 10.58   |
| First year cost of delivered H2 (\$/kg)                   | \$ | 8.94    |
| Levelized cost of delivered H2 (\$/kg)                    | \$ | 6.60    |
| Variable electricity use (kWh/kg)                         |    | 4.00    |
| Fixed electricity use (kW)                                |    | 2.00    |
| First year electricity demand & service charges (\$/year) | \$ | 2,100   |
| Levelized cost of electricity (\$/kWh)                    | \$ | 0.189   |
| First year rent (\$/year)                                 | \$ | 46,000  |
| First year maintenance (\$/year)                          | \$ | 133,100 |
| Purity testing (\$/year)                                  | \$ | 8,100   |
| Internet connection (\$/year)                             | \$ | 2,300   |

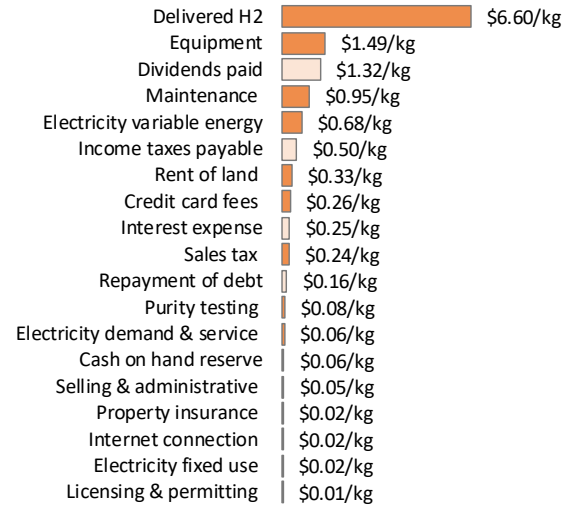
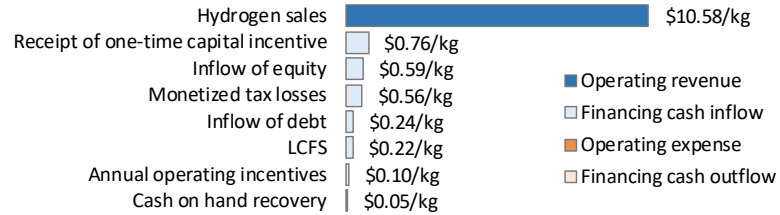
#### Key assumptions

|                                    |      |
|------------------------------------|------|
| Nameplate capacity (kg/day)        | 600  |
| Project initiation year            | 2017 |
| Equipment operational life (years) | 20   |
| Long term equipment utilization    | 80%  |
| Demand ramp-up period (years)      | 8.0  |

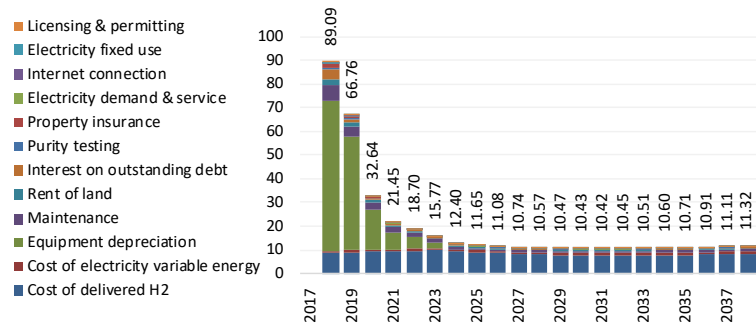
#### Financial performance and break-even retail price

|  |    |         |
|--|----|---------|
| Levelized break-even price of hydrogen (\$/kg) | \$ | 10.37   |
| Levelized retail margin (\$/kg)                | \$ | 3.31    |
| Levelized break-even margin (\$/kg)            | \$ | 3.10    |
| Project NPV                                    | \$ | 456,000 |
| Profitability index                            |    | 2.52    |
| Leveraged after-tax nominal IRR                |    | 14.9%   |

#### Real levelized value breakdown of hydrogen (\$/kg)



#### Cost of goods sold breakdown (\$/kg)



Source: NREL

This type of station tests the financial sensitivity of providing larger capacity stations in nascent hydrogen market. Field data are painting a slower utilization growth period for larger stations. If this trend is extrapolated to a station of this size, slow utilization may exceed any economies of scale offered by the larger capacity of the station. Nevertheless, such stations may be a prudent design for locations of high demand where they can achieve fast utilization growth. This may be the case when serving captive vehicle fleets or offering public fueling services. Moreover, once high station utilization is achieved, this station offers the lowest cost of goods sold. As such, the station has the best marginal profit potential per kilogram of hydrogen sold. At this station scale, owners can also possibly realize a lower cost of delivered hydrogen that is not factored in the above analysis.

# APPENDIX C: Station Commissioning

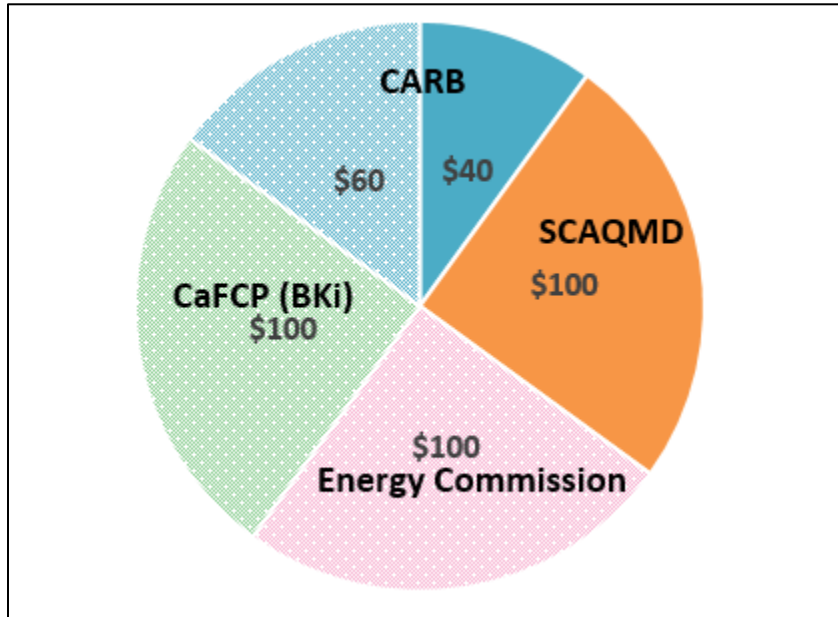
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This appendix discusses the safety and performance tests and standards associated with the hydrogen refueling station commissioning process that typically occurs prior to a station becoming open retail. Stations are tested to ensure accurate metrology, to ensure purity of dispensed hydrogen, and to verify that the station meets industry-standard fueling safety and performance protocols (SAE J2601). The California Department of Food and Agriculture's (CDFA) Division of Measurement Standards (DMS) plays a major role in station commissioning by conducting metrology compliance tests for station dispensers under California regulations. In addition to metrology testing by DMS, the purity of dispensed hydrogen is evaluated and reported by commercial testers. These metrology and purity aspects are outside the scope of this appendix, which focuses on safety and performance tests and standards associated with the hydrogen refueling station commissioning process.

All ARFVTP-funded stations undergo safety and performance testing by auto manufacturers in coordination with the station provider to perform this assessment and become open retail. In addition, the Hydrogen Station Equipment Performance (HyStEP) device, operated by CARB, is used when available to help streamline and accelerate the station safety and performance testing process.

The Sandia National Laboratories developed HyStEP in collaboration with the NREL, the U.S. DOE, and CARB to evaluate hydrogen refueling station performance per American National Standards Institute (ANSI)/ Canadian Standards Association Group Hydrogen Gas Vehicle and Fueling Installations 4.3. The U.S. DOE, through Sandia National Laboratories, lent HyStEP to CARB for use in California through 2018. Funding from CARB, the CEC, CaFCP, and SCAQMD support the operations, as shown in Figure C-1. The portion of the figure with a dotted pattern represents funding already spent, and the portion filled with solid color is the remaining funding: \$140,000. This remaining funding is sufficient for 10 to 15 weeks of on-site testing. In addition to implementing and overseeing the HyStEP test program, CARB contributes a staff program manager, field engineer, and two additional engineers for data analysis and program activities. CARB also contributes the truck needed to transport the HyStEP trailer device. DMS continues to provide invaluable experience and knowledge to the deployment of the HyStEP device.

**Figure C-1: HyStEP Program Funding (in Thousands)**



Source: CARB

Note: CaFCP is shown as CaFCP (BKl) because CaFCP was managed by BKl at the time of payment.

The ANSI/ Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3 standard establishes the test methods, criteria, and apparatus to evaluate if a retail hydrogen refueling station complies with SAE J2601, Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles, and the SAE J2799, Hydrogen Surface Vehicle to Station Communications Hardware and Software. Every effort is made to use the most current version of the standard promulgated by the standards development organization.

A revision of the ANSI/ Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3 is underway that may include factory acceptance testing (FAT) and station acceptance testing procedures with the FAT performed on station equipment at the factory or lab. The concept is that portions of the station could be validated through FAT and would occur before building the station. This would likely reduce the time spent testing stations via the station acceptance testing on-site, thus optimizing HyStEP testing time. HyStEP staff will participate in field-testing, development, and refinement of the test methods for the MC formula method test procedure in the next version of the ANSI/ Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3, which will align with the standards in the SAE J2601 2016 version.

HyStEP testing at stations with multiple dispensers began in 2017 and will become more common as many future stations will have multiple dispensers. ANSI/ Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3 does not address how to test a station with multiple dispensers. CARB is working with auto manufacturers to develop and refine a testing matrix for inclusion in a future Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3 revision that will evaluate the station as a whole and may not require repeating each test at all dispensers. CARB staff conducts and recommends safety tests at each dispenser. CARB staff is conducting a full performance test matrix at one dispenser and an abbreviated matrix at the second dispenser. This matrix was discussed and

vetted with both auto manufacturers and station providers. Further development of a testing matrix for ANSI/ Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3 to address multidispenser testing will be an ongoing activity that CARB staff participates in through the ANSI/ Canadian Standards Association technical working group.

Some of the benefits of HyStEP testing follow:

- As a validation tool, HyStEP is integral to validating the fill performance of a station.
- HyStEP allows CARB to assist hydrogen refueling station developers in fine-tuning the performance of station equipment. It also allows CARB the opportunity to better understand the current state of station compression, storage, and dispensing technology to be in a better position to help plan for future station performance needs.
- HyStEP test results can be used to verify fueling protocols and test procedures and potentially assist in faster and more effective standards development, as well as aid in certification and inspection. This will help permitting and installation of future fueling stations.

CARB works with stakeholders to optimize the resources required for testing, which is a four-person operation requiring an engineer and metrologist to perform tests on-site and two additional engineers to evaluate data and report findings to station operators. If technicians were to conduct the testing, the process could be more cost-effective, but to make this happen, the standard test method and fueling protocols would require modification. Modifications for both are underway and should be completed by the first quarter of 2019. Graphing the HyStEP test results could be made more efficient with additional modifications.

CARB anticipates HyStEP or a similar device could be used to test about 32 more stations through 2020. Station readiness, location, and availability of the HyStEP device will play a large role in the ultimate order of station testing. In addition, construction delays are common and often unpredictable, leading to large modifications of the planned HyStEP schedule.

Finally, CARB anticipates participating in development of a formalized state or third-party confirmation/certification process. While there is a clear need to make advances toward such a process, its definition and structure are still largely undetermined. The following concepts are under consideration, and early discussions have begun among industry partners. Additional options beyond those listed below may be introduced as a formal process is further developed:

- Develop a formalized HyStEP station certification process
- Incorporate Canadian Standards Association Hydrogen Gas Vehicle and Fueling Installations 4.3 into NFPA 2, expected to undergo revision in 2020
- Develop a third-party testing and certification process

As more stations are built, the need for more testing, optimizing, and tuning grows. Additional HyStEP testing devices will be necessary to meet station commissioning objectives. Recent interactions with station developers indicate that fueling protocol testing devices are needed not only for final confirmation testing to the SAE J2601 fueling protocol, but to tune and optimize the station before confirmation testing. One HyStEP device cannot handle this demand. To optimize the station opening process, several additional fueling protocol testing devices will be needed for tuning and optimizing the station prior to the final confirmation testing. A screening device with limited testing and tuning capabilities could be designed to fit

in the back of a truck; this would help demonstrate that the station was ready for full-scale ANSI/ Canadian Standards Association 4.3 tests. In addition, at least two full-scale HyStEP-like devices will be needed, one in Northern California and one in Southern California, to address the final confirmation testing needs. The long-term viability of HyStEP as a prototype device is unknown at this time. Therefore, CARB works to assess the interest of Nationally Recognized Testing Laboratories (NRTLs) to augment or supplant HyStEP, or both. Because some stations have required more than one HyStEP visit before tests are passed, CARB is exploring the idea of offering HyStEP to station developers for preliminary evaluations on a fee-for-service basis. This could enable developers to troubleshoot issues before official testing.

## **California Type Evaluation – Hydrogen Gas-Measuring Devices – Station Commissioning**

The California Department of Food and Agriculture/Division of Measurement Standards (CDFA/DMS) conducts metrology tests during station commissioning to certify the station can accurately sell hydrogen by the kilogram on a retail basis. Hydrogen refueling station dispensers must be evaluated for compliance with the California Code of Regulations (CCR), Title 4, Division 9, Chapter 1, Article 1, Section 4002.9 Hydrogen Gas-Measuring Devices (3.39). For dispensers that are already “type-approved,” meaning that a particular type of dispenser has already been certified by DMS, the local county weights and measures official is responsible for verifying that the newly installed devices conform to the approved tolerances. This test can be performed by a licensed service agent working for a registered service agency (RSA) with the local official witnessing.<sup>46</sup> Devices meeting the approved tolerances receive a county seal that verifies that the device is legal to use for trade.

RSA testing must be witnessed by a local weights and measurements official or DMS representative to obtain the required DMS temporary use permit and certificate of approval to sell hydrogen fuel. Temporary use permits are issued based on test results that conform to tolerances specified in the National Institute of Standards and Technology Handbook 44 Publication 14 from the National Conference on Weights and Measures and CCR Title 4, Division 9. Three temporary use permits have been issued. Those recipients issued temporary use permits are Hydrogenics, Powertech, and Air Liquide. The approximate cost of using an RSA service is \$2,200 to \$2,400 for a one-day (eight-hour) test. Companies to date that have dispensers with certificates of conformance are Bennett Pump Company, California State University, Los Angeles, Equilon Enterprises LLC, and Quantum Fuel Systems Technologies Worldwide.

## **Hydrogen Purity Testing**

Hydrogen purity testing is integral to station commissioning. Before declaring a station operational, station developers must arrange a hydrogen purity test according to CCR, Title 4, Division 9, Chapter 6, Article 8, Sections 4180 and 4181, which adopts SAE International

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<sup>46</sup> More information about the Registered Service Agency Program can be found in the California Department of Food and Agriculture, Division of Measurement Standards' [Registered Service Agency Program: Information Guide](https://www.cdfa.ca.gov/dms/programs/rsa/rsaInfoGuide.pdf). (https://www.cdfa.ca.gov/dms/programs/rsa/rsaInfoGuide.pdf)



J2719. The estimated cost per evaluation is \$2,500 to \$5,000, and the process typically takes one to two weeks. The service is commercially available.

# APPENDIX D: Fueling Trends

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The following tables and figures depict the actual use of California's hydrogen refueling station network. The data are obtained from the station operators and reported to the CEC regularly. The data in the following tables and figures are from Q4 2015 to Q3 2017 as of November 13, 2017, unless otherwise noted. For data from Q4 2015 to Q3 2016, some values may be different than what were provided in the 2016 Joint Report because of the receipt of additional data after the publishing of that report, and because of additional steps taken to clean the raw data submitted by station operators.

The following tables and figures report on station throughput and fueling pressures from the operational stations that have reporting obligations to the CEC. The analyses in this appendix do not include Torrance and Lawndale stations, with which the CEC does not have reporting agreements. The analyses also do not include the San Ramon station, which opened in Q3 2017 and for which some data gaps existed during that quarter. This appendix includes dispensing information including the time of day and day of week of the fueling. Data are also provided by the type of fuel dispensed: hydrogen at H70 or at H35. NREL compiles and analyzes the data. The CEC expects the hydrogen dispensing to continue to grow commensurate with FCEV deployment.

## Quarterly Trends

Table D-1 reports key infrastructure trend metrics throughout the reporting quarters, as well as the associated quarterly percentage change. These metrics include statistics based on the amount of hydrogen dispensed throughout the network and the price of hydrogen per kilogram.

The table shows that the amount of fuel dispensed has steadily increased over the past year. This increase can be seen in the average daily kilograms dispensed, average utilization percentage, and total number of fueling. The table also shows that the average unused capacity for the station network has increased by 3 percent since Q3 2016 (from 3,674 kg/day to 3,795 kg/day in Q3 2017). This increase is due to more stations in the network becoming open retail and able to offer a higher quantity of fuel. This increased amount of hydrogen dispensed has been closely followed by increase in demand, having increased 260 percent over Q3 2016 (353 kg/day in Q3 2016 to 1,291 kg/day in Q3 2017).

The average utilization has increased from just 8.8 percent in Q3 2016 to more than 25.4 percent in Q3 2017. Core markets were also evaluated by excluding connector station data (Coalinga, Truckee, and Santa Barbara). In these core markets, utilization grew from 9.8 percent in Q3 2016 to 27.7 percent in Q3 2017. This growth is a key indicator for infrastructure utilization growth and related financial performance. As more invested capital is used, fixed operating expenses can be spread among greater numbers of kilograms sold.

The average fueling quantity has steadily increased from 2.8 kg/fueling in Q3 2016 to 3.1 kg/fueling in Q3 2017. This increase implies that drivers are becoming more comfortable with vehicle range and are able to better use the available infrastructure coverage.

The total number of fueling events is growing rapidly. This provides infrastructure and car manufacturers with invaluable data for increasing reliability in stations, as well as vehicles. Increasing public exposure to how hydrogen fueling works is providing education and comfort with the fuel.

The overall price of hydrogen has increased by nearly 7 percent since Q3 2016 – increasing from \$14.93/kg to \$15.92/kg. This increase is still not felt by most customers as vehicles on the road still benefit from “free” fueling provided through auto manufacturer incentives. As such, competition among stations has yet to materialize in terms of pulling demand from competitors by offering lower hydrogen prices. The density of hydrogen stations is also relatively sparse, and as such, customers would fuel at the most convenient location rather than the one offering the most competitive price. As the density of stations increases and customers begin to pay for fuel out of pocket, competition will increase. This price pressure will translate throughout the supply chain for hydrogen, yielding opportunities for new producer market entries as well as for increased volume and competition among existing producers.

**Table D-1: Summary of Infrastructure Metrics**

| Quarterly statistics              | Q4/15    | Q1/16     | Q2/16    | Q3/16    | Q4/16    | Q1/17    | Q2/17    | Q3/17    | Q4/16-Q3/17 weighted average or total |
|-----------------------------------|----------|-----------|----------|----------|----------|----------|----------|----------|---------------------------------------|
| Average daily kilograms dispensed | 6        | 72        | 171      | 353      | 517      | 776      | 1,093    | 1,291    | 919                                   |
| % change over previous quarter    |          | ↑ +1,074% | ↑ +137%  | ↑ +106%  | ↑ +46%   | ↑ +50%   | ↑ +41%   | ↑ +18%   |                                       |
| Average utilization (%)           | 0.7%     | 3.3%      | 5.1%     | 8.8%     | 11.5%    | 16.2%    | 21.8%    | 25.4%    | 18.7%                                 |
| % change over previous quarter    |          | ↑ +345%   | ↑ +55%   | ↑ +73%   | ↑ +31%   | ↑ +41%   | ↑ +34%   | ↑ +17%   |                                       |
| Core market utilization (%)       | 0.7%     | 3.5%      | 5.5%     | 9.8%     | 12.8%    | 18.0%    | 23.8%    | 27.7%    | 20.6%                                 |
| % change over previous quarter    |          | ↑ +371%   | ↑ +58%   | ↑ +78%   | ↑ +31%   | ↑ +40%   | ↑ +33%   | ↑ +16%   |                                       |
| Average unused capacity (kg/day)  | 835      | 2,145     | 3,213    | 3,674    | 3,969    | 4,011    | 3,929    | 3,795    | 3,926                                 |
| % change over previous quarter    |          | ↑ +157%   | ↑ +50%   | ↑ +14%   | ↑ +8%    | ↑ +1%    | ↓ -2%    | ↓ -3%    |                                       |
| Total number of fuelings          | 499      | 3,174     | 5,457    | 11,490   | 15,877   | 22,837   | 31,493   | 38,089   | 108,296                               |
| % change over previous quarter    |          | ↑ +536%   | ↑ +72%   | ↑ +111%  | ↑ +38%   | ↑ +44%   | ↑ +38%   | ↑ +21%   |                                       |
| Average fueling quantity (kg)     | 2.4      | 2.6       | 2.9      | 2.8      | 3.0      | 3.0      | 3.1      | 3.1      | 3.07                                  |
| % change over previous quarter    |          | ↑ +6%     | ↑ +13%   | ↓ -3%    | ↑ +7%    | ↑ +0%    | ↑ +3%    | ↓ -1%    |                                       |
| Total hydrogen dispensed (kg)     | 1,212    | 8,195     | 15,946   | 32,528   | 48,168   | 69,512   | 98,259   | 117,749  | 333,688                               |
| % change over previous quarter    |          | ↑ +576%   | ↑ +95%   | ↑ +104%  | ↑ +48%   | ↑ +44%   | ↑ +41%   | ↑ +20%   |                                       |
| Maximum price of H70 (\$/kg)      | \$ 16.49 | \$ 16.63  | \$ 16.78 | \$ 16.78 | \$ 16.78 | \$ 16.78 | \$ 16.78 | \$ 16.89 |                                       |
| Minimum price of H70 (\$/kg)      | \$ 16.49 | \$ 10.00  | \$ 12.85 | \$ 12.85 | \$ 13.99 | \$ 9.99  | \$ 9.99  | \$ 9.99  |                                       |
| Sales-weighted price H70 (\$/kg)  | \$ 16.49 | \$ 14.51  | \$ 14.76 | \$ 14.99 | \$ 15.67 | \$ 15.72 | \$ 15.42 | \$ 15.93 | \$ 15.70                              |
| % change over previous quarter    |          | ↓ -12%    | ↑ +2%    | ↑ +2%    | ↑ +5%    | ↑ +0%    | ↓ -2%    | ↑ +3%    |                                       |
| Maximum price of H35 (\$/kg)      | \$ 16.49 | \$ 16.63  | \$ 16.78 | \$ 16.78 | \$ 16.78 | \$ 16.54 | \$ 16.78 | \$ 16.89 |                                       |
| Minimum price of H35 (\$/kg)      | \$ 16.49 | \$ 10.85  | \$ 10.85 | \$ 10.85 | \$ 11.99 | \$ 9.99  | \$ 9.99  | \$ 9.99  |                                       |
| Sales-weighted price H35 (\$/kg)  | \$ 16.49 | \$ 13.95  | \$ 13.15 | \$ 13.29 | \$ 14.03 | \$ 13.29 | \$ 12.88 | \$ 15.01 | \$ 13.84                              |
| % change over previous quarter    |          | ↓ -15%    | ↓ -6%    | ↑ +1%    | ↑ +6%    | ↓ -5%    | ↓ -3%    | ↑ +17%   |                                       |
| Sales-weighted price H2 (\$/kg)   | \$ 16.49 | \$ 14.47  | \$ 14.60 | \$ 14.93 | \$ 15.63 | \$ 15.69 | \$ 15.37 | \$ 15.92 | \$ 15.67                              |
| % change over previous quarter    |          | ↓ -12%    | ↑ +1%    | ↑ +2%    | ↑ +5%    | ↑ +0%    | ↓ -2%    | ↑ +4%    |                                       |

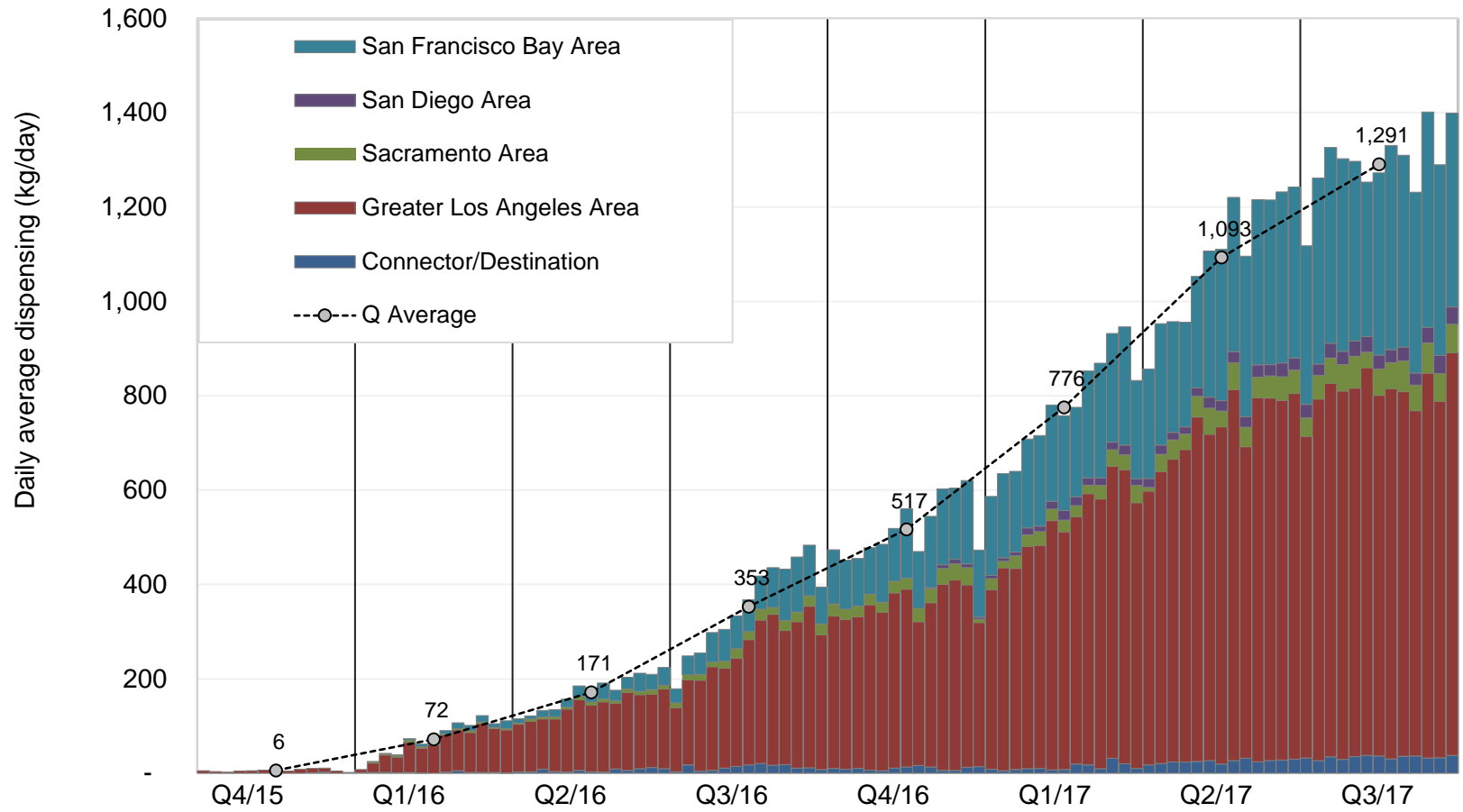
Source: NREL

## Weekly Dispensing and Utilization Trends

Figure D-1 shows daily hydrogen sales (kg/day), averaged weekly. The data are grouped by quarters and color coded by four regions (the Greater Los Angeles Area, the San Francisco Bay

Area, the Sacramento Area, and the San Diego Area), and there is a fifth category for the connector/destination stations (Coalinga, Truckee, and Santa Barbara). Furthermore, the average daily dispensing for each quarter is indicated by the dashed line. New FCEVs and the associated increased use over time are the main reasons for the recent strong positive trend. This figure shows the total fuel dispensed at both H70 and H35 pressures. The trend shows a strong growth in fuel demand, building on consistent growth in previous quarters. At the end of Q3 2017, demand for hydrogen fuel was 1,291 kg/day. There is significant noise in data from week to week, possibly due to the relatively small size of the market and the low statistical averaging. Also, any station down time may induce significant variations in fueling trends, as relatively few stations are on-line. Dips in demand are also visible in the last weeks of data for Q3 2016, Q4 2016, and Q1 2017. These may be features of data-gathering consistency relative to the cutoff dates of the quarters. On average, demand for fuel in Q1 2017 was 776 kg/day and in Q3 2017 was 1,291 kg/day. This represents a growth of 66 percent. The growth trend for the last five quarters has been mostly linear with a slight acceleration. The growth rate of demand has been roughly 200 kg/day each quarter. If this trend continues, demand would double in the subsequent five quarters or less.

**Figure D-1: Weekly Hydrogen Dispensing by Region, H70 and H35**

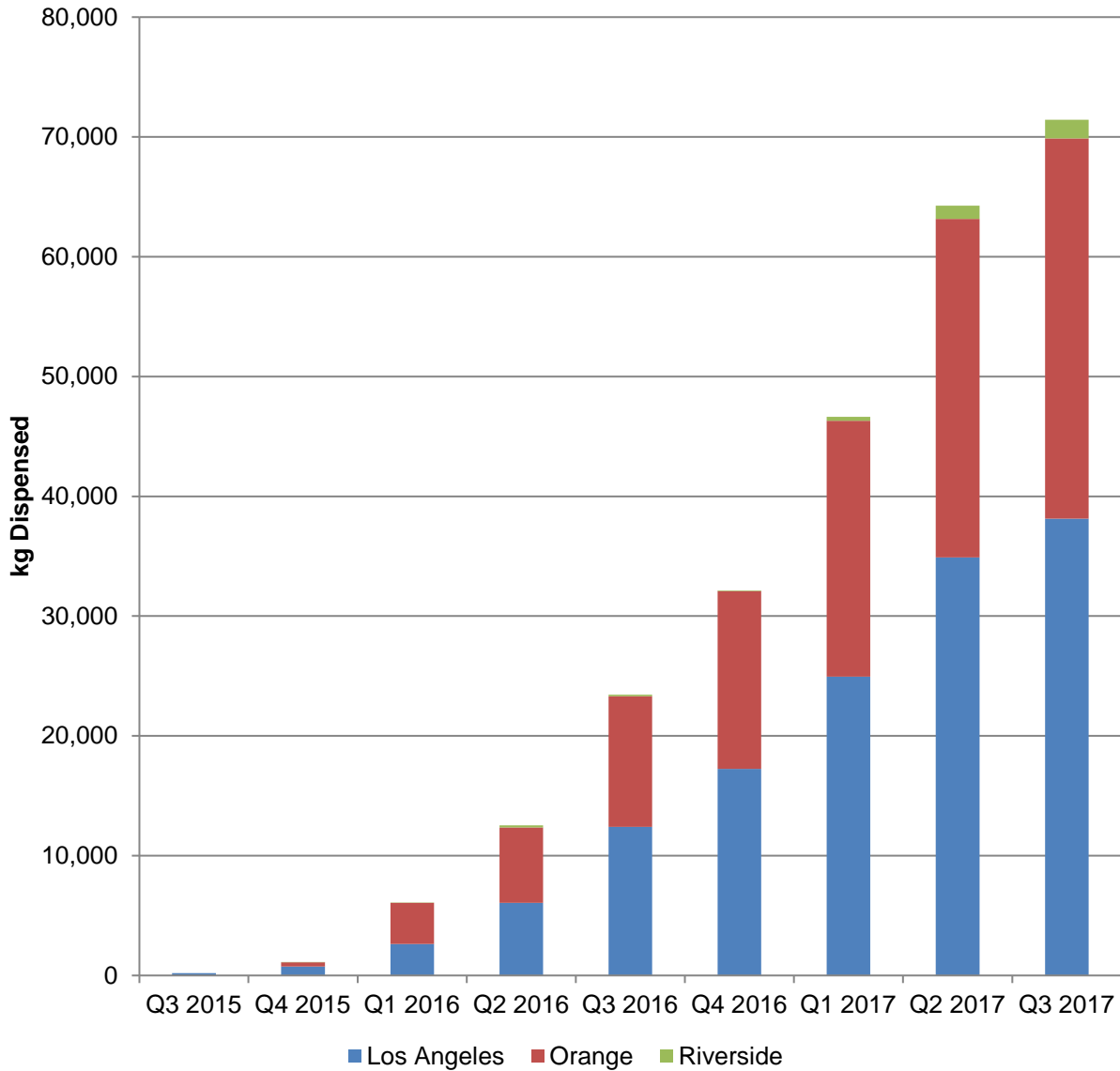


Source: NREL

## Regional Dispensing

The following four figures show quarterly dispensed kilograms by county in the four regions – the Greater Los Angeles Area, the San Francisco Bay Area, the Sacramento Area, and the San Diego Area. Figure D-2 shows the quarterly kilograms dispensed in the Greater Los Angeles Area. Each county in the area with hydrogen refueling stations has experienced a steady increase of kilograms dispensed each quarter. The total amount of hydrogen dispensed throughout Q3 2017 was 71,000 kg. This displaced about 177,500 gallons of gasoline in the Greater Los Angeles Area.

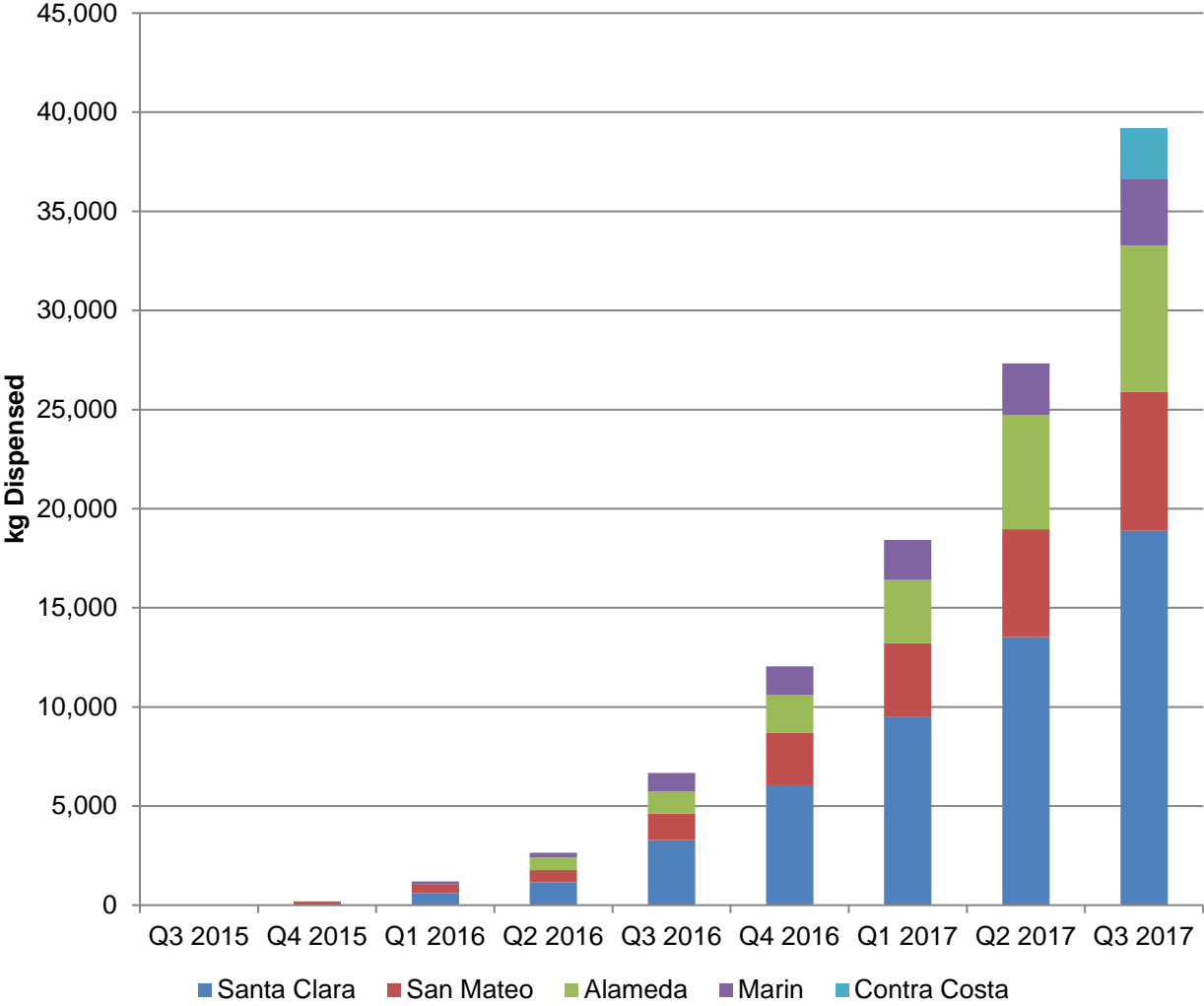
**Figure D-2: Greater Los Angeles Area Fueling Trends by County**



Source: CEC

Figure D-3 shows the quarterly kilograms dispensed in the San Francisco Bay Area. Each county experienced a steady increase of kilograms dispensed each quarter, with most fuel dispensed in Santa Clara County. The total amount of hydrogen dispensed in the area over Q3 2017 was 39,000 kg. This amount displaced about 97,500 gallons of gasoline in the San Francisco Bay Area.

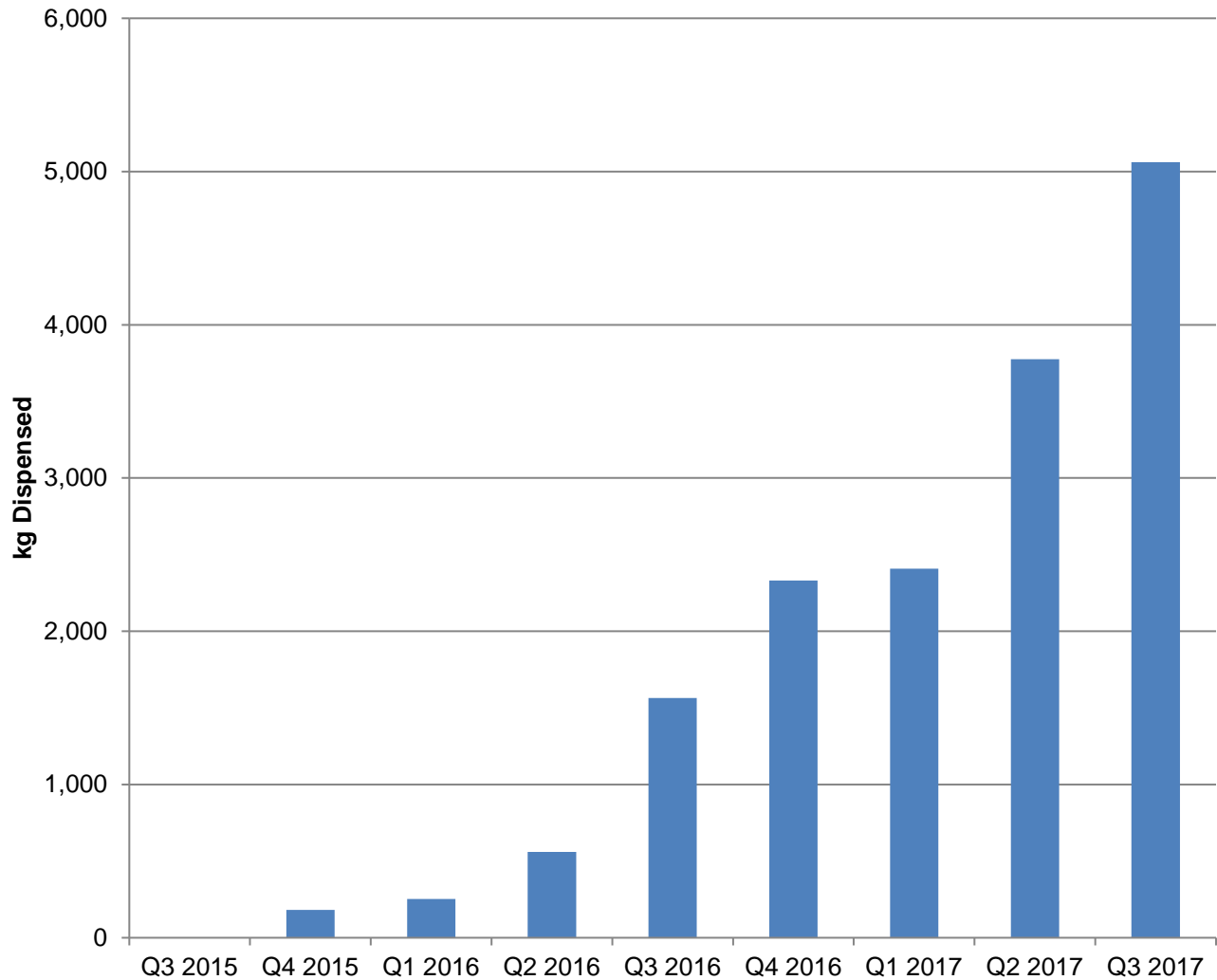
**Figure D-3: San Francisco Bay Area Fueling Trends by County**



Source: CEC

Figure D-4 shows the quarterly kilograms dispensed in the Sacramento Area. All fueling events have occurred in Yolo County since the Sacramento Area has just one open retail hydrogen refueling station in West Sacramento. Fuel dispensed has increased each quarter with the total amount of hydrogen dispensed in the area over Q3 2017 reaching just over 5,000 kg. This displaced about 12,500 gallons of gasoline in the Sacramento Area.

**Figure D-4: Sacramento Area Fueling Trends**

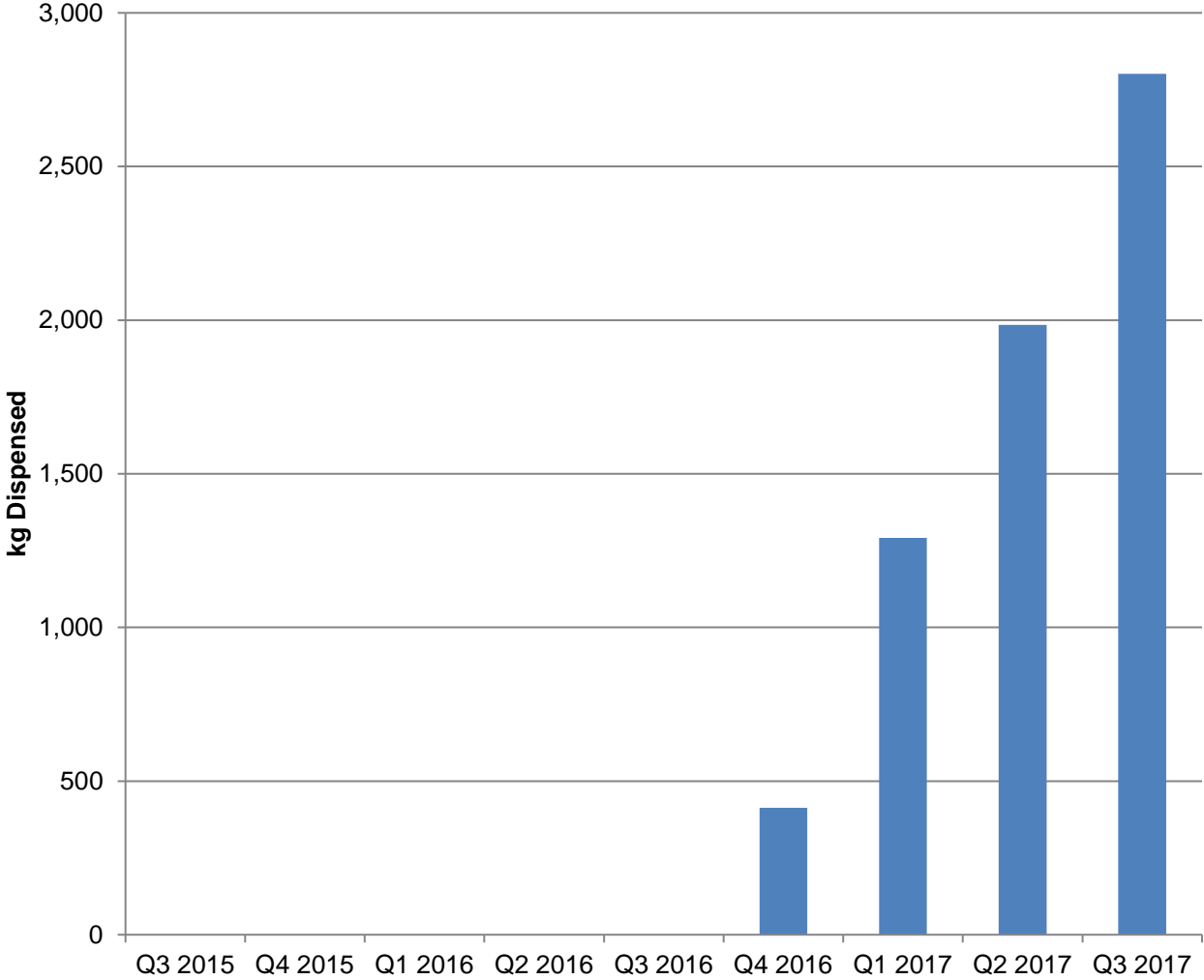


Source: CEC



Figure D-5 shows the quarterly kilograms dispensed in the San Diego Area. All fueling events have occurred in San Diego County since the San Diego area has just one open retail hydrogen refueling station. Fuel dispensed has increased each quarter with the total amount of hydrogen dispensed in the area throughout Q3 2017 reaching 2,800 kg. This amount displaced about 7,000 gallons of gasoline in the San Diego Area.

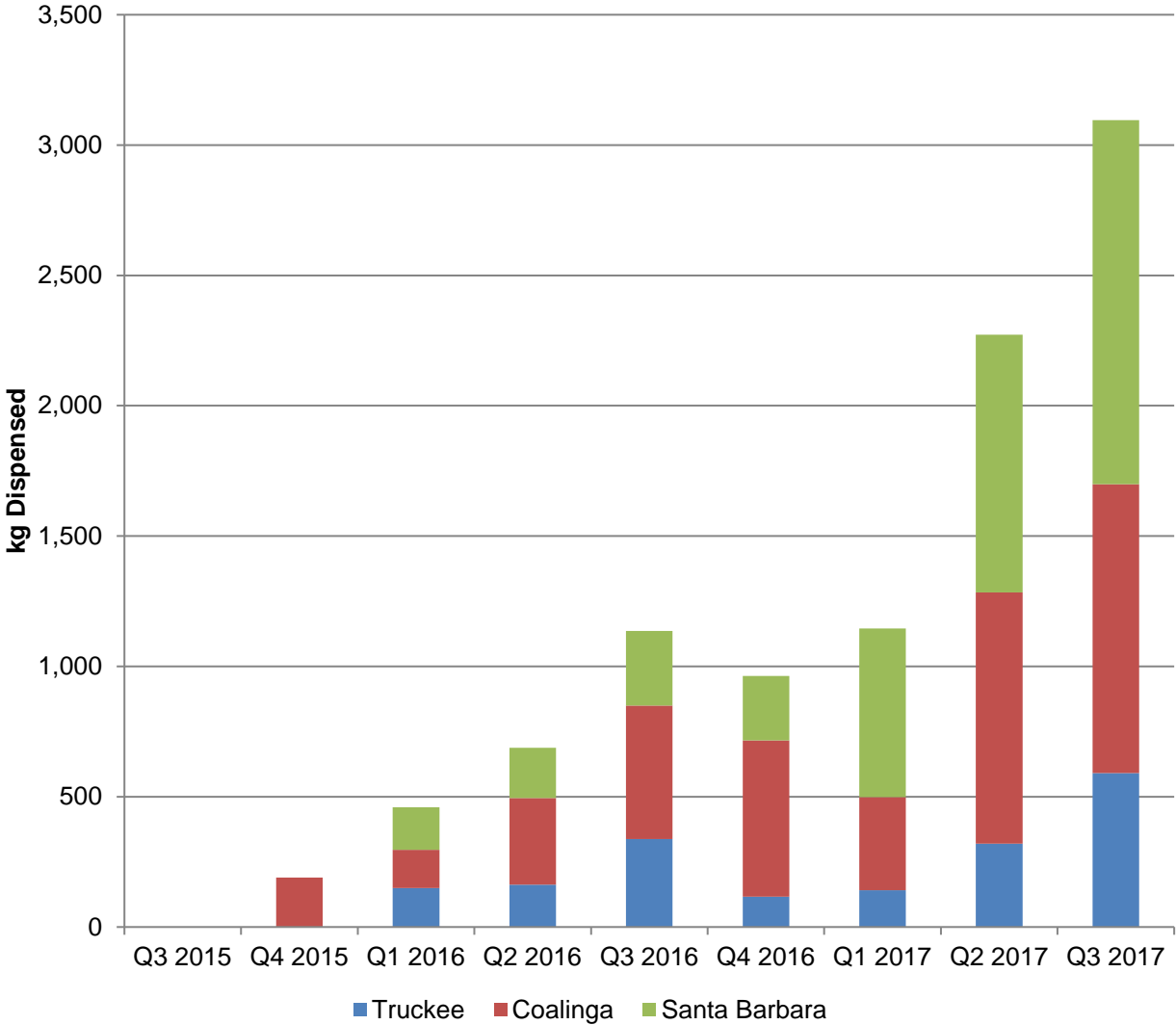
**Figure D-5: San Diego Area Fueling Trends**



Source: CEC

Figure D-6 shows the quarterly kilograms dispensed at each of the three connector stations. The total fueling dispensed has fluctuated each quarter. This fluctuation is expected because, by definition, the connector and destination stations are not expected to have the steady business of a core market. Rather, these stations depend mostly on recreational and other long-distance travel that is more irregular than typical commute travel. Of note is the growing demand in Santa Barbara, which may indicate that the number of local customers is growing such that this station could be moving toward more regular demand growth like that of a core market station. The total amount of hydrogen dispensed at each of the three stations during Q3 2017 is 3,100 kg. This amount displaced about 7,750 gallons of gasoline.

**Figure D-6: Connector Station Fueling Trends by Station**

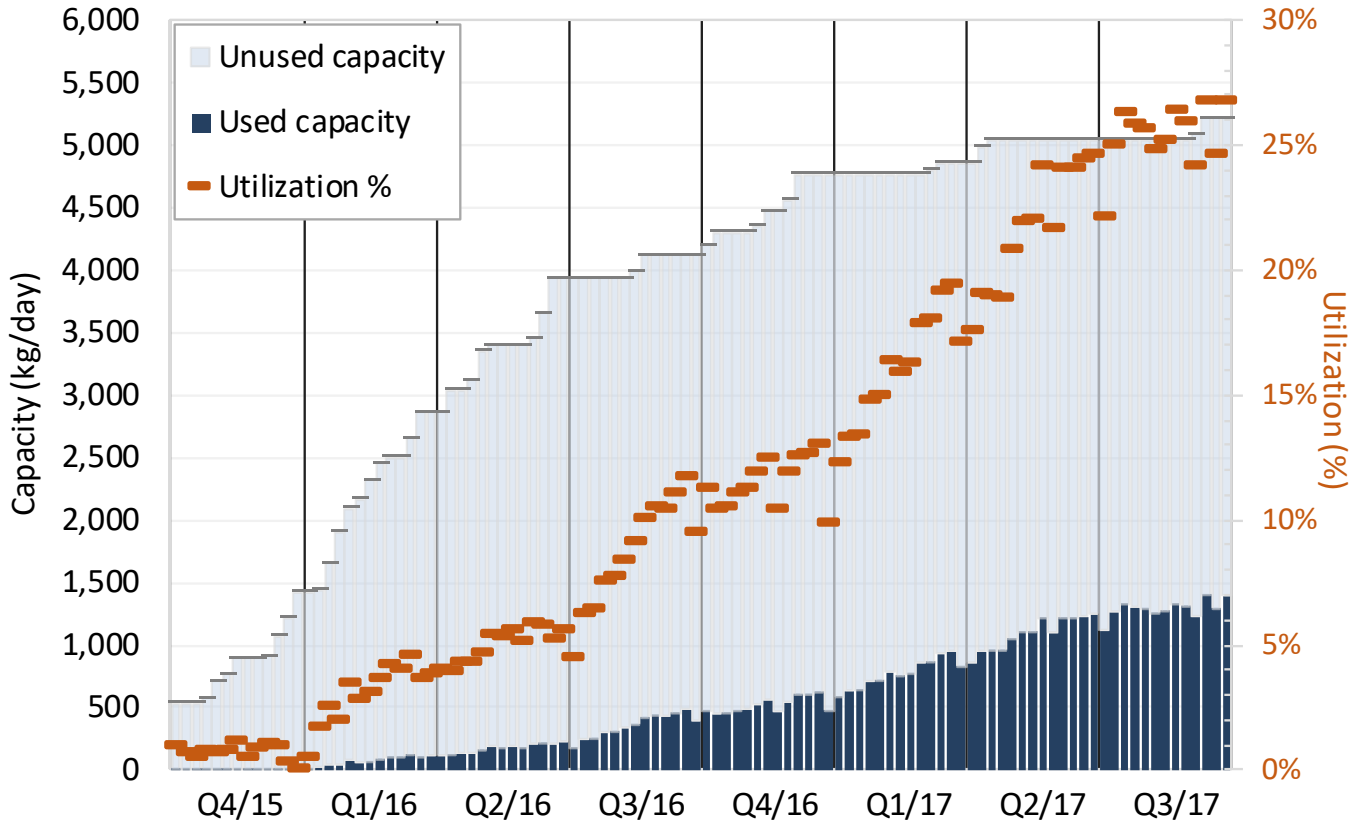


Source: CEC

## Utilization

Figure D-7 shows weekly average capacity of the network and utilization of the increasing number of open retail stations. Both demand and capacity have grown in each of the last eight quarters. Demand is growing at a faster pace, which yields an increasing utilization trend over time. If this trend continues, demand may outstrip capacity. As demand nears dispensing capacity limitations, and without appropriate and ongoing planning for network expansion, growth in FCEV market penetration could be limited by infrastructure capacity.

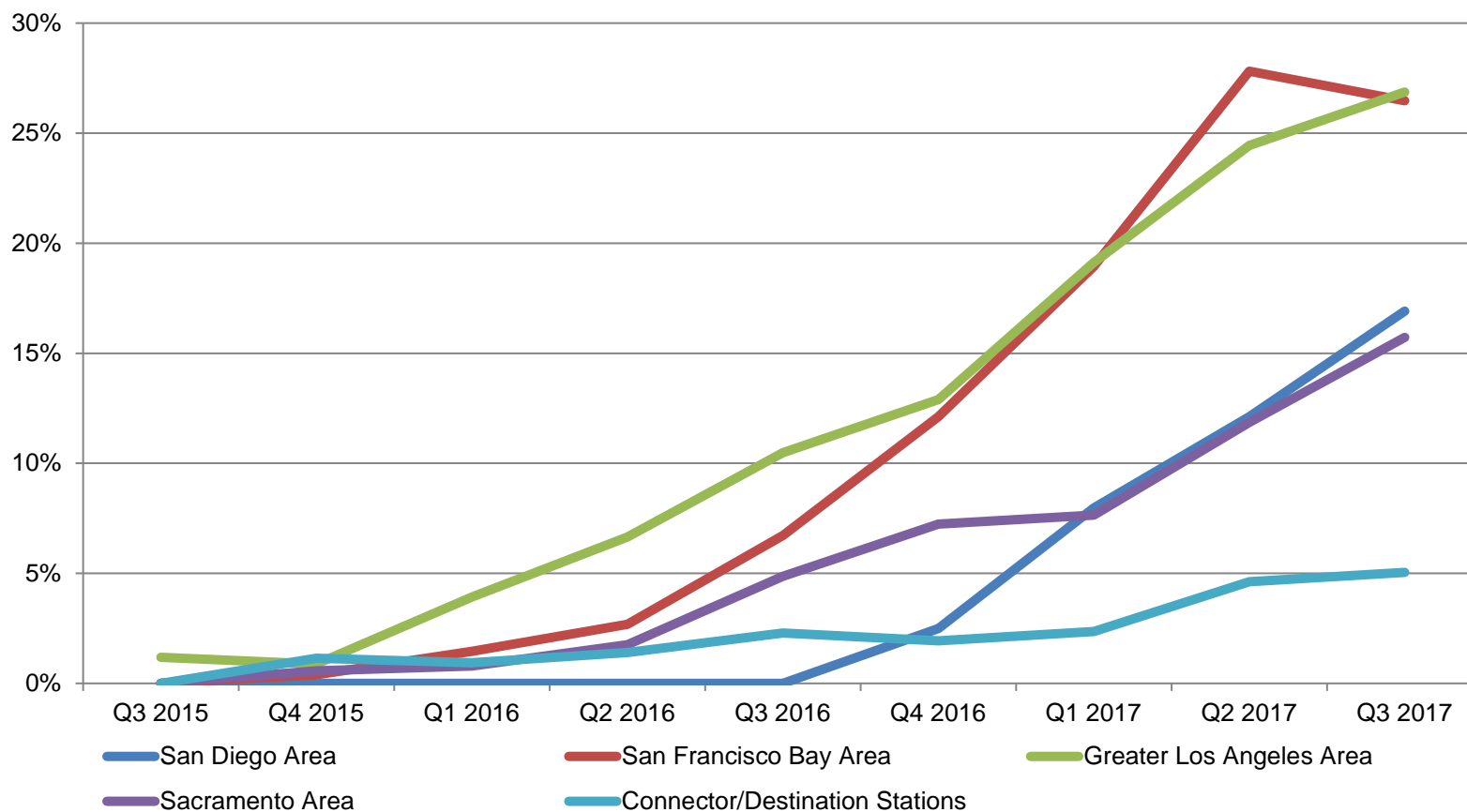
**Figure D-7: Weekly Average Network Capacity and Utilization**



Source: NREL

Figure D-8 shows utilization trend by geographical region. In the Greater Los Angeles Area, the use is up to about 27 percent, and in the San Francisco Bay Area, the use is 26 percent. In the Sacramento and San Diego areas, the station use is similar in Q3, around 16 percent use. The connector use is 5 percent. There was a slight drop in utilization for Q3 2017 in the San Francisco Bay Area due to the San Ramon and Fremont stations becoming open retail, which added 530 kg/day in total capacity for the area.

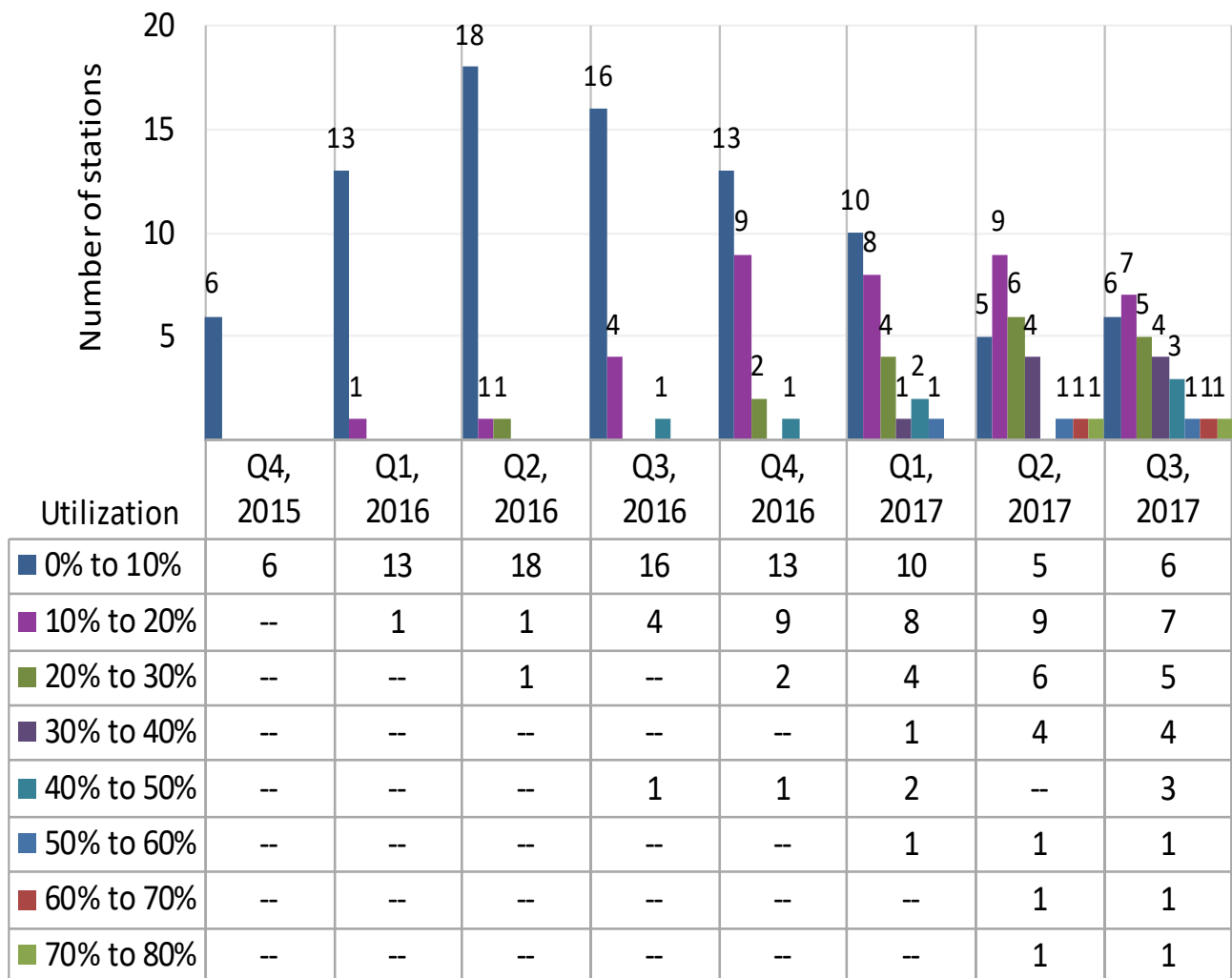
**Figure D-8: Regional Utilization Trend**



Source: CEC

Figure D-9 summarizes the utilization of each station based on the quarterly average kilograms dispensed relative to the nameplate capacity of the station (dispensed kg/capacity kg). Station count by quarterly average utilization is shown in 10 percent data buckets. All stations are increasing in utilization; this analysis in 2016 Joint Report spanned stations up to 45 percent utilization. Some stations are performing significantly better than average. Some stations show higher utilization growth due to being smaller, and some stations have higher utilization growth due to faster increase in sales. As most open retail stations have a capacity of 180 kg/day, the results above highly reflect actual differences in demand growth. In Q3 2017, two stations are already operating near full capacity, with one station squarely in the 70-80 percent utilization range. This is significant from the point of view of technology demonstration in that stations are showing capability of dispensing hydrogen in line with the associated stated nameplate capacity. As some stations are experiencing higher growth in demand than others, capacity shortage would be expected at these stations ahead of the average for the network.

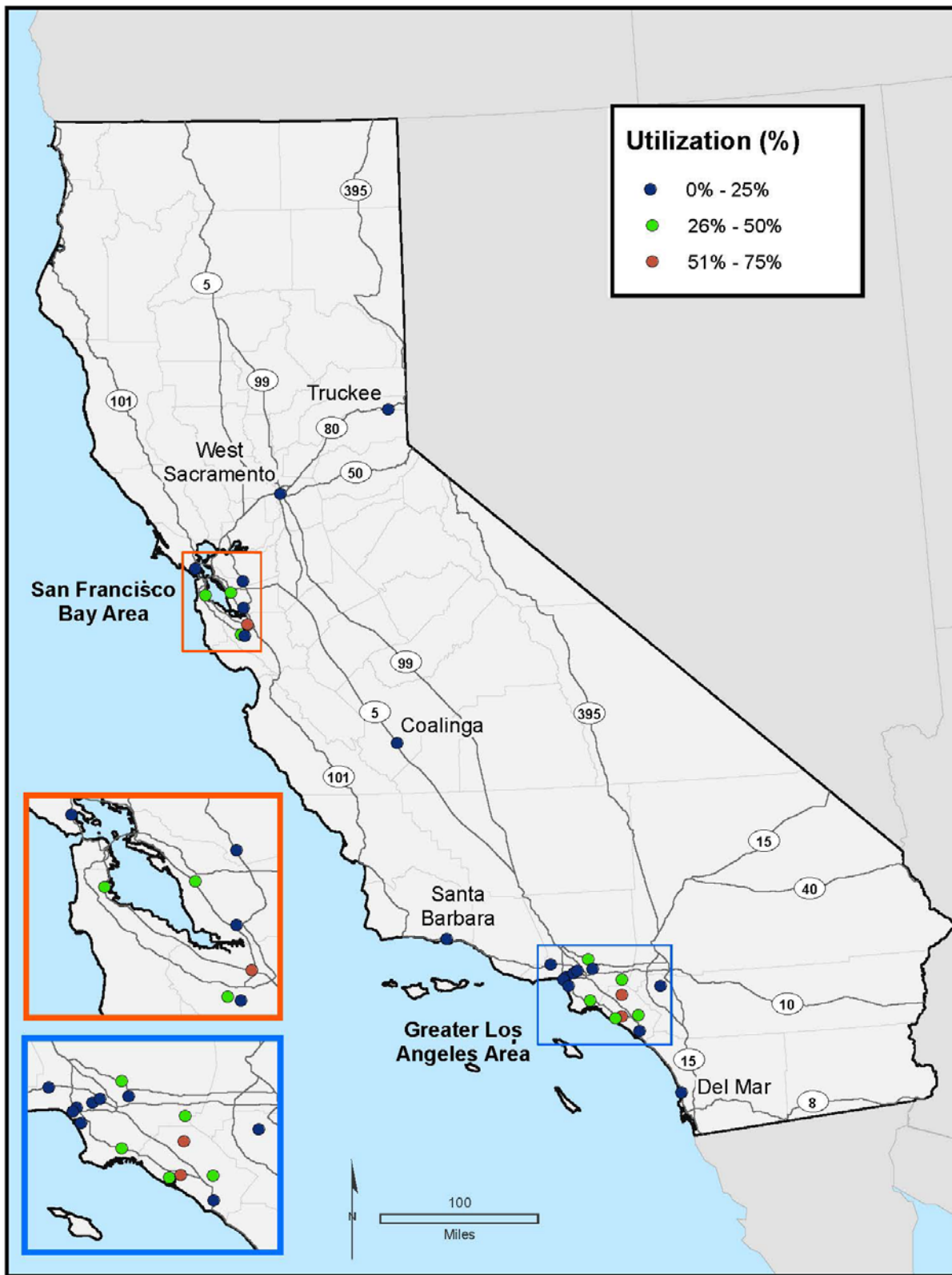
**Figure D-9: Station Count by Average Quarterly Utilization**



Source: NREL

Figure D-10 shows a map of station utilization percentages for each of the stations in Q3 of 2017.

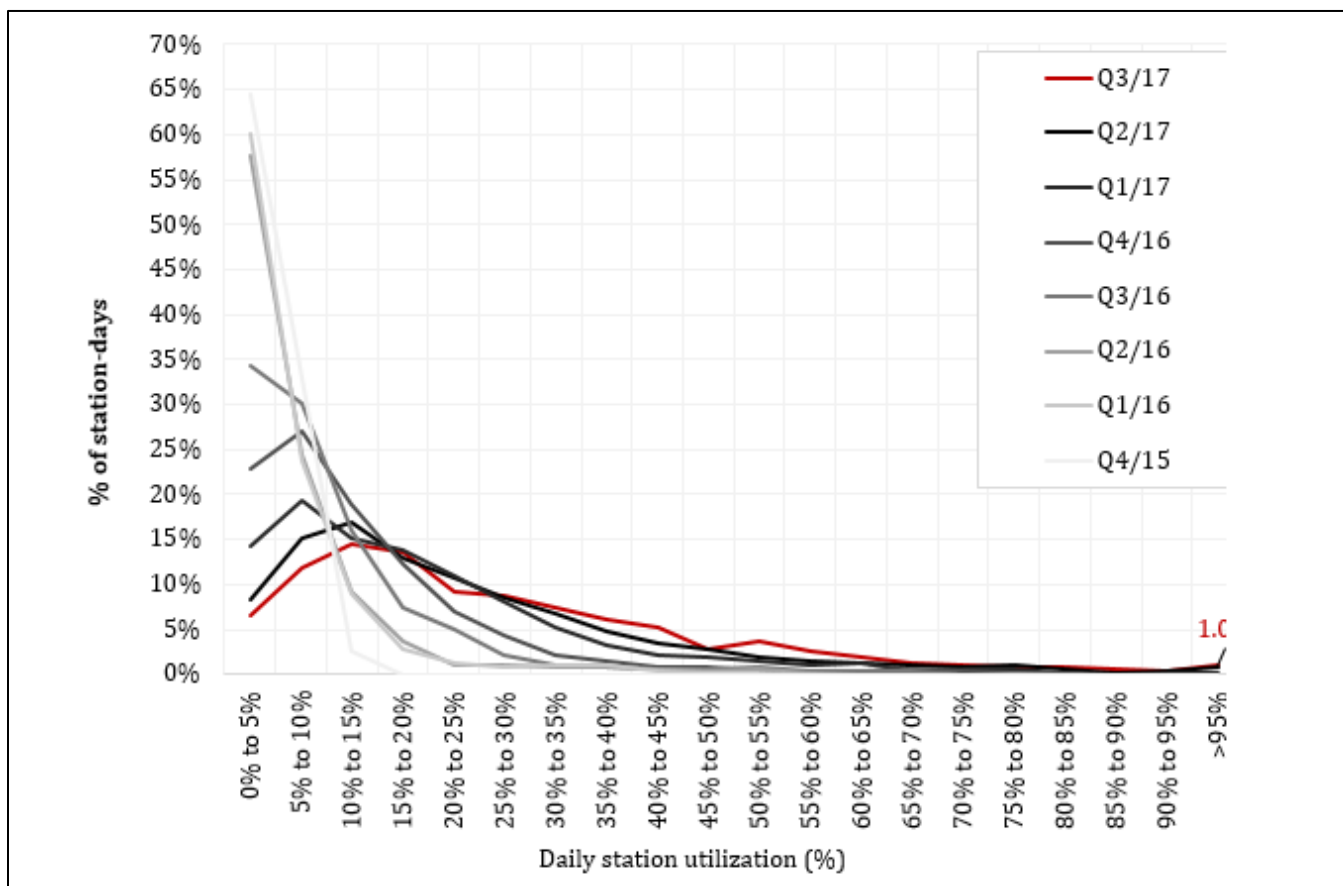
**Figure D-10: Station Utilization in Q3 of 2017**



Source: CEC

Figure D-11 shows the distribution of daily utilization across the network according to the number of days that each station operated within the indicated utilization ranges. The most recent quarter's data are shown in red, and growth over the prior seven quarters can be assessed by comparing this red-colored distribution to the seven prior quarters' distributions shown in various shades of gray. Based on these trends, stations are experiencing fewer extreme low-utilization days than in previous quarters and more mid- to high-utilization days. In addition, the peak (most common) utilization is shifting to the right, indicating the median station utilization has been steadily increasing over the past seven quarters. Some stations experience days with utilization of 95 to 100 percent. In Q3 2017, 0.9 percent of the station-days were spent at the nameplate capacity of the stations. Such high-demand days appear to be becoming more frequent as demand grows. The likelihood of such high demand days is still low, and station operators would have flexibility to refill their storage on a subsequent day. However, as total demand grows, the probability of back-to-back peak demand days will increase and further challenge resupply schedules and nameplate capacities of the stations.

**Figure D-11: Percentage of Station-Days by Utilization Rate**



Source: NREL

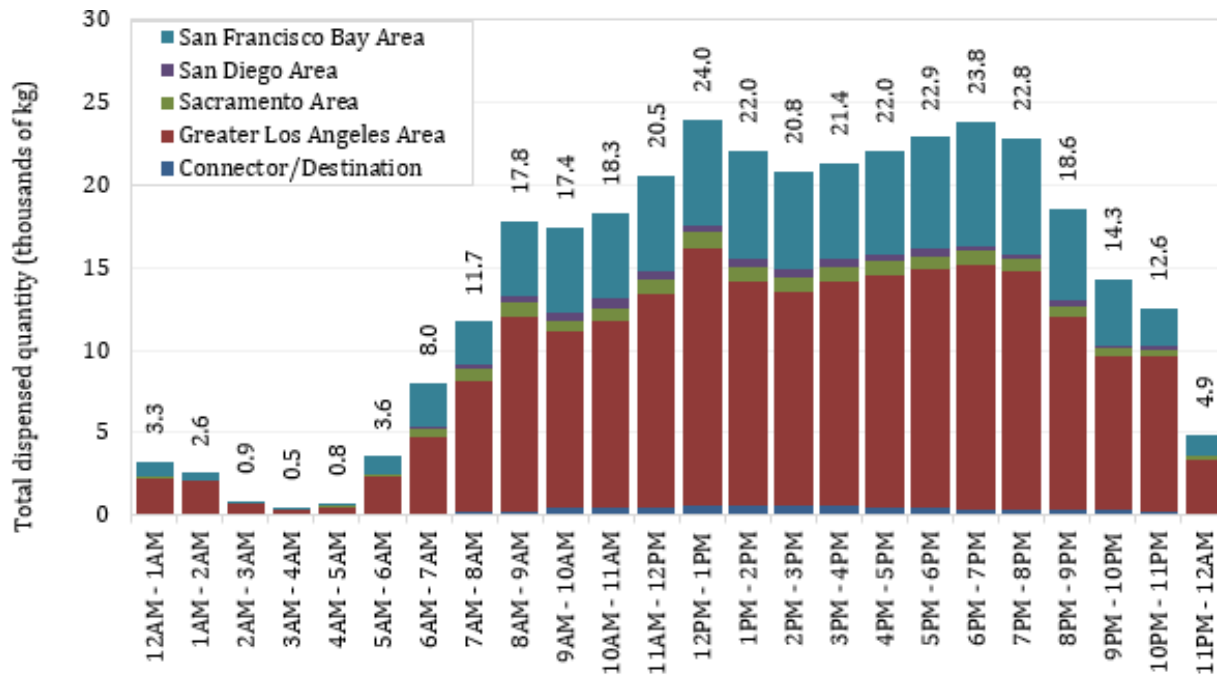
## Time-of-Day and Day-of-Week Trends

Figures D-12 through D-15 use data from Q4 2016 to Q3 2017 to focus on recent trends.

Figure D-12 shows that demand varies by time of day. The data are from all dispensing, both H35 and H70. This information may guide appropriately sizing station compressor and cascade storage to accommodate back-to-back refueling during peak hours.

As shown in Figure D-12, demand is highest during midday hours and could potentially lead to congestion if the FCEV rollout is not supported by sufficient refueling infrastructure development. Without coordinated development, there is a risk that the refueling network will become dominated by stations with excessively high demand, leaving customers to wait in line for fuel. The station developer is responsible for the station fueling plan that includes station refill based on demand. The time-of-day fueling pattern shown below is different from what is typically observed for gasoline refueling. Peak times are expected to be in the early morning and late afternoon on weekdays, when the majority of people are going to or coming home from work.<sup>47</sup> Therefore, the time-of-day pattern shown in Figure D-12 may change as the FCEV market continues to expand.

**Figure D-12: Total Cumulative Dispensing and Time of Day by Region (H70 and H35)**



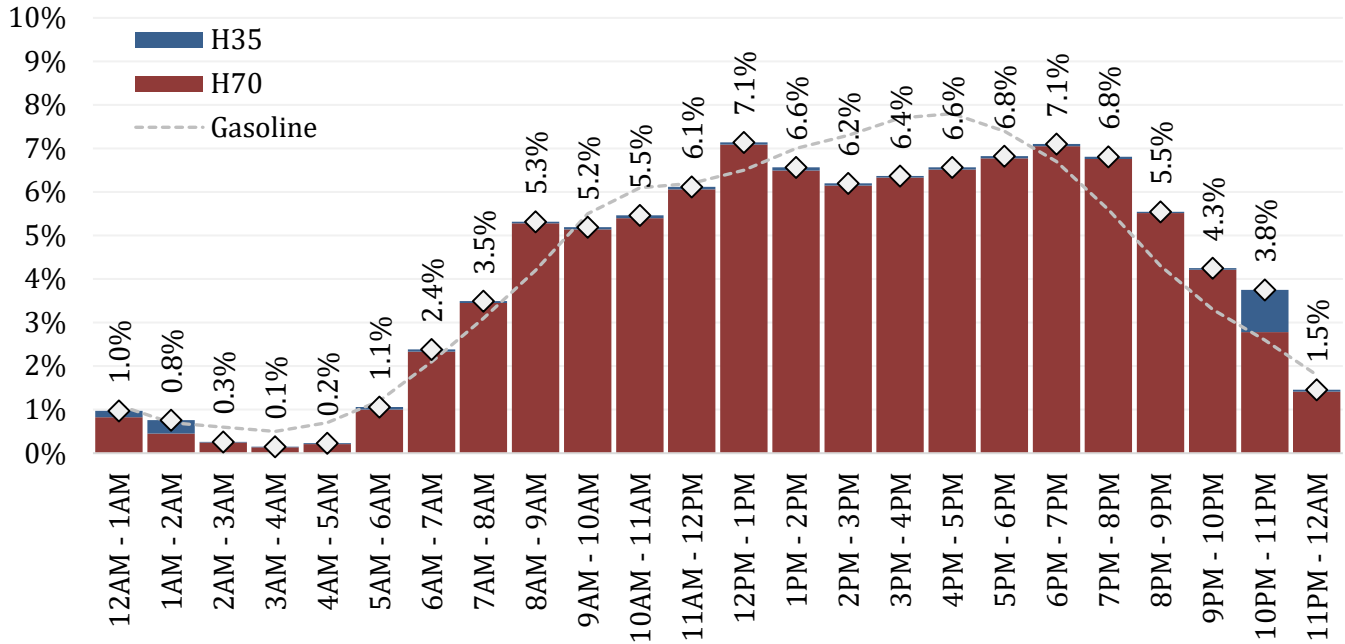
Source: NREL

<sup>47</sup> Chen, Tan-Ping. *Final Report: Hydrogen Delivery Infrastructure Options Analysis*. Nexant. DOE Award Number: DE-FG36-05GO15032. p. 53. ([http://energy.gov/sites/prod/files/2014/03/f11/delivery\\_infrastructure\\_analysis.pdf](http://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf))



Figure D-13 tracks the H70 and H35 fueling events across the network by time of day. Compared to previous years' daily profiles, demand for morning and evening fueling has grown. In the past, demand peaked during the afternoon, and now demand is close to being flat throughout the daytime. It is expected that growth for fuel demand will continue to grow especially in the late afternoon in accordance with consumer preference for fueling with gasoline. This figure shows consistent low station utilization between 1 a.m. and 6 a.m., which may provide station operators with time for maintenance with the least disruption to sales.

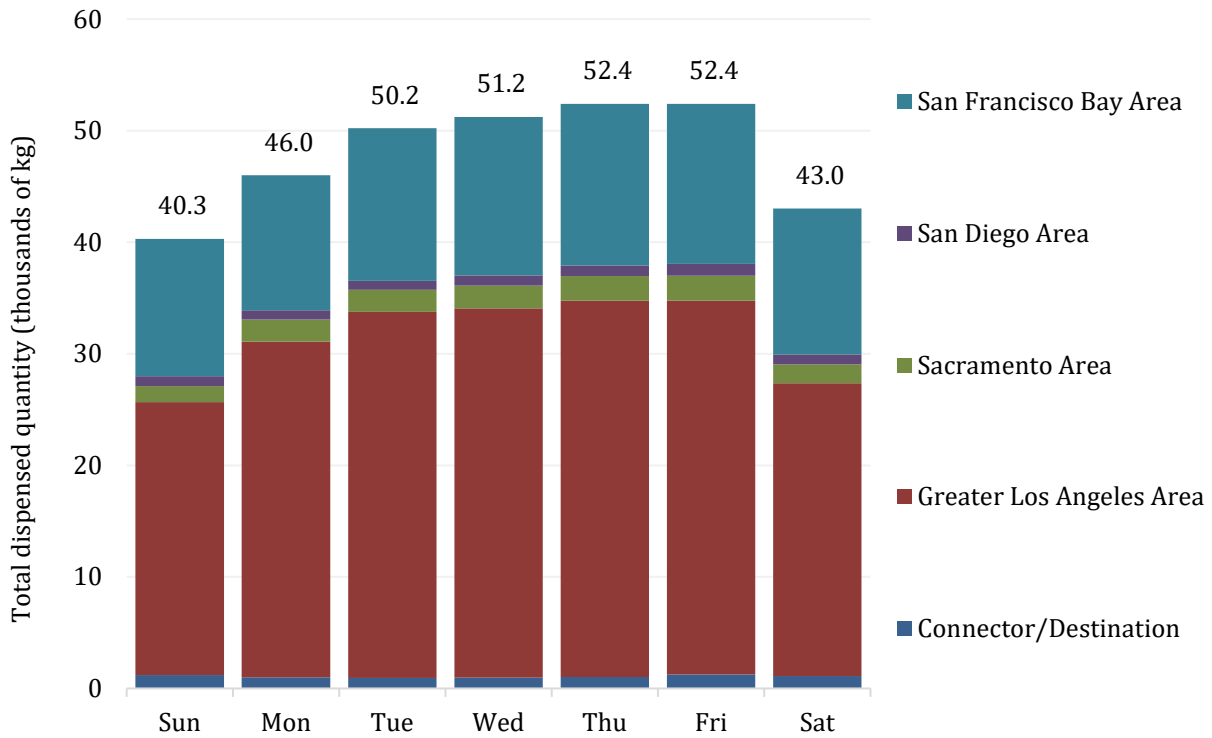
**Figure D-13: Fueling Events by Time of Day**



Source: NREL

Figure D-14 shows the variation in dispensing by day of week. On average, weekends have lower demand, with total dispensing about 10,000 kilograms less than on weekdays. In the figure below, dispensing is shown in total; this may help station developers select appropriate equipment to handle daily demand.

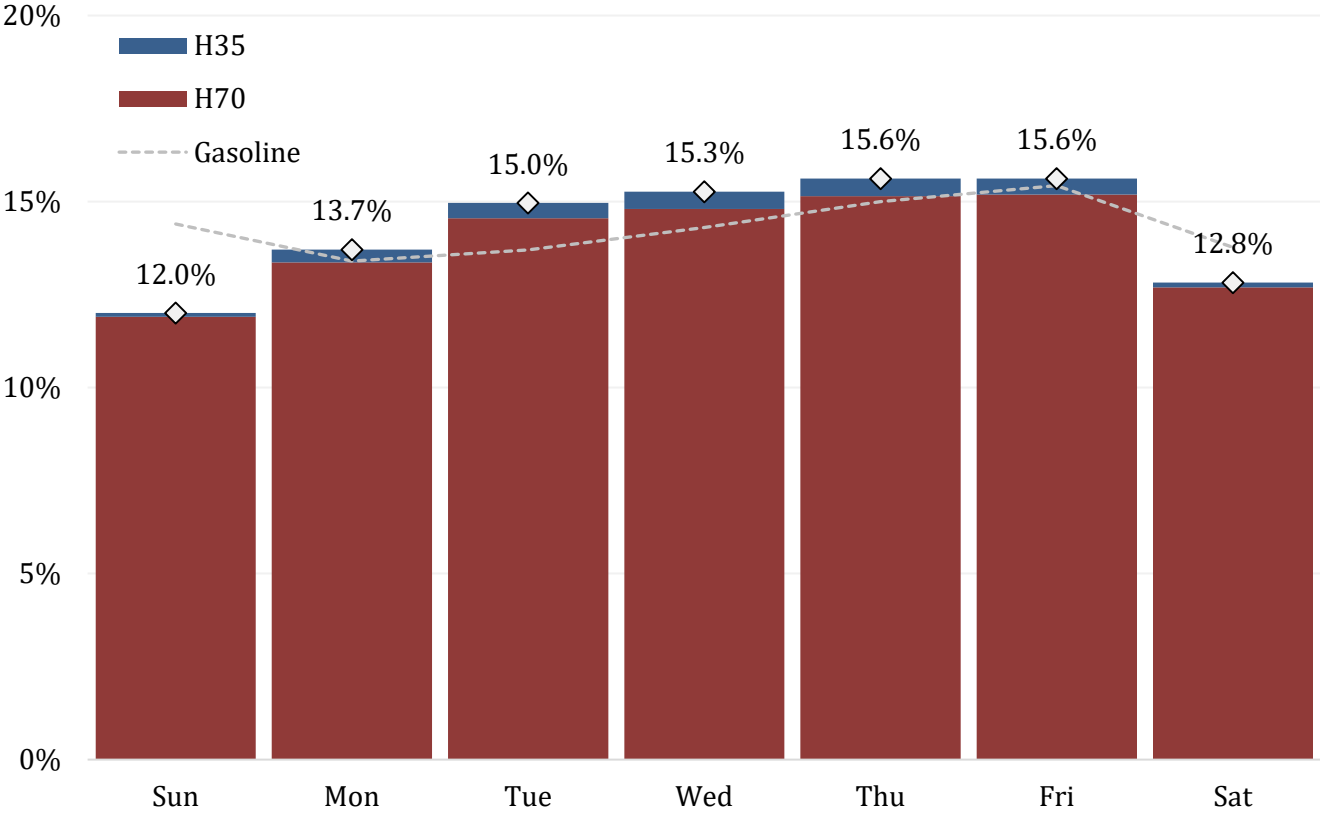
**Figure D-14: Total Cumulative Dispensing by Day of Week by Region (H70 and H35)**



Source: NREL

Figure D-15 tracks the H70 and H35 fueling events across the network by day of week. FCEVs fuel predominantly during the week instead of the weekend. These FCEVs are likely used by first adopters for commuting and running errands during the work week. A common notion is that H35 demand would be countercyclical to H70 demand, meaning as H70 use increases, H35 fuel decreases. However, data show that the two demands coincide, meaning demand exists for both, and trends appear similar. Fueling of light-duty vehicles occurs more so during the week than weekends, and fueling for H35 – including commercial and heavier vehicles – predominates during the week. This provides for little weekly benefit of leveraging fueling assets by serving both H35 and H70. Moreover, H35 fueling requires different equipment and may not provide exclusively higher utilization to H70 assets.

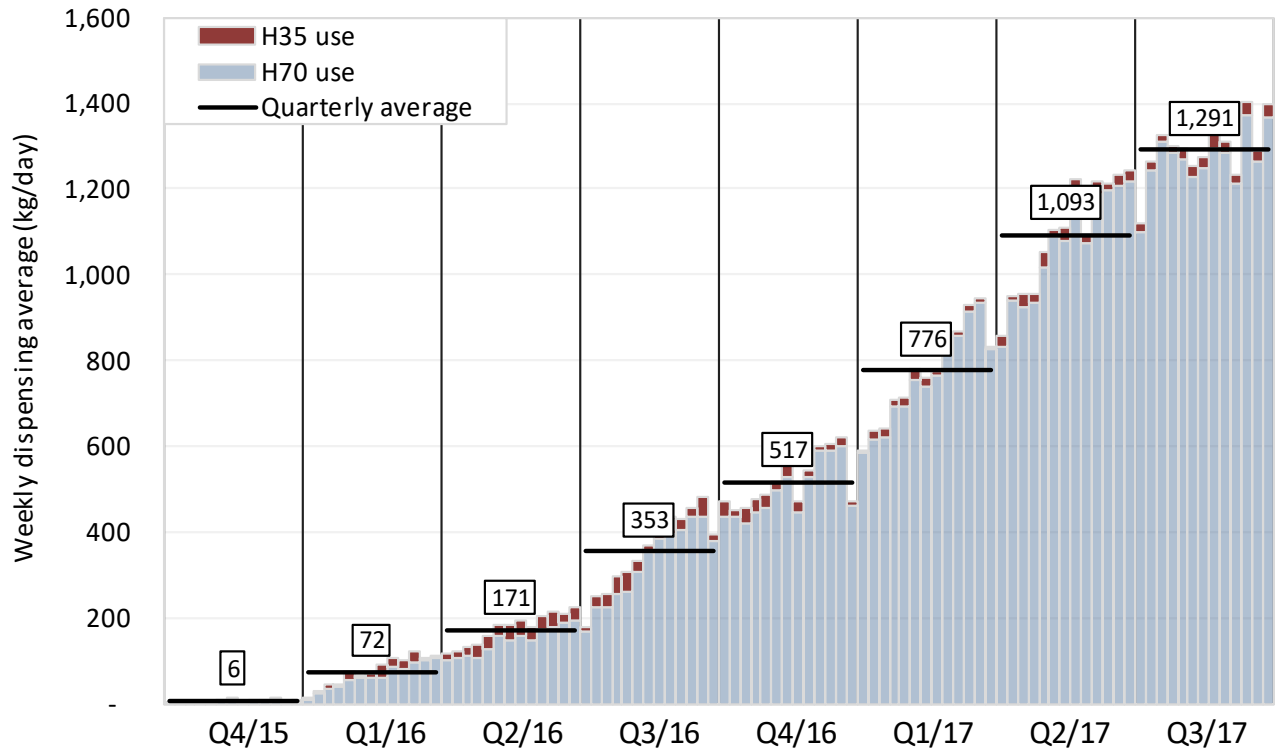
**Figure D-15: Fueling Events by Day of Week**



Source: NREL

Figure D-16 compares the weekly average dispensing at pressures of H70 and H35. The overall network, on average, fueled H70 98 percent of the time toward the end of Q1 2017. The latest funding solicitation, GFO-15-605, requires applicants to provide H70 fuel; H35 is optional. While demand for H70 has continued to grow in recent quarters, demand for H35 has declined.

**Figure D-16: Weekly Average Dispensing at H70 and H35**



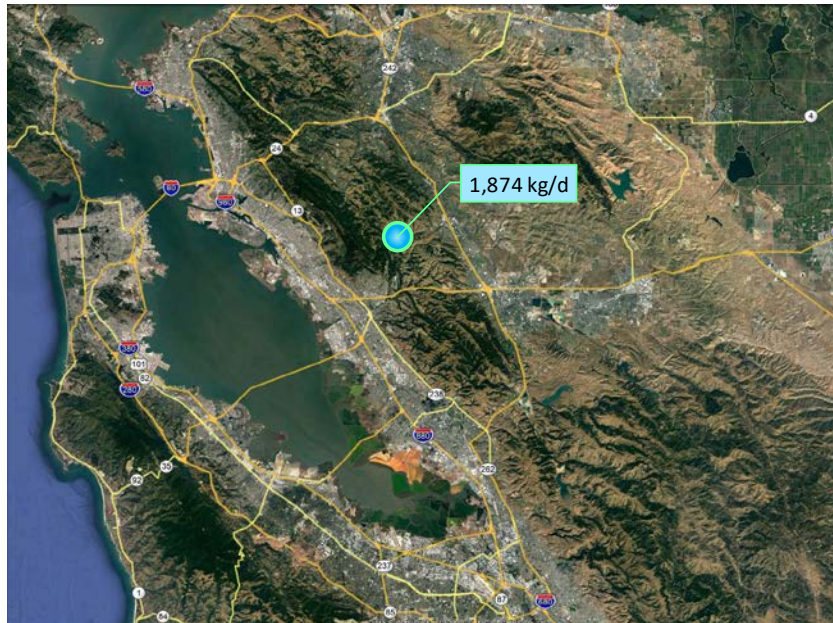
Source: NREL

## Renewable Hydrogen Production Analysis

Cluster analysis was conducted to determine geographic centers of mass based on growth in FCEV fueling demand. Renewable hydrogen production facilities (1,000 kg/day) are considered as meaningful in terms of economies of scale and capable of providing renewable hydrogen for fuel blends conforming to the 33 percent renewable requirements of Senate Bill 1505 and CEC grant agreements. The analysis was done for both Northern California and Southern California, assuming 80 percent utilization rate for all ARFVTP-funded stations, excluding the connector/destination stations (Coalinga, Santa Barbara, and Truckee).

For Northern California, Figure D-17 shows that the mathematically optimal location is in Alameda County. The total amount of hydrogen dispensed at stations in Northern California is assumed to be 5,680 kg/day (80 percent of the nameplate capacity). With the 33 percent renewable hydrogen requirement, 3,030 kg/day of total sales are required to justify a 1,000 kg/day 100 percent renewable hydrogen production facility. The current network in Northern California justifies a 1,000 kg/day facility and could benefit from up to a 1,874 kg/day facility.

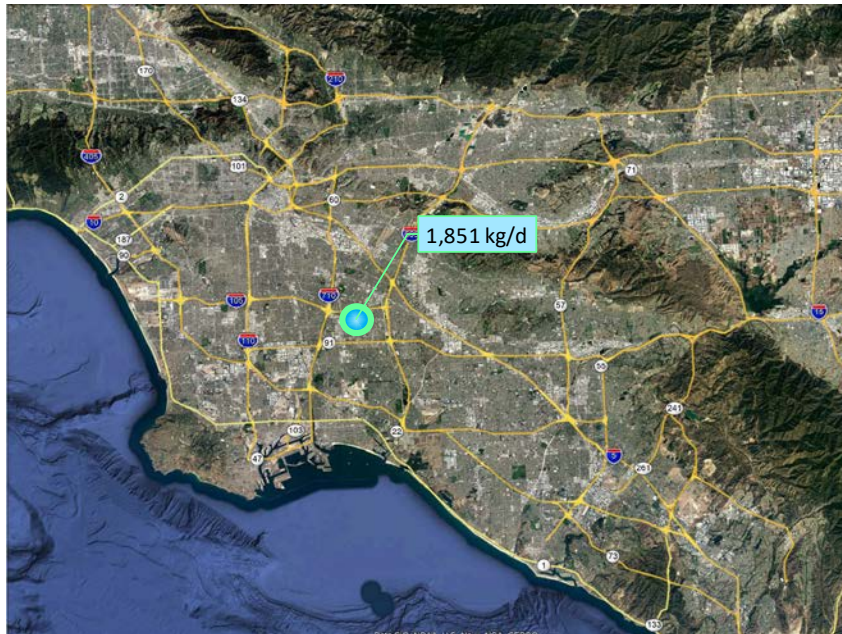
**Figure D-17: North Cluster Sales-Weighted Geographic Center (Demand Center-of-Mass Basis)**



Source: NREL

For Southern California, Figure D-18 shows that the mathematically optimal location is near Paramount in Los Angeles County. The total amount of hydrogen dispensed at stations in Southern California is assumed to be 5,608 kg/day (80 percent of nameplate capacity). The current network in Southern California justifies a 1,000 kg/day facility and could benefit from up to a 1,851 kg/day facility.

**Figure D-18: South Cluster Sales-Weighted Geographic Center (Demand Center-of-Mass Basis)**



Source: NREL

# APPENDIX E: Safety Planning, Codes and Standards, and Station Size

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Local land-use ordinances and state, national, and international safety codes and standards govern aspects of hydrogen refueling station design. These codes and standards in many ways dictate where a station can be built and how a station is designed. This appendix discusses some of the newer developments in safety planning, including a summary of the safety planning components of the most recent hydrogen refueling station solicitation, GFO-15-605.

This appendix also provides updated information on the amount of space (or the *footprint*) needed for the components of a hydrogen station, based on information provided by station developers in their applications for GFO-15-605. The fact that proposed station footprints continue to shrink indicates that station developers are finding technical solutions that satisfy safety code requirements and promote more space-efficient equipment design and/or reduce the required setbacks.

## Safety Plan Development and Review

When a hydrogen station is designed, an essential part of the design is a safety plan. A good safety plan consolidates and integrates relevant experience from the operation of other stations and draws from long-term experience in closely related technologies.

In 2016, the GFO-15-605 requested proposals to develop hydrogen stations. A safety plan was required and evaluated for each hydrogen refueling station proposal to ensure that all funded stations would include the latest best practices in the related safety plans. The expertise behind these evaluations was supplied by the Hydrogen Safety Panel of the Pacific Northwest National Laboratory, which has been involved with hydrogen-related projects for the U.S. Department of Energy since 2003. The three main roles of the panel in this process are to consult for the developers to help them formulate their safety plans, to evaluate the submitted safety plans, and to periodically inspect the stations during development and advise the developers of any safety considerations that are identified.

In March 2016, the Hydrogen Safety Panel published *Safety Planning for Hydrogen and Fuel Cell Projects*.<sup>48</sup> This planning document included a comprehensive guideline for hydrogen station developers to consider and was integrated into GFO-15-605 as an example to follow. Critical topics included in the GFO-15-605 safety plan evaluation included the following aspects that the public may review:

1. Scope of Work for the Safety Plan
2. Organizational Safety Information
  - Organizational Policies and Procedures
  - Hydrogen and Fuel Cell Experience
3. Project Safety

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<sup>48</sup> Pacific Northwest National Laboratory. [Safety Planning for Hydrogen and Fuel Cell Projects](https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-March_2016.pdf). March 2016. ([https://h2tools.org/sites/default/files/Safety\\_Planning\\_for\\_Hydrogen\\_and\\_Fuel\\_Cell\\_Projects-March\\_2016.pdf](https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-March_2016.pdf))

- Identification of Safety Vulnerabilities (ISV)
  - Risk Reduction Plan
  - Operating Procedures
  - Equipment and Mechanical Integrity
  - Management of Change (MOC) Procedures
4. Communications Plan
- Training
  - Safety Reviews
  - Safety Events and Lessons Learned
  - Emergency Response
  - Self-Audits

The Hydrogen Safety Panel used its collective experience to evaluate the completeness of submitted safety plans. The review document was used by GFO-15-605 evaluation team during proposal scoring.<sup>49</sup> The review document contained background, summary of results, and detailed comments, followed by a scoring rubric. The evaluation rubric shows whether safety plans adequately addressed specific safety topics. Developers may use their specific reviews to evaluate what information, processes, and documentation may be required for safe operation of a hydrogen refueling station. Although this review gathered the experts in hydrogen refueling technology, the industry is developing quickly, and safety should always be kept at the forefront of infrastructure development.

Throughout the review of the hydrogen safety plans, there was high variance in completeness. Possible reasons for this lack of description can vary. Proprietary information can hinder an applicant's ability to share information or to disclose certain aspects of the proposals. Applicants were explicitly directed to not include any proprietary information in their proposals. Another reason may be that some details required may not yet be available to the developer at the time of application submission, such as site control and detailed knowledge of site-specific requirements or hazards. Hydrogen stations have a relatively high reliance on internal safety systems, including sensors and alarms, but emergency processes and planning are a critical aspect of safety planning as well. First responders, station operators, and the public will need to be familiar or have protective procedures in place in case of emergencies. Safety training and documentation are also important aspects of maintaining high confidence in developing this expanding part of California's infrastructure.

Submitted application packages for GFO-15-605 showed that the current state of the industry has many levels of understanding with regard to safety. Experience and time in the industry varied highly among applicants. The goal of keeping safety as a priority is to establish trust and build confidence in this new fueling platform that offers direct and indirect benefits for the environment, human health, and the economy. The CEC and its partners in developing infrastructure will always consider safety the highest priority. To maintain high-level expertise

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<sup>49</sup> [Safety resources and reviews](https://h2tools.org/hsp/reviews) (https://h2tools.org/hsp/reviews)

in safety planning review, in September 2017 the CEC requested funding to continue working with the Hydrogen Safety Panel through a request for proposals issued by NREL.<sup>50</sup>

## Station Footprint Analysis

The 2016 Joint Report detailed how land-use and safety codes and standards influence the amount of space needed for a hydrogen refueling station and reviewed existing literature, most notably a study from the Sandia National Laboratories, about station footprint size.<sup>51</sup> The CEC then analyzed the proposed station footprints given in applications to previous grant solicitations and presented its findings on the range of sizes, which were from 660 square feet to 4,300 square feet.

This year, the CEC reviewed the proposed stations that were submitted under GFO-15-605 to compare these station footprints to the ones previously analyzed. The CEC also reviewed the 21 stations that were awarded funding under GFO-15-605 to evaluate the associated footprints in relation to the wider set of proposals. There are a few caveats about this analysis, the first being that there were a handful of proposed stations for which footprint dimensions were not apparent in the application documents. These proposed stations were therefore excluded from the analysis. Furthermore, this evaluation does rely on some subjective judgment because not all applications use the same language when describing footprint size. Sometimes it is not completely clear if information refers to certain components or the complete hydrogen station.

Given these limitations, the GFO-15-605 analysis found that, in cases where applicants mentioned dimensions for the station equipment, footprints varied from 300 square feet to just over 2,000 square feet. In many cases, applicants also discussed larger “project” footprints (that, for example, included a dispenser located away from the main equipment pad) or “excavation” footprints (related to construction impacts), and these ranged from 500 square feet to 2,500 square feet. Regardless of which type of footprint (equipment, project, or excavation) one uses, this latest round of proposals moved the lower bound of station footprint size to something smaller than what was seen in the previously proposed stations. There were no stations proposed that reached the previous analysis upper bound of 4,300 square feet. On average, the trend on proposed station design is toward smaller footprints.

Narrowing the analysis to only the GFO-15-605-funded stations, these were primarily of two designs, one with an estimated equipment footprint size of 670 square feet and one with an estimated size of 825 square feet. These footprints of the GFO-15-605-funded stations are not the smallest that were proposed, but they are on the smaller side when looking at the full range. They are also closer to the lower bound of proposed station footprints from last year’s analysis. This analysis indicates that the stations that scored high had relatively compact station designs.

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<sup>50</sup> [H2@SCALE Lab Call](https://www.nrel.gov/hydrogen/h2-at-scale-crada-call.html) (https://www.nrel.gov/hydrogen/h2-at-scale-crada-call.html)

<sup>51</sup> Harris, A.P. Daniel E. Dedrick, Chris LaFleur, and Chris San Marchi. [Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development](#). Sandia National Laboratories, SAND2014-3416. April 2014. ([http://energy.sandia.gov/wp-content/gallery/uploads/SAND\\_2014-3416-SCS-Metrics-Development\\_distribution.pdf](http://energy.sandia.gov/wp-content/gallery/uploads/SAND_2014-3416-SCS-Metrics-Development_distribution.pdf))









# APPENDIX F: ARFVTP-Funded Stations










## Open Retail Stations

Table F-1 shows photos and station information for the 31 open retail stations.

**Table F-1: 31 Open Retail Stations**

| Open Retail Stations Funded by ARFVTP |   |  |  |
|---------------------------------------|---|--|--|
|                                       |    |     |   |
|                                       | Photo Credit: Air Liquide   |  | Photo Credit: FirstElement Fuel  |
| <b>Name</b>                           | Anaheim   | Campbell   | Coalinga   |
| <b>Address</b>                        | 3731 East La Palma Ave.   | 2855 Winchester Blvd.  | 24505 W. Dorris Ave.   |
| <b>Open Date</b>                      | 11/29/2016  | 6/9/2016   | 12/11/2015   |
|                                       |  |  |  |
| <b>Name</b>                           | Costa Mesa  | Del Mar (San Diego)  | Diamond Bar  |
| <b>Address</b>                        | 2050 Harbor Blvd.   | 3060 Carmel Valley Rd.   | 21865 East Copley Dr.  |
| <b>Open Date</b>                      | 1/21/2016   | 12/2/2016  | 8/18/2015  |

## Open Retail Stations Funded by ARFVTP

|                  |   |  |   |
|------------------|---|--|---|
|                  |    |    |    |
|                  | Photo Credit: Air Products and Chemicals, Inc.                                      | Photo Credit: FirstElement Fuel  |   |
| <b>Name</b>      | Fairfax (Los Angeles)   | Fremont  | Hayward   |
| <b>Address</b>   | 7751 Beverly Blvd.  | 41700 Grimmer Blvd.  | 391 West A St.  |
| <b>Open Date</b> | 5/2/2016  | 9/7/2017   | 4/27/2016   |
|                  |    |    |    |
|                  |   |  | Photo Credit: FirstElement Fuel   |
| <b>Name</b>      | Hollywood (Los Angeles)   | La Cañada Flintridge   | Lake Forest   |
| <b>Address</b>   | 5700 Hollywood Blvd.  | 550 Foothill Blvd.   | 20731 Lake Forest Drive   |
| <b>Open Date</b> | 11/10/2016  | 1/25/2016  | 3/18/2016   |
|                  |  |  |  |
|                  | Photo Credit: Air Products and Chemicals, Inc.                                      |  | Photo Credit: FirstElement Fuel   |
| <b>Name</b>      | Lawndale  | Long Beach   | Mill Valley   |
| <b>Address</b>   | 15606 Inglewood Ave.  | 3401 Long Beach Blvd.  | 570 Redwood Hwy   |
| <b>Open Date</b> | 6/22/2017   | 2/22/2016  | 6/16/2016   |

## Open Retail Stations Funded by ARFVTP

|                         |   |  |   |
|-------------------------|---|--|---|
|                         |    |    |    |
|                         | Photo Credit: FirstElement Fuel   | Photo Credit: ITM Power  | Photo Credit: FirstElement Fuel   |
| <b>Name<br/>Address</b> | Playa Del Rey (Los Angeles)<br>8126 Lincoln Blvd.                                   | Riverside<br>8095 Lincoln Ave.   | San Jose<br>2101 North 1st St.  |
| <b>Open Date</b>        | 8/18/2016   | 3/8/2017   | 1/15/2016   |
|                         |    |    |    |
|                         |   | Photo Credit: California Fuel Cell Partnership                                       | Photo Credit: FirstElement Fuel   |
| <b>Name<br/>Address</b> | San Juan Capistrano<br>26572 Junipero Serra Rd.                                     | San Ramon<br>4475 Norris Canyon Road   | Santa Barbara<br>150 South La Cumbre Rd.  |
| <b>Open Date</b>        | 12/23/2015  | 7/26/2017  | 4/9/2016  |
|                         |  |  |  |
|                         |   |  | Photo Credit: FirstElement Fuel   |
| <b>Name<br/>Address</b> | Santa Monica - Cloverfield<br>1819 Cloverfield Blvd.                                | Saratoga<br>12600 Saratoga Ave.  | South Pasadena<br>1200 Fair Oaks Ave.   |
| <b>Open Date</b>        | 2/1/2016  | 3/14/2016  | 4/10/2017   |

## Open Retail Stations Funded by ARFVTP

|                     |   |   |   |
|---------------------|---|---|---|
|                     |    |   |  |
|                     |   | Photo Credit: SCAQMD  | Photo Credit: FirstElement Fuel   |
| <b>Name Address</b> | South San Francisco<br>248 South Airport Blvd.                                      | Torrance<br>2051 West 190th St.   | Truckee<br>12105 Donner Pass Rd.  |
| <b>Open Date</b>    | 2/12/2016   | 8/18/2017   | 6/17/2016   |
|                     |   |  |  |
| <b>Name Address</b> | UC Irvine<br>19172 Jamboree Rd.   | West LA (Los Angeles)<br>11261 Santa Monica Blvd.                                   | West Sacramento<br>1515 South River Rd.   |
| <b>Open Date</b>    | 11/12/2015  | 10/29/2015  | 7/7/2015  |
|                     |  |   |   |
|                     | Photo Credit: Air Products and Chemicals, Inc.                                      |   |   |
| <b>Name Address</b> | Woodland Hills<br>5314 Topanga Canyon Rd.   |   |   |
| <b>Open Date</b>    | 10/5/2016   |   |   |

Source: CEC, photo credit: CEC unless otherwise stated

Table F-2 lists 34 planned stations that are in planning, in permitting, or under construction.

**Table F-2: 34 Planned Stations**

| <b>County</b>  | <b>Address</b>   | <b>Operational</b>                          | <b>Open Retail</b> |
|----------------|--|---|--------------------|
| Alameda        | 1250 University Avenue<br>Berkeley, CA 94702                       | Pending                                     | Pending            |
|                | 1172 45th Street<br>Emeryville, CA 94608                           | 9/16/2011                                   | N/A                |
|                | 350 Grand Avenue<br>Oakland, CA 94610                              | Pending                                     | Pending            |
| Contra Costa   | 2900 N Main Street<br>Walnut Creek, CA 94597                       | Pending                                     | Pending            |
| Los Angeles    | 9988 Wilshire Boulevard<br>Beverly Hills, CA 90210                 | Pending                                     | Pending            |
|                | 145 West Verdugo Avenue<br>Burbank, CA 91510                       | 11/24/2010                                  | N/A                |
|                | 10400 Aviation Boulevard<br>Los Angeles, CA, 90046                 | 2/1/2009                                    | N/A                |
|                | 5151 State University Drive<br>Los Angeles, CA 90032               | 5/7/2014                                    | N/A                |
|                | 15544 San Fernando Mission<br>Boulevard<br>Mission Hills, CA 91345 | Pending                                     | Pending            |
|                | 28103 Hawthorne Boulevard<br>Rancho Palos Verdes, CA 90275         | Pending                                     | Pending            |
|                | 24551 Lyons Avenue<br>Santa Clarita, CA 91321                      | Pending                                     | Pending            |
|                | 1866 Lincoln Boulevard<br>Santa Monica, CA 90405                   | Pending                                     | Pending            |
|                | 14478 Ventura Boulevard<br>Sherman Oaks, CA 91423                  | Pending                                     | Pending            |
|                | 3780 Cahuenga Boulevard<br>Studio City, CA 91604                   | Pending                                     | Pending            |
|                | Merced   | 12754 State Hwy 33<br>Santa Nella, CA 95322 | Pending            |
| Orange         | 16001 Beach Boulevard<br>Huntington Beach, CA 92647                | Pending                                     | Pending            |
|                | 5333 University Drive<br>Irvine, CA 92612                          | Pending                                     | Pending            |
| Sacramento     | 6141 Greenback Lane<br>Citrus Heights, CA 95621                    | Pending                                     | Pending            |
|                | 3510 Fair Oaks Boulevard<br>Sacramento, CA 95864                   | Pending                                     | Pending            |
| San Bernardino | 12600 East End Avenue<br>Chino, CA 91710                           | Pending                                     | Pending            |
|                | 1850 E. Holt Boulevard   | 11/9/2017                                   | Pending            |

| <b>County</b> | <b>Address</b>  | <b>Operational</b> | <b>Open Retail</b> |
|---------------|---|--------------------|--------------------|
|               | Ontario, CA 91761                                       |                    |                    |
| San Diego     | 5494 Mission Center Road<br>San Diego, CA 92108         | Pending            | Pending            |
| San Francisco | 551 Third Street<br>San Francisco, CA 94107             | Pending            | Pending            |
|               | 1201 Harrison Street<br>San Francisco, CA 94103         | Pending            | Pending            |
|               | 3550 Mission Street<br>San Francisco, CA 94110          | Pending            | Pending            |
| San Mateo     | 503 Whipple Avenue<br>Redwood City, CA 94063            | Pending            | Pending            |
|               | 17287 Skyline Boulevard<br>Woodside, CA 94062           | Pending            | Pending            |
| Santa Clara   | 337 East Hamilton Avenue<br>Campbell, CA 95008          | Pending            | Pending            |
|               | 830 Leong Drive<br>Mountain View, CA 94043              | Pending            | Pending            |
|               | 3601 El Camino Real<br>Palo Alto, CA 94036              | Pending            | Pending            |
|               | 101 Bernal Road<br>San Jose, CA 95119                   | Pending            | Pending            |
|               | 1296 Sunnyvale Saratoga Road<br>Sunnyvale, CA 94087     | Pending            | Pending            |
| Ventura       | 3102 Thousand Oaks Boulevard<br>Thousand Oaks, CA 91362 | Pending            | Pending            |
| Statewide     | Temporary Refueler                                      | Pending            | Pending            |

Source: CEC

# APPENDIX G: Station Status Terminology

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The following four categories are used to describe the status of a hydrogen refueling station.

**Open Non-retail:** This category does not have a prescribed condition set other than that it is funded under an early research or demonstration grant program (not intended to provide retail fueling service) but is, nonetheless, able to continue providing fueling service to early FCEV adopters. Approval for FCEV drivers to fuel at these stations varies according to the vehicle manufacturer. Some of these are expected to be upgraded so they can provide retail service, at which time they will need to demonstrate all requirements of the Open Retail definition have been met.

**Open Retail:** a station that meets the following criteria:

1. The station passed final inspection by the appropriate AHJ and has a permit to operate.
2. The station operator has fully commissioned the station and has declared it fit to service retail FCEV drivers. This includes the operator's declaration that the station meets appropriate SAE fueling protocol, as required in California.
3. At least two auto manufacturers have confirmed that the station meets protocol and fueling interface expectations (including point-of-sale), and their customers can fuel at the station.
4. The dispenser metering performance has been verified, enabling the station to sell hydrogen by the kilogram (under CCR, Title 4, Division 9, Chapter 1).
5. The station is connected to Station Operational Status System.<sup>52</sup>

**Operational:** a station that meets the following criteria as defined in GFO-15-605 (the definition included in previous CEC grant programs like PON-13-607 may have different provisions). The current definition requires that the station:

1. Has a hydrogen fuel supply.
2. Has an energized utility connection and source of system power.
3. Has installed all of the hydrogen refueling station/dispenser components identified in the CEC agreement to make the station functional.
4. Has passed a test for hydrogen quality that meets standards and definitions specified in the CCR, Title 4, Division 9, Chapter 6, Article 8, Sections 4180 and 4181 (that is, the most recent version of SAE International J2719).
5. Has successfully fueled one FCEV with hydrogen.
6. Dispenses hydrogen at the mandatory H70-T40 (700 bar) and 350 bar (if this optional fueling capability is included in the proposed project).
7. Is open to the public, meaning that no obstructions or obstacles exist to preclude any individual from entering the station premises.

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<sup>52</sup> [CaFCP's Station Operational Status System](http://m.cafcp.org/). (<http://m.cafcp.org/>)

8. Has all the required state, local, county, and city permits to build and to operate.
9. Meets all of the minimum technical requirements in Section VI of GFO 15-605.<sup>53</sup>

**Planned:** a funded station that is in some phase of development, such as planning, permitting, design, or construction.

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<sup>53</sup> Definition is from the [GFO-15-605 Solicitation Manual](http://www.energy.ca.gov/contracts/GFO-15-605/). Stations funded under previous solicitations must meet the minimum technical requirements of the solicitation under which they were funded. (<http://www.energy.ca.gov/contracts/GFO-15-605/>)



## APPENDIX H: References

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- Baronas, Jean, Gerhard Ahtelik, et al. [\*Joint Agency Staff Report on Assembly Bill 8: 2016 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California\*](#). California Energy Commission. Publication Number: CEC-600-2017-002. (<http://www.energy.ca.gov/2017publications/CEC-600-2017-002/CEC-600-2017-002.pdf>.)
- Boudette, Neal E. "[\*First Came the Hydrogen Cars. Now, the Refilling Stations.\*](#)" *The New York Times*. May 18, 2017. (<https://nyti.ms/2rwnPBx>.)
- Brecht, Patrick. 2017. [\*Localized Health Impacts Report For Selected Projects Awarded Funding Through the Alternative and Renewable Fuel and Vehicle Technology Program Under Solicitation GFO-15-605 – Light Duty Vehicle Hydrogen Refueling Infrastructure\*](#). California Energy Commission, Fuels and Transportation Division. Publication Number: CEC-600-2017-006. (<http://www.energy.ca.gov/2017publications/CEC-600-2017-006/CEC-600-2017-006.pdf>.)
- California Air Resources Board. [\*2017 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development\*](#). August 2017. ([https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8\\_report\\_2017.pdf](https://ww2.arb.ca.gov/sites/default/files/2018-12/ab8_report_2017.pdf))
- California Air Resources Board. [\*Low Carbon Fuel Standard, Credit Price Calculator\*](#). (<http://www.arb.ca.gov/fuels/lcfs/dashboard/creditpricecalculator.xlsx>.)
- California Air Resources Board. [\*Low Carbon Fuel Standard, Data Dashboard\*](#). (<https://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm>.)
- California Air Resources Board. [\*First Update to the Climate Change Scoping Plan, Transportation Appendix\*](#). May 2014. ([https://www.arb.ca.gov/cc/scopingplan/2013\\_update/transportation.pdf](https://www.arb.ca.gov/cc/scopingplan/2013_update/transportation.pdf).)
- California Air Resources Board. [\*Hydrogen Fueling Infrastructure Assessments\*](#). (<https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm>.)
- California Air Resources Board. [\*Low Carbon Fuel Standard\*](#). (<https://www.arb.ca.gov/fuels/lcfs/lcfs.htm>.)
- California Air Resources Board. [\*Mobile Source Strategy\*](#). May 2016. (<https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrsrc.pdf>.)
- California Code of Regulations, Title 4, Division 9, Chapter 6, Article 8, Sections 4180 and 4181. The CCR adopts the SAE International J2719, "[\*Hydrogen Fuel Quality for Fuel Cell Vehicles\*](#)." ([http://standards.sae.org/j2719\\_201511/](http://standards.sae.org/j2719_201511/).)
- California Code of Regulations, Title 24, California Building Standards Code, Part 2 California Building Code, Vol I, Chapter 11B – Accessibility to Public Buildings, Public Accommodations, Commercial Building and Public Housing.

- California Department of Food and Agriculture, Division of Measurement Standards. [Registered Service Agency Program: Information Guide](https://www.cdffa.ca.gov/dms/programs/rsa/rsaInfoGuide.pdf).  
(<https://www.cdffa.ca.gov/dms/programs/rsa/rsaInfoGuide.pdf>.)
- California Energy Commission. [Grant Funding Opportunity \(GFO\)-15-605: Alternative and Renewable Fuel and Vehicle Technology Program, Light Duty Vehicle Hydrogen Refueling Infrastructure, Application Manual](http://www.energy.ca.gov/contracts/GFO-15-605). April 2016.  
(<http://www.energy.ca.gov/contracts/GFO-15-605>.)
- California Fuel Cell Partnership. [By The Numbers](https://cafcp.org/by_the_numbers). ([https://cafcp.org/by\\_the\\_numbers](https://cafcp.org/by_the_numbers).)
- California Office of Environmental Health Hazard Assessment. [CalEnviroScreen Version 3.0](https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30).  
(<https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30>.)
- Chen, Tan-Ping. [Final Report: Hydrogen Delivery Infrastructure Options Analysis](http://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf). Nexant. DOE Award Number: DE-FG36-05GO15032.  
([http://energy.gov/sites/prod/files/2014/03/f11/delivery\\_infrastructure\\_analysis.pdf](http://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf).)
- Canadian Standards Association Group (formerly the Canadian Standards Association), Toronto, Canada. *Canadian Standards Association Hydrogen Gas Vehicle 4.3 Test Method for Hydrogen Fueling Parameter Evaluation*: 2012.
- Elgowainy, A., et al. [Life-Cycle Analysis of Air Pollutants Emission for Refinery and Hydrogen Production from SMR](https://www.hydrogen.energy.gov/pdfs/review17/sa066_elgowainy_2017_o.pdf). Argonne National Laboratory. 2017.  
([https://www.hydrogen.energy.gov/pdfs/review17/sa066\\_elgowainy\\_2017\\_o.pdf](https://www.hydrogen.energy.gov/pdfs/review17/sa066_elgowainy_2017_o.pdf).)
- Governor's Interagency Working Group on Zero-emission Vehicles. October 2016. [2016 ZEV Action Plan: An updated roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025](https://www.ca.gov/archive/gov39/wp-content/uploads/2018/01/2016_ZEV_Action_Plan-1.pdf). ([https://www.ca.gov/archive/gov39/wp-content/uploads/2018/01/2016\\_ZEV\\_Action\\_Plan-1.pdf](https://www.ca.gov/archive/gov39/wp-content/uploads/2018/01/2016_ZEV_Action_Plan-1.pdf))
- Harris, Aaron P., Daniel E. Dedrick, Angela Christine LaFleur, and Christopher W. San Marchi. [Safety, Codes and Standards for Hydrogen Installations](http://energy.sandia.gov/wp-content/gallery/uploads/SAND_2014-3416-SCS-Metrics-Development_distribution.pdf). Sandia National Laboratories, SAND2014-3416. April 2014. ([http://energy.sandia.gov/wp-content/gallery/uploads/SAND\\_2014-3416-SCS-Metrics-Development\\_distribution.pdf](http://energy.sandia.gov/wp-content/gallery/uploads/SAND_2014-3416-SCS-Metrics-Development_distribution.pdf).)
- McKinney, Jim, et al. 2015. [Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California](http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf). California Energy Commission. Publication Number: CEC-600-2015-016.  
(<http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf>.)
- National Fire Protection Association, [NFPA 2: Hydrogen Technologies Code, 2016 Edition](http://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards?mode=code&code=2).  
(<http://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards?mode=code&code=2>.)
- Pacific Northwest National Laboratory. [Safety Planning for Hydrogen and Fuel Cell Projects](https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-March_2016.pdf).  
March 2016.  
([https://h2tools.org/sites/default/files/Safety\\_Planning\\_for\\_Hydrogen\\_and\\_Fuel\\_Cell\\_Projects-March\\_2016.pdf](https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-March_2016.pdf).)

- Pratt, Joseph, Danny Terlip, Chris Ainscough, Jennifer Kurtz, and Amgad Elgowainy. [H2FIRST Reference Station Design Task, Project Deliverable 2-2](#). National Renewable Energy Laboratory and Sandia National Laboratories. 2015.  
(<http://www.osti.gov/scitech/servlets/purl/1215215>.)
- SAE International. [J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles](#). ([http://standards.sae.org/j2601\\_201612/](http://standards.sae.org/j2601_201612/).) Note: SAE International was established as the Society of Automotive Engineers.
- SAE International. [J2719 Hydrogen Fuel Quality for Fuel Cell Vehicles](#): 2015.  
([http://standards.sae.org/j2719\\_201511/](http://standards.sae.org/j2719_201511/).)
- SAE International. [J2799 Hydrogen Surface Vehicle to Station Communications Hardware and Software](#): 2014. ([http://standards.sae.org/j2799\\_201404/](http://standards.sae.org/j2799_201404/).)
- South Coast Air Quality Management District, Technology Advancement Office. [Clean Fuels Program 2016 Annual Report and 2017 Plan Update](#). March 2017.  
([http://www.aqmd.gov/docs/default-source/technology-research/annual-reports-and-plan-updates/2016annualreport\\_2017planupdate.pdf?sfvrsn=6](http://www.aqmd.gov/docs/default-source/technology-research/annual-reports-and-plan-updates/2016annualreport_2017planupdate.pdf?sfvrsn=6).)