CALIFORNIA
AIR RESOURCES BOARD

2018 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development

Pursuant to AB 8, Statutes of 2013

arb.ca.gov

July 2018

List of Acronyms

AB 8	Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013)
AFV	Alternative-Fueled Vehicle
AHJ	Authority Having Jurisdiction
APRR	Average Pressure Ramp Rate
ARFVTP	Alternative and Renewable Fuel and Vehicle Technology Program
BEV	Battery Electric Vehicle
CaFCP	California Fuel Cell Partnership
CARB	California Air Resources Board
CEQA	California Environmental Quality Act
CES	CalEnviroScreen (v3.0)
CHAT	California Hydrogen Accounting Tool
CHIT	California Hydrogen Infrastructure Tool
CNG	Compressed Natural Gas
CTEP	California's Type Evaluation Program
CVRP	California Vehicle Rebate Project
DAC	Disadvantaged Community
DMS	Division of Measurement Standards
DMV	Department of Motor Vehicles
EO	Executive Order
FCEB	Fuel Cell Electric Bus
FCEV	Fuel Cell Electric Vehicle
GO-Biz	Governor's Office of Business and Economic Development
GFO	Grant Funding Opportunity
HEV	Hybrid Electric Vehicle
H2FIRST	Hydrogen Fueling Infrastructure Research and Station Technology
H70	Hydrogen at a pressure of 70 megapascal
HGV	Hydrogen Gas Vehicle
HyStEP	Hydrogen Station Equipment Performance
JHyM	Japan Hydrogen Mobility
LCFS	Low Carbon Fuel Standard
NREL	National Renewable Energy Laboratory
OEHHA	Office of Environmental Health Hazard Assessment
PEV	Plug-In Electric Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
PON	Program Opportunity Notice (California Energy Commission's formal communication of a grant program in prior years)
RFS	Renewable Fuel Standard
RSA	Registered Service Agent
SB 1505	Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006)
SB 535	Senate Bill 535 (De León, Chapter 830, Statutes of 2012)
SERA	Scenario Evaluation and Regionalization Analysis
SOC	State of Charge
SOSS	Station Operational Status System developed by CaFCP
ZEV	Zero Emission Vehicle

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Executive Summary

> "In terms of climate action, California and more than a dozen other [U.S.] states are taking real action. I'm looking forward to forging agreements with various provinces in Canada and particularly in zero-emission vehicles — electric cars, hydrogen cars"
>
> California Governor
> Edmund G. Brown

Over the past twelve months, there has been a significant shift in the momentum of California's hydrogen fueling station network development and Fuel Cell Electric Vehicle (FCEV) deployment. Growth of the on-the-road FCEV fleet has continued to accelerate year-over-year, with 4,411 FCEVs registered to the Department of Motor Vehicles (DMV) as of April 4, and the most recent industry estimates indicating a total of 4,819 vehicles deployed through May of 2018 [1]. The hydrogen fueling network has gained seven additional Open-Retail stations, for totals of 36 Open-Retail and 28 additional funded stations.

This network development has largely kept pace with projections provided one year ago, and the growth of the FCEV fleet is within the range of projections provided by auto manufacturers in annual surveys completed over the past four years. Many of the stations that remain under development were initiated through the most recent grant funding program, Grant Funding Opportunity (GFO) 15-605 (with station awards approved at Energy Commission business meetings between June 2017 and January 2018). Even though these are the most recent stations to begin their development process, some of them have been reported to be on pace to open prior to the close of 2018. This would represent a major improvement in the pace of individual station development timelines.

> "The years 2020 to 2030 will be for hydrogen what the 1990s were for solar and wind."
>
> Pierre-Etienne Franc
> Vice President of Advanced Business and Technologies, Air Liquide SA

The California Energy Commission (Energy Commission) also accomplished a first-of-its-kind milestone for the State, awarding grant funding to a hydrogen production facility to supply two tons per day of 100% renewable hydrogen to California's growing network of retail fueling stations. This project begins to address the potential gap in hydrogen production capacity identified in last year's Annual Evaluation, especially in-state and renewable hydrogen production capacity.

Projections for FCEVs and hydrogen stations in the future have greatly increased. In January, Governor Brown issued Executive Order (EO) B-48-18. Among other provisions, the order sets an additional hydrogen station network development target of 200 stations by 2025 [2]. This is double the current target in Assembly Bill 8 (AB 8; Perea, Chapter 201, Statues of 2013) but set only two years later [3]. Meeting this ambitious target clearly requires accelerated effort on the part of the State to ensure its achievement. The EO additionally sets a target for 5 million ZEVs by 2030; FCEVs are expected to comprise a significant portion of this future ZEV fleet.

Moreover, the public/private California Fuel Cell Partnership (CaFCP) members recently published an equally ambitious shared vision for the potential growth of the industry to 2030. In their vision, the targets of the Executive Order are a stepping stone on the path to 1,000,000 FCEVs on the road by 2030, supported by a network of 1,000 hydrogen stations [4]. Predicated on the continuing development of regulatory and policy environments sufficient to sustain this remarkably swift growth, CaFCP members anticipate:

- diversification of hydrogen and fuel cells into other transportation sectors
- a retail fueling experience that provides station and network convenience on par with today's gasoline station network
- hydrogen fuel that is cost-competitive with gasoline on a per-mile basis
- the potential for increased renewable hydrogen production, and
- a transition away from government financial support and towards industry financial self-reliance

Accomplishing these goals in such a short period of time also requires a significant change in the pace of developments going forward, along with combined resolve and commitment from all stakeholders.

As ambitious as these goals may be, they are not without merit. The experience to date through the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) has already proven that focused activity and year over year commitment can create a nascent hydrogen fueling station network. That effort has enabled the deployment of nearly 5,000 FCEVs to California's roadways. These milestones were made possible by a similarly ambitious earlier vision of the path towards commercialization. Taken together, these achievements appear to indicate a turning point in the State's efforts to ensure hydrogen as a viable zero-emission transportation fuel to help meet the State's future greenhouse gas and criteria pollutant emission reduction goals.

The analyses presented in this year's Annual Evaluation are guided by the requirements outlined in AB 8 and rely heavily on CARB's participation in the State's implementation and ongoing public-private cooperation and collaboration. From these informational resources, CARB has made the following determinations:

- Today's open (36 stations) and funded (an additional 28 stations) hydrogen fueling network continues to expand fueling opportunities for FCEV drivers in early adopter markets.
- The transition from demonstration stations to full retail stations is nearly complete. Today's station network no longer contains any Open-Non-Retail stations and any stations that were reported as such in the 2017 Annual Evaluation have either been upgraded to full Retail specification or are currently under construction for such an upgrade. This has been achieved through developing consensus-based definitions and requirements for the retail fueling experience. Going forward, CARB anticipates retail fueling to be the de facto customer experience for all State co-funded hydrogen stations.
- Hydrogen station development timelines for the newest stations continue to improve. Some stations funded under GFO 15-605 may reportedly achieve Open-Retail status by the end of the year (faster than the most-recently reported average of 18 months). Projections for total station development time have become more reliable as experience continues to be gained in the state. With few exceptions, projections for total Open-Retail stations made a year ago were met by station developers within three months of expectations.
- Projections for on-the-road FCEV counts now exceed 23,000 in 2021 and 47,000 in 2024. These projections represent increases over the previously reported data. While the total number of vehicles projected in the long-term continues to grow, a path towards the goals of the CaFCP members' vision has not yet been conveyed through the annual survey process.
- CARB's scenario analysis for hydrogen fueling station network buildout in support of the CaFCP 2030 vision can be used as a reference for evaluating proposed station locations in future funding programs. Developing a network similar to this reference scenario ensures balanced growth between markets that will need a high density of high-capacity stations to supply overlapping coverage and providing initial coverage in markets projected to grow soon after today's first-adopter markets are established. Convenience of station locations on par with today's network of 8,000 gasoline fueling stations can be achieved with 1,000 properly-placed hydrogen stations to enable both short- and long-distance travel. In addition, the network in this scenario is able to ensure nearly every member of a Disadvantaged Community (DAC) has convenient access to a hydrogen fueling station near their home by 2030, thereby broadening the population for whom a switch to a zero-emission FCEV is a viable transportation choice.
- Hydrogen station network growth must accelerate between now and 2024 in order to meet both the 2025 goals of EO B-48-18 and the 2030 goals of the CaFCP. The required acceleration would ensure that hydrogen fueling network coverage and capacity lead FCEV deployment and hydrogen demand. Therefore, if the station network goals are met, there will be ample support for auto manufacturers to accelerate their FCEV deployment plans well beyond the rates reported to date.
- The projected hydrogen refueling station network will continue to meet the minimum renewable implementation requirements of Senate Bill 1505 (SB 1505; Lowenthal, Chapter 877, Statutes of 2006) [5]. By 2024, the network will dispense hydrogen with at least a 34% renewable content and the potential to reach 39% according to recent industry stakeholder indications.

"We will forge ahead with fuel cell development, because we are convinced that we need alternative power-train technologies in order to cover all possible solutions, from hybrids to fuel cell vehicles. That's because our range of models is so broad, ranging from very small cars to 40-ton trucks."

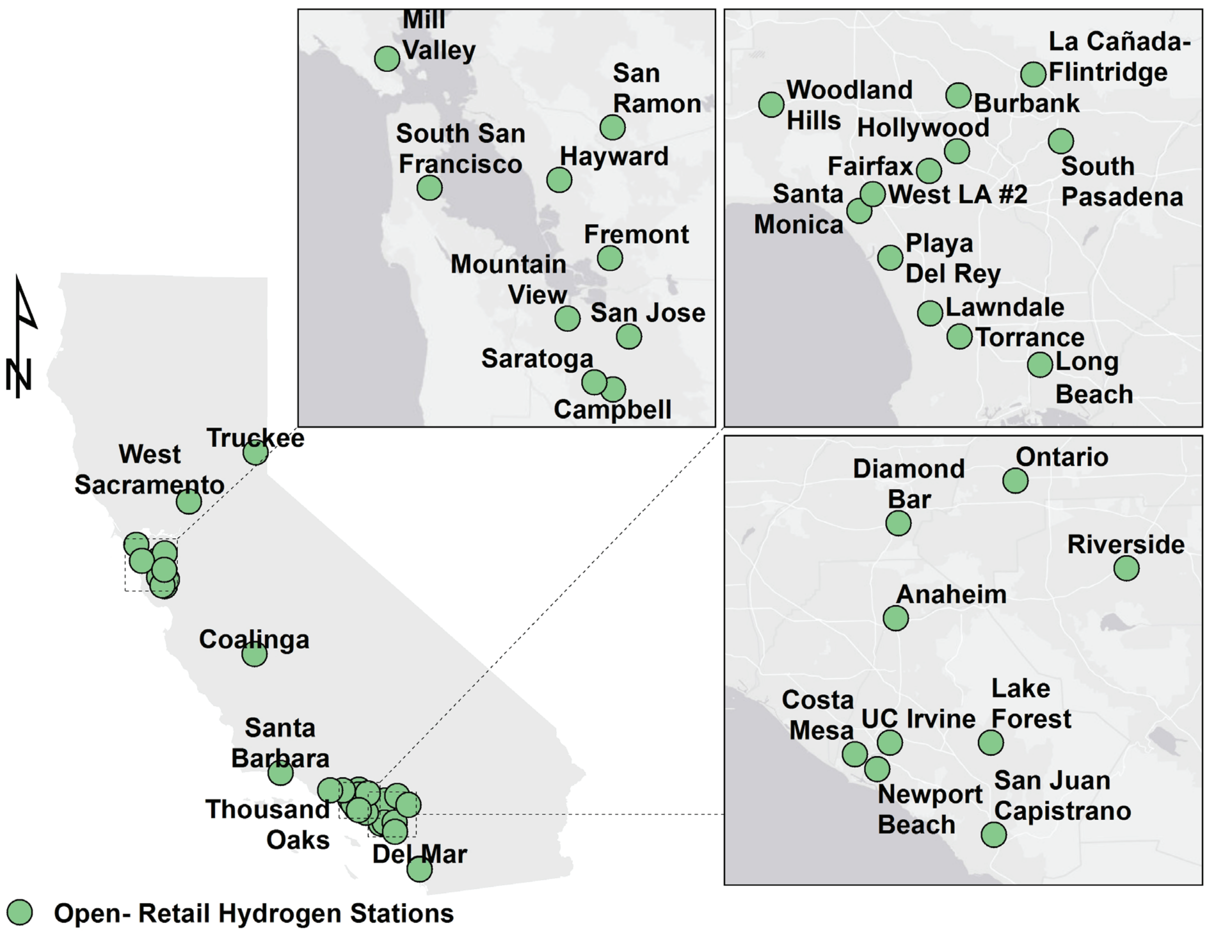
Prof. Christian Mohrdieck
Head of the Fuel Cell unit,
Daimler AG

Findings

Finding 1: California's hydrogen fueling network has continued to mature with growth in the number of stations, continued emphasis on a fully retail customer experience, and private investment in station development.

As of June 30, 2018[1], there are 36 retail hydrogen fueling stations open across the state of California, as shown in Figure ES1. Some of these stations are new development (Ontario, Fremont, and Mountain View). Others are upgrades from previously non-retail stations to fully retail operations (Burbank, Torrance, and Newport Beach). California has set the example for defining the retail hydrogen fueling experience. The entirety of the state's network development is now solely focused on retail stations. The only remaining non-retail station, Emeryville, is actively under construction to upgrade to full retail capability. In addition, the upgrade to retail of the Newport Beach station represents a significant milestone. This is the first hydrogen fueling station upgrade fully funded by private industry. As California's hydrogen fueling network and FCEV fleet continue to grow, the business cases for new and upgraded hydrogen fueling station development are expected to continue to improve. CARB expects stations fully-funded by industry to become increasingly common in the next decade.

Figure ES1: California's Currently Open Hydrogen Fueling Network (as of June 30, 2018[1]



1 The Burbank station is expected to open after June 30, while this report is in press.

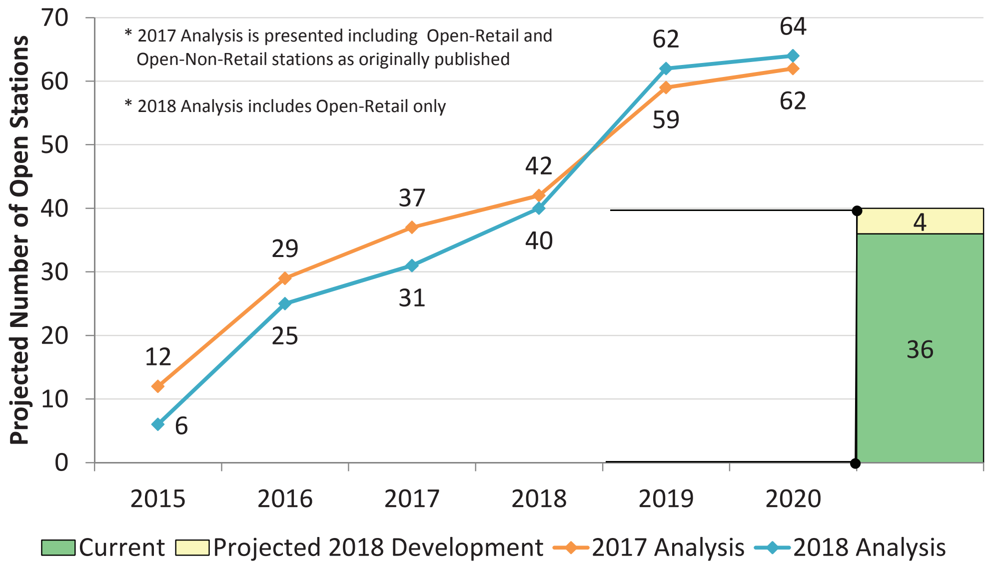
Finding 2: Station development progress in the past year has remained almost completely on-schedule compared to projections provided a year ago.

Hydrogen fueling station development has continued essentially at the pace of expectations reported in the previous Annual Evaluation. The pace of Open-Retail station development in the past year was delayed by less than half a year from the previous year's expectations. Figure ES2 shows the previous projection of 37 Open (Retail and Non-Retail) stations by the close of 2017, which is closely matched by the current status of 36 Open-Retail stations. Today's network of 36 Open-Retail hydrogen stations has grown from 25 stations in 2016, to 31 by the end of 2017, and is expected to grow to 40 by the close of 2018. In addition, during the past year the California Energy Commission approved the award of four additional stations through GFO 15-605. If the 20 stations funded through GFO 15-605 maintain their expected pace of development, California's hydrogen fueling network should reach at least 64 stations by the close of 2020.

FCEV and Hydrogen Station Progress across the U.S.

- In November 2017, the Locations Roadmap Working Group of the public-private partnership H2USA published a nationwide hydrogen and FCEV deployment scenarios evaluation [24]. The report envisions scenarios spanning various levels of success and support for expansion of hydrogen fueling networks and FCEV market growth outside of California and the Northeast states. Based on analyses completed by the National Renewable Energy Laboratory (NREL) using their Scenario Evaluation and Regionalization Analysis tool, the report envisions national cumulative FCEV sales up to 200,000, 4.5 million, and 61 million by 2025, 2035, and 2050 respectively. To achieve these deployment rates, the report finds that 570, 3,300, and 21,000 total stations would be necessary nationwide at those same milestones.
- The Connecticut Department of Energy and Environmental Protection, in cooperation with the Connecticut Center for Advanced Technology, Inc. has recently closed the application period for a grant funding program to provide up to $840,000 for the development of hydrogen fueling station(s) in southern Connecticut [25]. The grant program includes several provisions similar to those implemented in California's funding programs, especially related to the retail fueling requirements for the awarded station(s). Location-based requirements indicate that the funding agency has placed a priority on developing hydrogen fueling infrastructure in the area of New Haven County.
- Industrial gas company Air Liquide is in the process of developing the first network of hydrogen fueling stations in the northeast United States. In celebration of the 2017 National Hydrogen and Fuel Cell Day (October 8), the company announced that their first station in this network (near Hartford, Connecticut) had completed successful commissioning and testing [26].
- In Hawaii, the automotive products and services company Servco is building the state's first publicly-accessible hydrogen fueling station, which will lead to the deployment of a local fleet of Mirai FCEVs [27]. The station will be located at the company's headquarters on the island of O'ahu and be able to fuel up to five vehicles per day, with all of its hydrogen produced on-site through electrolysis. The company is fully funding the development of the station, which has been described by Hawaii's Governor Ige as "the beginning of hydrogen fuel cell vehicles in Hawaii."
- On April 3, 2018, Governor Murphy of New Jersey announced that the state would be signing the Multi-State Zero Emission Vehicles Programs Memorandum of Understanding [28]. Signing onto the program makes New Jersey the tenth state to collaborate in the Multi-State Zero Emission Vehicle Task Force. Among the Task Force's goals are collective deployment of 3.3 million vehicles (including FCEVs) by 2025 and the establishment of sufficient fueling infrastructure to enable this scale of deployment. Participating states also explicitly agree to investigate the potential for hydrogen fueling station deployment strategies and requirements for FCEV commercialization within their state.

Figure ES2: Comparison of Statewide Station Projections between 2017 and 2018 Annual Evaluations



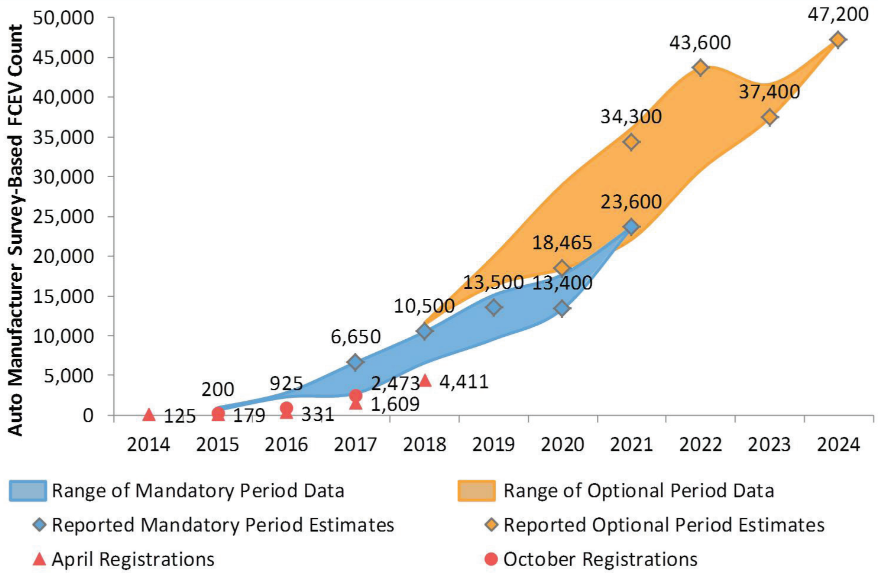
Finding 3: Auto manufacturer projections for future FCEV deployments have recovered substantially from 2017 projections.

Based on auto manufacturers' responses to the 2017 annual survey, long-term projections of FCEV deployment reported at the time were up to two years later than reported in previous years. In 2018, auto manufacturer confidence in the FCEV market appears to have recovered substantially with a continued expectation of growth. Although responses to the 2018 survey do not provide the most-accelerated FCEV expectations recorded to date, they do indicate a deployment pace that continues to grow throughout the entire survey period and the highest total number of anticipated FCEV deployments. Based on these survey data, CARB's current projections, shown in Figure ES3, are 23,600 FCEVs on the road by 2021 and 47,200 FCEVs on the road by 2024. This is the largest projected FCEV fleet reported to date, even greater than the previous peak of 43,600 in 2022. While these are encouraging volumes, they are not yet large enough to exhibit a clear pathway to meet a 1,000,000 FCEV target by 2030. However, the survey was conducted before CaFCP targets were announced. Future responses to the annual auto manufacturer survey may provide greater insight on the industry's outlook for the path to achieving these goals.

"The world in the 21st century must transition to widespread low carbon energy use… Hydrogen is an indispensable resource to achieve this transition because it can be used to store and transport wind, solar and other renewable electricity to power transportation and many other things. The Hydrogen Council has identified seven roles for hydrogen, which is why we are encouraging governments and investors to give it a prominent role in their energy plans. The sooner we get the hydrogen economy going, the better, and we are all committed to making this a reality."

Takeshi Uchiyamada
Chairman,Toyota Motor Corporation and
Co-Chair, Hydrogen Council

Figure ES3: Current and Projected On-Road FCEV Populations and Comparison to Previously Collected and Reported Projections



Finding 4: CHIT-based analyses provide recommendations for State co-funded hydrogen station location priorities in markets across California that help meet the 2025 goals of Executive Order B-48-18. These locations additionally ensure the developing network meets coverage and capacity needs to enable the 2030 goals expressed by the California Fuel Cell Partnership.

The California Hydrogen Infrastructure Tool (CHIT) provides the capability to perform spatially-resolved analyses of projected FCEV market growth, fueling network coverage, and the gap between these two metrics. CARB has relied on these analyses to define its recommendations for station network development that may serve as guides in the Energy Commission's next hydrogen fueling station funding program. These analyses are expanded compared to previous years and provide multiple methods of comparison between proposed station projects and the anticipated network need. In addition, because the projected expansion of the FCEV market needs to accelerate to achieve the goal of 200 stations by 2025, the number of recommended new station locations is much greater than in previous years. These analyses and recommendations are also consistent with the shared vision of FCEV deployment and hydrogen station development by 2030 envisioned by the CaFCP's latest publication, "The California Fuel Cell Revolution: A Vision for Advancing Economic, Social, and Environmental Priorities" (hereafter referred to as the "CaFCP Vision") [4]. Using an iterative process of evaluating need for new station coverage and capacity considered together, CARB leveraged the capabilities of CHIT to investigate fueling network development scenarios that assume growth towards a market-driven network of 1,000 stations by 2030.

Finding 5: Scenario analysis through CHIT demonstrates that a path towards the EO goal of 200 stations and the CaFCP goal of 1,000 stations can meet the hydrogen coverage, capacity, and convenience needs of all of California's communities, identified as Disadvantaged Communities or otherwise.

CARB's recommendations for future station development through 2025 and its scenario-based projections to 2030 are based on a CHIT-led evaluation of growing market needs across the state. In addition to this market-based assessment, CARB analyzed the projected station network's ability to meet medium-and long-distance driving needs and to enable FCEV driving as an option for a wide array of communities in the state. Funding stations according to this vision of station network development places California's hydrogen fueling network on a path such that the following features will start to become apparent in 2025 and will be firmly secured by 2030:

- Sufficiently redundant, high-capacity fueling opportunities established at convenient locations within high-adoption market areas commensurate to projected FCEV adoption rates
- Equitable baseline fueling opportunities to all potential FCEV drivers in DACs and other communities, regardless of their home locations or their trip destinations

- Enabling FCEV drivers to take full advantage of the long range provided by their vehicles with ample refueling opportunities as needed along their journey

In particular, as table ES1 demonstrates, it is possible to meet market demand needs and ensure sufficient and growing coverage of DACs through the network development scenario investigated by CARB. Today's network of 64 funded hydrogen fueling stations ensures a station is within a 15-minute drive of roughly one-third of the state's DAC population. By 2025, coverage could grow to two-thirds of the DAC population, and by 2030 nearly all residents in a DAC may have access to hydrogen fueling stations within the limits of convenience for everyday use.

> "[I]n response to those who say that hydrogen will always be the technology of the future, I would like to suggest that they have not been paying attention to the successes of the last decade… The next few years are going to be very interesting as we watch the ongoing development of the now-commercial FCEV market."
>
> Chris Gearhart
> "Hydrogen: What's Different Now" for IEEE Electrification magazine: Center Director, Transportation and Hydrogen Systems Center at National Renewable Energy Laboratory

Additional Markets for Fuel Cells and Hydrogen Station Advancements

- The fuel cell truck and hydrogen fuel startup Nikola has made several announcements over the past year. Most recently, the company has announced a major deal with Anheuser-Busch. The beverage company has reportedly made an order for 800 of Nikola's zero-emission trucks, with deliveries of the vehicles to begin in 2020 [12]. The pre-order is a part of Anheuser-Busch's strategy to convert its entire trucking fleet to renewable power by 2025. In addition, Nikola appears to be making progress toward its goal of providing all of its customers with 100% renewably-sourced hydrogen. Hydrogen production and fueling station equipment manufacturer Nel ASA announced a $5.5 million order was placed for equipment to support Nikola's prototype truck development [13]. This builds on a previous order for two sets of demonstration hydrogen station equipment.
- Toyota has launched the commercial sales of its Sora fuel cell bus, which is the first fuel cell bus to receive vehicle type certification in Japan [14]. The bus will be featured heavily at the 2020 Olympic games, though the company expects to first release 100 of the vehicles mostly within the Tokyo metropolitan area. The bus' technology leverages developments made for the fuel cell stack included in Toyota's Mirai passenger vehicle and several other technology advancements for rider comfort and driver assistance to enhance safety when the vehicle is in operation.
- Plug Power and Workhorse, with funding provided by the U.S. Department of Energy's Fuel Cell Technologies Office, has delivered the FedEx Express' first fuel cell electric delivery van [15]. The vehicle will enter normal daily delivery service along a standard route, based in Menands, New York. This will highlight the vehicle's ability to operate much in the same way as conventionally-fueled delivery vans without requiring any change in operators' fueling behavior. The vehicle's range exceeds 160 miles per delivery cycle and it is expected to travel more than 27,000 miles in its first six months of operation alone.
- On July 15, 2017, the Energy Observer self-powered hydrogen boat began a six-year journey across the globe [16]. The mission for the boat and its team of engineers is to demonstrate the ability to travel around the globe on a vessel that makes use of all available natural resources without wasting energy, and without emissions. The design of the vessel is notable for its ability to harness wind and solar power during the day and use hydrogen electrolyzed from seawater when these resources are not available (the electrolysis itself is powered by the renewable power generated onboard). The vessel will visit 50 countries on its travels, with a planned 101 stops along the way. The vessel is currently touring ports in the Mediterranean Sea.
- Hydrogen station and electrolysis equipment provider Nel ASA has been granted the world's first UL system certification for a hydrogen fueling station dispensing system [17]. Listed hydrogen fueling station components and systems may have the potential to streamline and accelerate hydrogen fueling station permitting processes, and provide assurance of consistency of equipment design, construction, and performance. The upgrade of the hydrogen fueling station at Burbank will be the first of California's stations to feature the listed equipment, with the stations awarded to Shell in GFO 15-605 also incorporating the equipment.

Table ES1: Potential Coverage of DAC Communities Provided by a Network of 1,000 Hydrogen Fueling Stations

CalEnviroScreen Score	Count of Stations in Future Priority Areas*	Population in Priority Areas	Population in 15-Minute Coverage	Percent of CA Population in 15-Minute Coverage	Percent of Covered Population
Non-DAC Subtotals:	403	17,704,848	26,199,288	70.3%	75%
DAC Subtotals:	597	7,663,418 (~84% of all DAC)	8,883,966 (~97 of all DAC)	23.8%	25%
Totals	**1,000**	**25,368,266**	**35,083,254**	**94.1%**	**100%**
For Reference: CalEnviroScreen Indicates 9,152,024 Residents Living in Disadvantaged Communities					

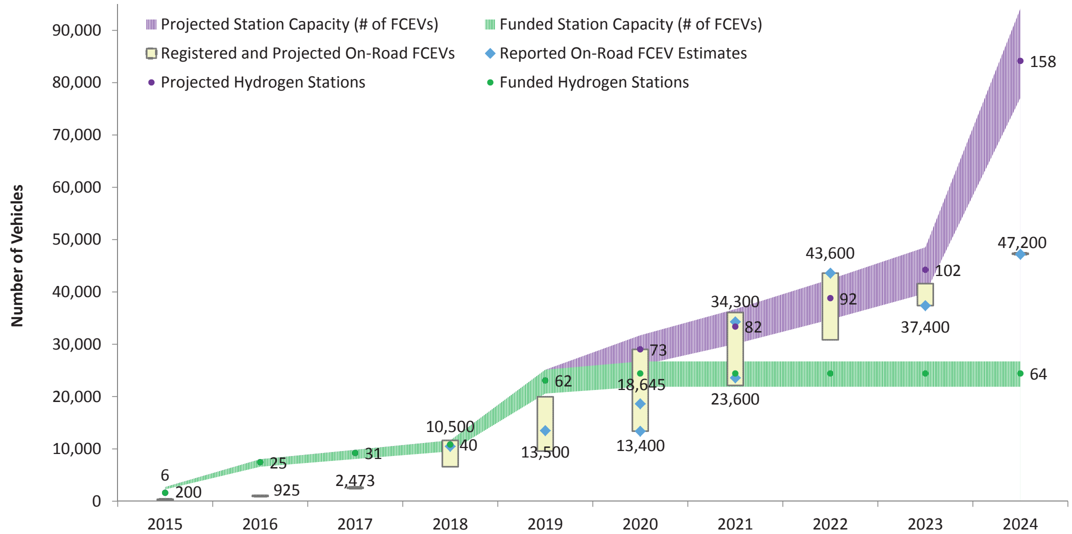
* **Counts for Priority Areas include all Priority Areas that partially or wholly overlap a DAC. Data for populations in Priority Areas and 15-Minute Coverage are exact and only include population wholly contained within both the DACs and either Priority Areas or 15-Minute Coverage.**

Finding 6: The pace of station development needed to meet EO B-48-18 should ensure sufficient hydrogen fueling capacity well into 2025.

Prior Annual Evaluations have found that business-as-usual pace of hydrogen fueling network development would result in a hydrogen capacity shortfall as early as 2020. In these early analyses, the pace of station deployment was in keeping with the original AB 8 goal of 100 stations funded by January 1, 2024. Recent analyses and commitments indicate industry's desire to accelerate the hydrogen and FCEV markets. Governor Brown's Executive Order B-48-18 is consistent with this movement, identifying a substantially accelerated goal of 200 stations by 2025. The EO's goals therefore represent a doubling of network growth with only two additional years of station development. This new goal requires a rapid change in station deployment. For analysis purposes, CARB has assumed a pace of station development necessary to meet the original goals of AB 8, followed by a step change in station development pace necessary to satisfy EO B-48-18. Assuming this scenario, the nameplate capacity of the hydrogen station network is projected to be sufficient to meet the projected FCEV population from now to 2024, as shown in Figure ES4. In 2024, CARB's analyses anticipate that hydrogen fueling network capacity will lead FCEV deployment by a factor of 2-to-1. Therefore, perhaps to a greater degree even than AB 8 itself, EO B-48-18 targets forecast hydrogen fueling station network development will lead FCEV deployment. This will ensure that potential FCEV adopters will be able to comfortably integrate the vehicles into their daily lives and represents an important and positive shift in the projected balance between hydrogen fueling supply and demand compared to prior reports.

Photo courtesy of California Fuel Cell Partnership

Figure ES4: Projected Hydrogen Demand and Fueling Capacity Under Assumptions of Meeting the Original AB 8 Goals, Followed by Meeting EO B-48-18 Goals



Finding 7: Due to the anticipated acceleration in hydrogen fueling network growth, sufficient fueling capacity and coverage should be available by 2025 to enable FCEV deployments at a rate two to three times greater than currently-reported plans.

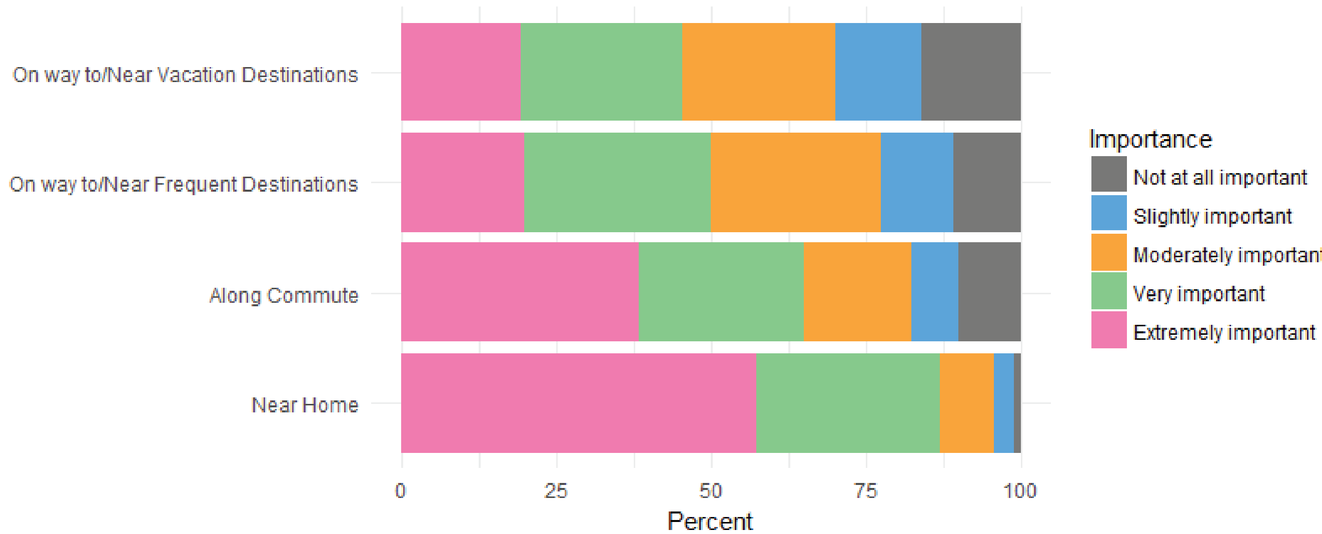
Since the inception of the AB 8 program, it has been the State's strategy for hydrogen station development to lead FCEV deployment in order to maximize the opportunity for vehicle adoption across the state. As the hydrogen fueling network grows to 200 stations statewide by 2025, focus for improving network coverage may shift primarily to secondary markets and increasing capacity in first adopter markets. As shown in Figure ES4, a margin of surplus hydrogen fueling network capacity is expected to grow at a rapid pace beginning in 2023. By 2025, the projected capacity of the network may be as high as three times the projected demand, if auto manufacturer survey responses are extrapolated out an additional year. Thus, it appears that there is ample opportunity for FCEV deployment projections in the near-to-mid-term (from now to 2025) to accelerate without concern for stressing the capacity of the overall station network.

Finding 8: Responses to the Clean Vehicle Rebate Project consumer survey provide valuable insight to confirm fundamental assumptions and analysis methods in CHIT.

The station location analyses performed by CHIT incorporate a set of fundamental assumptions in their operation and formulation. Several of these assumptions are based on prior works and observations of technology first-adopter and FCEV fueling customer behaviors. With 5,000 FCEVs now on the road, the existing customer base provides an opportunity to validate or correct these assumptions as necessary. Through the Clean Vehicle Rebate Project (CVRP), FCEV drivers are surveyed regarding their purchase decision-making process and their early experience with the hydrogen fueling network. These survey responses are providing positive indications of the veracity of several of CHIT's FCEV market assessment methods.

CHIT's assumptions of coverage needs are also investigated through the survey. For example, the availability of a hydrogen fueling station near home is nearly universally the most influential station location during FCEV adopters' purchase decision-making process, as shown in Figure ES5. Stations along their typical commute route remain a noticeable second-ranked importance. These two locations maintain their relative importance into the daily use patterns, as reported by FCEV first adopters. However, CARB's geospatial assessment of FCEV drivers' fueling opportunities indicates that stations identified by drivers as their near-home station may not always be the station within the shortest drive from home, and that there are some potentially surprising fueling behaviors in the early FCEV market. These observations may be valuable for informing future analyses of hydrogen fueling station location needs and driver preferences.

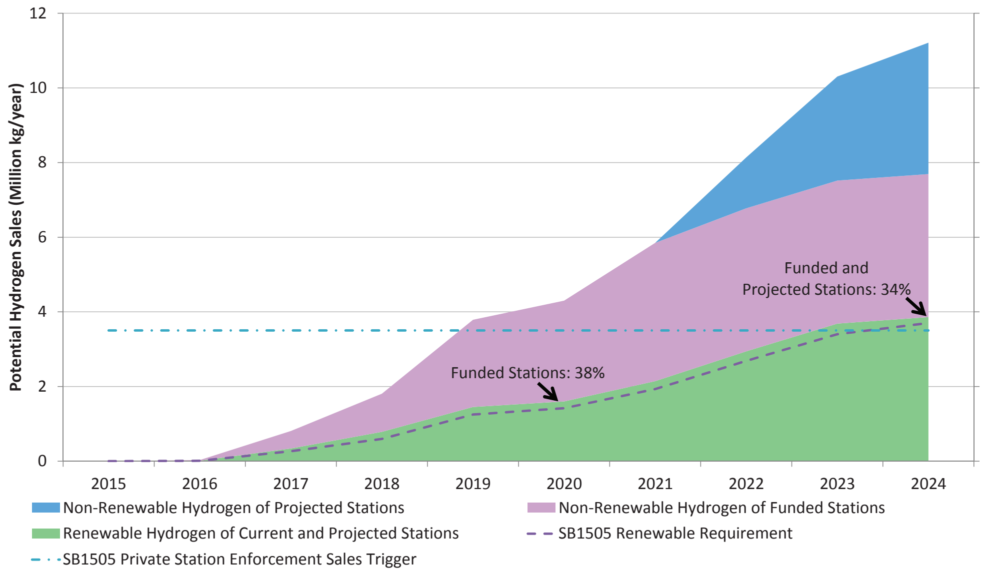
Figure ES5: Importance of Various Station Locations on FCEV First Adopters' Purchase Decision



Finding 9: California's State co-funded hydrogen fueling network is on track to meet or exceed renewable requirements per Senate Bill 1505. Application of these requirements to privately-funded stations may be required as soon as 2019.

Based on analysis of projected FCEV fuel demand, specifications of the 64 State co-funded stations, and projections for network buildout satisfying EO B-48-18, CARB anticipates that the 33% renewable content minimum specified in SB 1505 will be met for all light-duty hydrogen fuel sales. The currently-funded network, when completely constructed by the end of 2020, will dispense hydrogen with a 38% renewable content. Assuming any stations funded and built beyond this 64 station network meet the minimum requirements of SB 1505, the projected 2024 network will dispense hydrogen with a 34% renewable content. In a proposal for new hydrogen infrastructure provisions in the Low Carbon Fuel Standard (LCFS) program, industry stakeholders have drafted a suggestion for future stations to dispense hydrogen with at least a 40% renewable content; such a plan would result in a 2024 network that dispenses hydrogen with a 39% renewable content. Given potential fuel sales to meet the growing FCEV population in the next two years, the total light duty hydrogen fuel demand could exceed 3,500 tons per year in 2019. After this point, hydrogen fueling stations built in California with or without public funding support would also be required to comply with the 33% minimum renewable requirement of SB 1505.

Figure ES6: Projected Minimum Renewable Content of Hydrogen Dispensed in California's Light-Duty Fueling Network



Finding 10: Achieving 200 stations by 2025 places California on a path to enable the CaFCP goals of 1,000 stations and 1,000,000 FCEVs by 2030 and requires acceleration of the annual station funding and deployment rate. CARB recommends that the Energy Commission increases funds to hydrogen fueling station deployments in its next funding program(s) to the maximum feasible extent.

As reported in the 2017 Joint Agency Staff Report on AB 8, costs per kilogram of daily capacity for new hydrogen fueling stations have decreased over successive grant funding programs through the ARFVTP [29]. This has the potential to allow incremental increases in the number of stations funded with $20 million annual allotments over time. However, the goal of 200 stations by 2025 implies a swifter growth in the average annual station funding and deployment rate. In addition, much like the way in which early station network funding enabled the launch of California's FCEV market, expansion of funding for additional stations will increase the market potential for growing FCEV deployments in the near-term.

Energy Independence Now Publishes Renewable Hydrogen Roadmap for California

On May 17, 2018, the non-profit organization Energy Independence Now, with support from the Leonardo DiCaprio Foundation and the California Hydrogen Business Council, published a Renewable Hydrogen Roadmap focused on opportunities and challenges in California's developing market [32]. The report builds from a premise that renewable hydrogen is a key technology for California's carbon reduction goals. In particular, hydrogen represents opportunities at the nexus between renewable sources of energy, the electrical grid "duck curve"*, and the industrial and transport sectors. Through a series of analyses, the report provides a set of succinct policy recommendations with the potential to facilitate renewable hydrogen production and utilization in the State of California.

The report also reviews the global and California-based current hydrogen supply, key stakeholders, and current applications. An overview of the major production pathways for conventional and renewable hydrogen is presented along with their respective technologies, applications, current utilization rates, and potential for growth. Logistical and economic challenges of each technology, including an analysis of distribution options, are also described. The report's eight policy recommendations for the adoption of renewable hydrogen into the California economy are:

1. Begin the journey to 100% renewable hydrogen now
2. Fund scalable projects for 100% renewable hydrogen production
3. Improve LCFS incentives
4. Promote tools to lower the cost of electricity for renewable hydrogen producers
5. Address hydrogen distribution and storage challenges
6. Expand the US Environmental Protection Agency's Renewable Fuel Standard (RFS) program
7. Incentivize consumers and stakeholders
8. Broaden the hydrogen community through education and outreach

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* The "duck curve" is a term commonly used to refer to the potential imbalance on the electrical grid that occurs with higher renewable energy utilization. The shape of the hourly curve representing the balance between demand and generation sources in these scenarios is characterized by over-generation from renewable energy resources in the middle of the day (reminiscent of the "belly" of a duck) followed by challenging demand ramps in the early evening when renewable resources are dwindling (reminiscent of the "neck" of a duck).


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Investments today that ensure 200 stations by 2025 will maximize the potential for accelerated FCEV deployment through at least 2030. CARB therefore recommends that the Energy Commission provide increased funds for hydrogen fueling infrastructure in the next grant funding program(s), to the maximum amount feasibly possible while meeting all the needs of the broader ARFVTP program.

Conclusions

The past year has been marked by a significant positive shift in the outlook for FCEV deployment and hydrogen fueling network development. Multiple analyses and industry commitments are pointing toward a desire for near-term acceleration to build upon the accomplishments made to date. Within California, this would build upon observations made only a year ago that the FCEV market had moved out of its pre-commercial phase and into an early commercial market phase. Sustaining forward progress now requires acceleration, including financial support and the development of a policy environment that enables growth. The right conditions can enable not only a viable hydrogen fueling network and FCEV market, but one that is self-sustaining and independent of ongoing State financial support. Governor Brown's Executive Order B-48-18 provides guideposts for establishing these conditions, and the CaFCP Vision for 2030 provides a scenario for ultimate success.

The transition to heightened ambitions for FCEV success is only possible because of the accomplishments made to date. Hydrogen fueling network development and FCEV deployment in the past year have maintained pace from previous years' projections, indicating growing maturity in the hydrogen-powered transportation system in California. Moreover, it appears that today's FCEV drivers and the auto manufacturers who supply the vehicles have been able to make greater use of a more limited network than was previously envisioned. In 2012, the California Fuel Cell Partnership's "A California Roadmap: The Commercialization of Hydrogen Fuel Vehicles" [29] envisioned that a network of 68 hydrogen fueling stations would need to be in place in order to begin commercial sales of vehicles.

Approximately this number of stations are currently funded, but even with 36 of the 64 open and providing retail sales of hydrogen fuel to the public, California's FCEV fleet has managed to grow to thousands of vehicles. As more vehicles are deployed, the overall station network utilization rate increases, and the business case for the Open-Retail stations improves. This provides vital proof of the future potential to continue to improve as station technology develops to allow larger-capacity stations at lower cost, demand from an ever-growing FCEV fleet becomes firmer, and economies of scale become increasingly apparent.

As the analyses of this report indicate, the culmination of these recent developments is a refreshed vision of California's hydrogen transportation future. This new vision builds on the extensive experience gained within the state and acknowledges the potential for long-term industry development goals. Due to these demonstrated successes and continued State support, there has been an inflection point in the conversations around hydrogen fuel and FCEVs within California. The consensus outlook from industry and public stakeholders is increasingly positive, and California stands well-positioned for FCEVs to step into the role they must ultimately play in order for the State's long-term GHG reduction goals to become a reality.

California Fuel Cell Partnership Publishes "The California Fuel Cell Revolution"

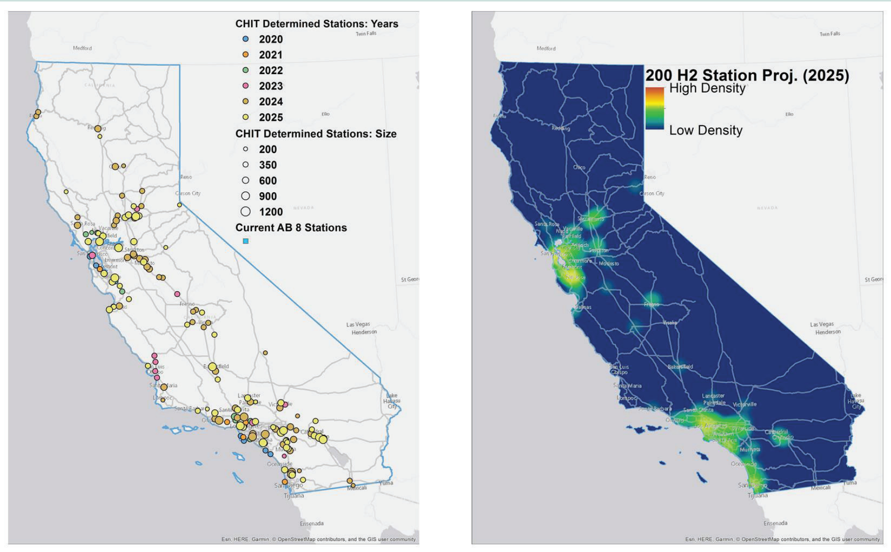
In the summer of 2012, the California Fuel Cell Partnership published the landmark document "A California Roadmap: Bringing Hydrogen Fuel Cell Electric Vehicles to the Golden State" [30] and its companion technical document "A California Roadmap: The Commercialization of Hydrogen Fuel Cell Vehicles" [29]. These documents represented extensive public and private cooperative effort to outline developments necessary to successfully enable the market introduction of FCEVs in California. At the time, major focus was placed on defining metrics of coverage and capacity primarily to meet light duty early adopters' projected refueling needs and support mechanisms that would enable a State co-funded network of stations to meet these early market needs. Much of this work was a first-of-its-kind exercise, with California serving as a living laboratory for the proof of potential for successful FCEV market launch. While the developments of the hydrogen fueling and FCEV markets have progressed somewhat differently from the scenarios presented in those reports, one message had become clear by mid-2017: early market launch had successfully been accomplished.

Recognizing this achievement, the members of the CaFCP have undertaken a similarly rigorous process to develop a consensus vision looking beyond market launch and towards a future in which FCEVs and hydrogen as a fuel have attained market maturity. This latest effort built upon accelerating developments and commitments within the global hydrogen and FCEV industries in the past year to define the vision of these technologies' roles in California by 2030. In July 2018, the Partnership published "The California Fuel Cell Revolution: A Vision for Advancing Economic, Social, and Environmental Priorities" [4]. This new document conceives a future where 1,000,000 FCEVs have been deployed as early as 2030, served by 1,000 light-duty hydrogen fueling stations.

In addition, this new Vision anticipates significant deployment of fuel cell technology into medium and heavy duty applications (such as buses, drayage trucks, port equipment, long-haul trucks, forklifts, and potentially even locomotives and aviation). Hydrogen in this future is also multipurpose, as exemplified by the U.S. Department of Energy's H2@Scale concept [31]. Hydrogen not only fuels vehicles and continues to be a key industrial process gas, but plays a major role in renewable energy storage and other electric grid services. This results in not only greater use of hydrogen, but also greater use of renewable and zero-carbon resources in the production of hydrogen. At the same time, the cost of retail hydrogen fuel to the consumer is projected to fall (at least to cost-parity with gasoline used in conventional hybrid vehicles), forming a cornerstone of widespread market acceptance. The core message of the Vision is clear: aggressive goals for California have been set; success requires a fundamental shift in methods and practices of both private and public efforts, with an eye towards ensuring a rapid transition to large-scale hydrogen-powered enterprise.

The analyses of this 2018 edition of the Annual Evaluation adopt the station network growth forecast in the CaFCP publication as a benchmark scenario, with particular emphasis on the 2025 network of approximately 200 hydrogen fueling stations. This network is reviewed in greater detail in later chapters and appendices, but readers of this report are encouraged to review the network features displayed in Figure 1 in order to be familiar with the scenario underpinning many of this report's analyses and recommendations.

Figure 1: Hydrogen Fueling Network Projected for 2025 through Collaborative Efforts of California Fuel Cell Partnership Members



Introduction

In 2017, CARB reported that California's FCEV and hydrogen fueling markets had successfully made the transition from the pre-commercial to the early commercial market phase. Continued advancements over the past year have begun to chart out the path for continued growth of the early commercial market and towards a transition into a fully established and robust commercial market. Critical issues of in-state and renewable hydrogen production have started to be addressed through an innovative State co-funding program. Public-private collaboration has continued over the past year to define a shared vision towards a self-reliant and fully realized zero-emission, hydrogen-fueled transportation industry within California. Recent public workshops and ongoing discussions establish a common understanding of the necessary scale of growth, the features of an enabling policy environment, and the crucial role that economies of scale will play in enabling full-fledged FCEV market reality in California.

Over the past five years of reporting, there has been significant progress in transforming California's initial research and pilot efforts into the early market reality that is exhibited every day on California's roadways and the vision for tomorrow's widespread market potential. The momentum must not only be maintained, but further accelerated to ensure all of these goals can be achieved. The 2018 Annual Evaluation adopts these targets and presents analyses of the coordinated efforts between hydrogen station network growth and FCEV deployment that must materialize in the next several years and provides insight for the scale of growth that must occur compared to the most recent expectations.

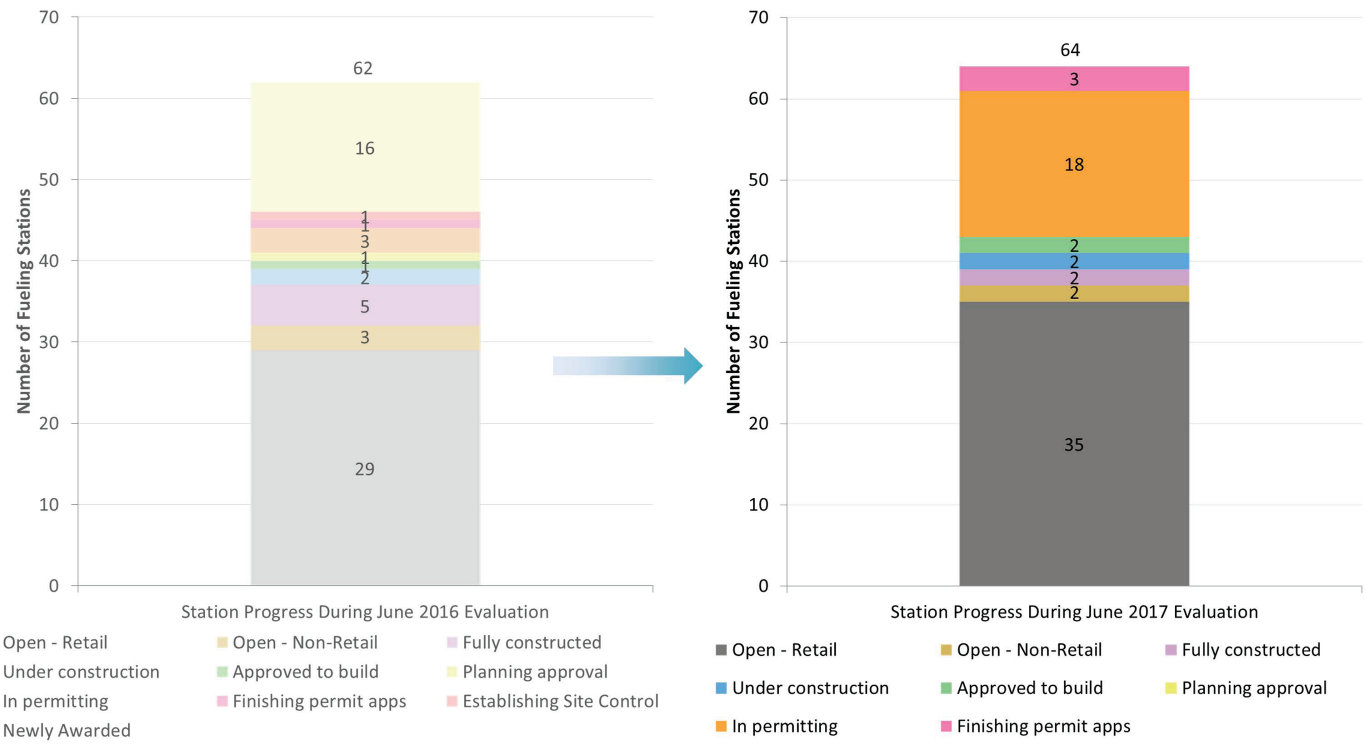
As with all previous Annual Evaluations, CARB has endeavored to meet the reporting requirements described in AB 8 (text of the relevant sections is provided in Appendix A) and provides expanded analysis and reporting in order to provide a comprehensive perspective of today's hydrogen fueling and FCEV markets and their potential future evolution.

Station Network Progress

Photo courtesy of ITM Power

Over the past year, California's hydrogen fueling network has continued to grow, both in terms of funded stations under development and Open-Retail stations. Seven new retail stations (Burbank, Fremont, Mountain View, Newport Beach, Ontario, Thousand Oaks, and Torrance) have completed construction and permitting since July 27, 2017 and are now Open-Retail stations. Torrance and Newport Beach were upgrades of previously Non-Retail stations to full retail station capability. In addition, the Newport Beach upgrade is unique and a first within California's Open-Retail hydrogen fueling network, as the station's upgrade was funded completely through private capital rather than utilizing State co-funding. While this does not indicate industry-wide self-sufficiency, it does demonstrate that the business propositions for hydrogen fueling stations are continuing to improve and that individual cases already exist in which public funds are not necessary for continued advancement.

Figure 2: Hydrogen Fueling Station Network Status, as of June 19, 2018 (the lightened figure on the left is reproduced from the 2017 Annual Evaluation; the full-saturation figure on the right is the current status)[1]



In addition, the June 2017 Annual Evaluation reported that staff of the Energy Commission had proposed funding for 16 new hydrogen fueling stations through GFO 15-605. These 16 stations have since been approved for funding and there is a possibility that the first of these stations could become Open-Retail later this year or in the first quarter of 2019, representing an unprecedented pace for station development in California. Five additional stations were later proposed for award through GFO 15-605; four of these awards were accepted by the developer, approved by the Energy Commission, and are now under construction (Beverly Hills, Mission Hills, Studio City, and Redwood City). Finally, three stations that encountered completion difficulties (North Hollywood, Rohnert Park, and Orange) are not included in this analysis; the removal of these stations from this analysis results in reduced coverage in the respective nearby neighborhoods.

A summary of the station network's development advancements in the past year is presented in Figure 2. The current total of Open-Retail and developing stations is now 64, with 36 Open-Retail[1]. The majority of the remaining stations were awarded in GFO 15-605 and are currently in the permitting phase. In contrast to prior years, there are no Open Non-Retail stations to report, as all stations that had previously been reported in this classification have now either been upgraded to Open-Retail status or are currently closed and in active development of their upgrades to Open-Retail. Stations that had previously been reported as Open-Non-Retail were largely a group of stations built through earlier grant funding programs intended as pilot and demonstration projects, before the requirements of a retail hydrogen fueling experience had been well-defined. Given the goals of AB 8 and public-private efforts to develop a fully retail hydrogen fueling network in California, the network has likely moved beyond the need to report these Open-Non-Retail stations. This has been a milestone that cannot be understated, solidifying the expectations of retail fueling customers and the ability of hydrogen fueling station developers to deliver stations that meet these expectations.

Major Developments Guiding the 2018 Annual Evaluation

In addition to the substantial station network progress, there have been a series of hydrogen-related developments over the course of the past year that significantly impact the analyses provided in this Annual Evaluation. These actions are summarized below:

Governor Brown's Executive Order B-48-18

On January 26, 2018, Governor Brown issued Executive Order B-48-18 and an accompanying budget request. Among other provisions, EO B-48-18 instructs California agencies to work towards a new hydrogen fueling infrastructure goal of 200 stations by 2025 and towards a ZEV deployment goal of 5 million vehicles by 2030. In addition, the EO specifically instructs CARB to consider ways in which the LCFS program can be leveraged to expand ZEV fueling infrastructure. It is important to note that the Governor's goals reflect ZEV industry goals that are significantly more aggressive than business-as-usual. However, the goals stated in the EO are complementary to the overall momentum of the industry within California. Locally, domestically, and internationally, there is a movement to accelerate towards broader commercialization of FCEVs through hydrogen network development and supporting policies [4], [24], [18]. The Governor's Executive Order is thus complementary to these broader goals and provides a pathway to ensure the market success envisioned through these efforts can be realized within California. In order to meet these goals, all agencies and industry stakeholders will need to act soon to accelerate the pace or progress significantly beyond business-as-usual. This Annual Evaluation demonstrates the opportunity for significant FCEV deployment growth beyond known auto manufacturer plans that will become apparent as a path to full commercialization within California is implemented.

The California Fuel Cell Partnership publishes "The California Fuel Cell Revolution"

Over the course of the past year, the members of the public-private California Fuel Cell Partnership have undertaken a significant effort to develop a 2030 Vision document. The goal of the document is to recognize the achievement of establishing the early commercial FCEV market in California, and to communicate a member-driven shared perspective for the necessary public and private developments that will enable a transition for growth into a more mainstream market. This shared vision anticipates 1,000,000 FCEVs on California's roads in the early 2030s, supported by a fueling network of 1,000 hydrogen fueling stations that enable drivers to travel to nearly every location in the State that today's conventional gasoline drivers are able to reach. CARB participated in many of the analysis and goal-setting efforts that informed this document and has made every effort within this Annual Evaluation to provide complementary analyses and recommendations in agreement with the Partnership's publication.

Capacity Credit Generation within the Low Carbon Fuel Standard Program

CARB's Low Carbon Fuel Standard program is a critical piece of California's strategy to ensure continuing reductions in transportation fuel-based greenhouse gas emissions through a system of:

- Decreasing transportation fuel carbon intensity standards
- Generation of fuel lifecycle emission credits/deficits for all regulated parties
- Emission credit trading market such that entities with outstanding deficits may purchase, at industry-driven market prices, credits from other fuel producers with excess available credits

The program is currently undergoing development of a set of revisions since it was last re-adopted in 2015 [33]. Although hydrogen fuel producers have always had the opportunity to participate in the program and potentially generate credits, CARB is currently considering potential changes for hydrogen's role in the program [34]. The largest potential shift that has been proposed is a method for hydrogen fueling infrastructure developers to be eligible to generate LCFS credits based on the capacity of hydrogen fueling stations that they develop and register with the program.

As proposed by a consortium of hydrogen fueling industry stakeholders, hydrogen fueling station operators would be eligible (for a limited period of time) to generate credits in the LCFS system equal to the difference between the credits that could be earned at full station utilization (based on the station's daily fueling capacity) and the amount generated based on actual hydrogen sales. The additional credits are intended to serve as a supplementary revenue stream during the early FCEV deployment phase, when the California FCEV population is still small and hydrogen sales volumes and revenue may still remain limited. If adopted, the ability for station operators to generate credits that make up the difference between sales and station capacity will provide those developers with a more certain stream of revenue through the LCFS program than would otherwise be available. This improves not only the in-operation business case but also the outlook for station development during a company's project planning and budgeting phase.

Hydrogen fueling station stakeholders have communicated that a change to the LCFS program similar to their proposal could be an influential factor in moving the industry towards the ability to develop a station network more quickly and at larger scale, with the potential to ultimately provide significant fuel savings to FCEV customers. In addition, as the industry could be incentivized to build at larger scale, upstream investments that would be necessary (such as manufacturing facilities and technologies for hydrogen fueling station equipment, hydrogen fuel production, etc.) could move the industry closer to financial self-sufficiency earlier than could otherwise be achievable. This and other potential regulation changes are still under development and consideration by the Board prior to adoption.

Workshops in Support of Future Grant Funding Opportunity Development

In November and December 2017, CARB and the Energy Commission convened a series of workshops and webinars to facilitate public discussion of concepts to inform the structure and requirements of the next hydrogen fueling station grant solicitation. Topics included the development and use of the 2017 Release Version of CHIT, hydrogen station technical specifications and requirements, alternative funding mechanisms, and potential evaluation criteria. Discussions within and following these workshops continue to inform CARB's assessments of the technical requirements for stations funded in future grant programs.

Additional Awards under GFO 15-605

On November 8, 2017, the Energy Commission released a revised Notice of Proposed Award recommending five more hydrogen stations in addition to the previously recommended awards for 16 new hydrogen fueling stations approved in August 2017. Four of the recommended awards were approved at an Energy Commission Business Meeting on January 17, 2018 and one was not ultimately finalized. These four stations (Beverly Hills, Mission Hills, Studio City, and Redwood City) were found to provide coverage, capacity, and redundancy in high-priority first adopter markets in both Northern and Southern California [35]. These stations have been included in all analyses presented in this Annual Evaluation.

Selection of Renewable Hydrogen Production Facility under GFO 17-602

On June 13, 2018, the Energy Commission approved an award for a 100% renewable hydrogen production facility under GFO 17-602. The selected facility will be developed by Stratos Fuel, the developer of the hydrogen fueling station in Ontario. While the solicitation required a minimum production capacity of 1 ton (1,000 kilograms) per day intended primarily for use at light-duty FCEV fueling stations, the awarded funds will be utilized to add 2 tons/day production capacity to a 3 ton/day facility already under development. The full project is expected to be developed in three phases:

- Phase 1: Development of a 5,000 kg/day electrolyzer-based hydrogen production facility in Moreno Valley. The electrolyzers will use grid-tied 100% renewable electricity for the production of hydrogen fuel that will be supplied to in-state hydrogen refueling stations. Current California Environmental Quality Act (CEQA) review and Energy Commission grant funds include this phase.
- Phase 2: Future planned expansion of Phase 1 with an additional 10,000 kg/day of electrolyzer capacity on an adjacent parcel. Current California Environmental Quality Act (CEQA) review includes this phase, but Energy Commission grant funds do not.
- Phase 3: Long-term planned expansion to include a 15-ton/day biogas steam-methane reformation system and a 20-ton liquefaction plant on an adjacent parcel. Current CEQA review includes this phase, but Energy Commission grant funds do not.

Selection of a Hydrogen-Powered Freight Infrastructure Project under GFO 17-603

On April 5, 2018, the Energy Commission announced the recommendation of award for three projects in its Advanced Freight Infrastructure solicitation. One of the selected projects was for the development of a hydrogen fueling facility at the Port of Long Beach. The project is a collaborative effort between Shell (doing business as Equilon Enterprise, LLC), Toyota, and FuelCell Energy. The refueling facility will be supplied by an on-site tri-generation facility with the capability to produce hydrogen for transportation fueling, electricity for on-site facility use, and thermal energy for other local heating uses. These on-site resources are produced via a Molten Carbonate Fuel Cell operating on directed bio-waste gas produced by agricultural processes in California's Central Valley. The fueling infrastructure in this project will be used to fuel trucks provided by Toyota (the previously-announced Project Portal Class 8 freight hauling truck), smaller FCEV trucks in drayage service, and light-duty Mirai FCEVs as they are delivered via cargo ship and then transported to dealerships throughout California. In total, the facility will be developed to provide fueling capacity of 1,270 kilograms per day, 1,000 of which is intended for the heavy-duty truck pilot and demonstration.

Global Announcements of FCEV Commitments

- The multinational industrial hydrogen collaborative Hydrogen Council published its vision of the global potential for hydrogen as a fuel and industrial resource through 2050 [18]. With analytical support provided by McKinsey & Company, the Hydrogen Council estimates the potential for hydrogen to meet 18% of final energy demand in 2050, leading to 6 Gt/year reductions in carbon dioxide emissions, $2.5 trillion in annual hydrogen and equipment sales, and 30 million jobs worldwide. In addition, the report estimates that by 2030, one in twelve cars sold in markets that are currently developing fueling infrastructure (like California) could be powered by hydrogen.
- The French government has recently announced a new and ambitious plan that will dedicate €100 million ($117 million USD) to support deployment of hydrogen as a transportation fuel, an industrial process gas, and as an energy resource. The goals of the plan include 5,000 FCEV deployments, 200 heavy-duty fuel cell vehicle deployments, and 100 hydrogen fueling stations by 2023 with a ten-fold expansion planned by 2028. In addition, hydrogen will play a role in the nation's growing renewable energy market, primarily through energy storage applications. The French government anticipates 10% of all hydrogen to be decarbonized by 2023 and 20% to 40% decarbonized by 2028. [19]
- On March 5, 2018, seventeen Japanese corporations representing auto manufacturers, fueling infrastructure developers, and the investment community announced the formation of Japan H2 Mobility (JHyM) [20]. The collaborative was formed as an effort to work together towards a shared goal of increased hydrogen-powered mobility in Japan. The group's three main initiatives include strategic hydrogen station deployment, hydrogen station cost reductions, and improved convenience for FCEV customers.

Location and Number of Fuel Cell Electric Vehicles

AB 8 Requirements: Estimates of FCEV fleet size and bases for evaluating hydrogen fueling network coverage

CARB Actions: Distribute and analyze auto manufacturer surveys of planned FCEV deployments. Analyze DMV records of FCEVs. Develop correlations between survey regional descriptors and widely accepted stakeholder frameworks for evaluating coverage.

Information Sources for FCEV Projections

As has been done for previous editions of the Annual Evaluation and in accordance with the requirements of AB 8, CARB has based its estimates of current and projected FCEV fleets on two primary data sources:

- Current FCEV registration data as provided by the California Department of Motor Vehicles, and
- Responses from auto manufacturers to an annual confidential survey of their future FCEV release plans; for this year's survey, responses for model years 2018 through 2021 fell in the mandatory reporting period while the optional reporting period covered the years 2022 through 2024.

In past years, the confidential auto manufacturer survey has asked respondents for a statewide number of FCEVs expected to be released in each reporting year and has employed various formats to also request auto manufacturers provide information on the approximate geographic distribution expected for those vehicles. In general, the intent was for CARB to understand where auto manufacturers envisioned the FCEV market would grow in future years, and the relative pace of growth between regions. This could then be used to guide CARB's assessment of where new hydrogen fueling stations would need to be deployed in order to support the market expansion vision that was represented by the auto manufacturers' collective survey responses.

Over the past four years of reporting, this strategy for regionalized data has shown varying degrees of participation from auto manufacturers and has therefore had varying degrees of applicability to CARB's analyses. Following discussions with auto manufacturers regarding the process by which they developed their June 2017 priority area location letter published through the California Fuel Cell Partnership, CARB modified the method by which it attempted to gain industry feedback on likely market adoption rates and adoption pace around the state.

In the 2018 annual survey for auto manufacturers, CARB supplied respondents with a map of the current funded hydrogen fueling network (shown in Appendix C) and a map of the projected 2025 network shown in Figure 1. In brief, this map of station locations was informed by iterative assessment of station need through CHIT evaluation, with review and feedback on methodology provided by public and private members of the California Fuel Cell Partnership. Later chapters and Appendix D provide greater detail. The map (a larger version is supplied in Figure 48) illustrates the locations, timing, and projected capacity of slightly more than 200 total stations (including the 64 currently open and funded) in a 2025 hydrogen fueling network. Survey respondents were then instructed that CARB would assume the statewide total of vehicles should be distributed according to the station network development process portrayed in the map unless additional feedback was provided.

For auto manufacturers that desired to provide additional feedback, a hydrogen fueling station location worksheet was provided. The worksheet was accompanied by an annotated copy of the June 2017 priority location list previously provided by auto manufacturers and respondents were asked for any modifications their company would individually recommend for the list. In addition, the worksheet asked respondents to detail their preferred hydrogen station network development through 2025. For any portion of this worksheet that the respondent provided information, CARB used this information as the basis for determining where vehicles were likely to be deployed in the future. Whether respondents left the default assumptions or provided their own deployment plan, FCEVs were allocated to each county based on the proportion of hydrogen station network development in that county compared to the whole of the projected statewide hydrogen fueling network.

Too few auto manufacturers chose to complete the infrastructure worksheet to present direct comparisons of survey responses and the default assumptions utilized. However, when an auto manufacturer did complete the worksheet, their data was used to allocate their future vehicle projections to each county. Because individual manufacturer projections are then combined with current FCEV registration data and a set of vehicles allocated according to the default parameters, individual auto manufacturers' market development expectations remain non-attributable in aggregated results.

Current FCEV registration data were provided on April 4, 2018. Similar to previous years, CARB filtered the data to remove any vehicles that appeared to be registered out of state or for which the registration status did not provide certainty of the vehicle's active status.

CARB Analysis of DMV Registrations and Auto Manufacturer Survey Reponses

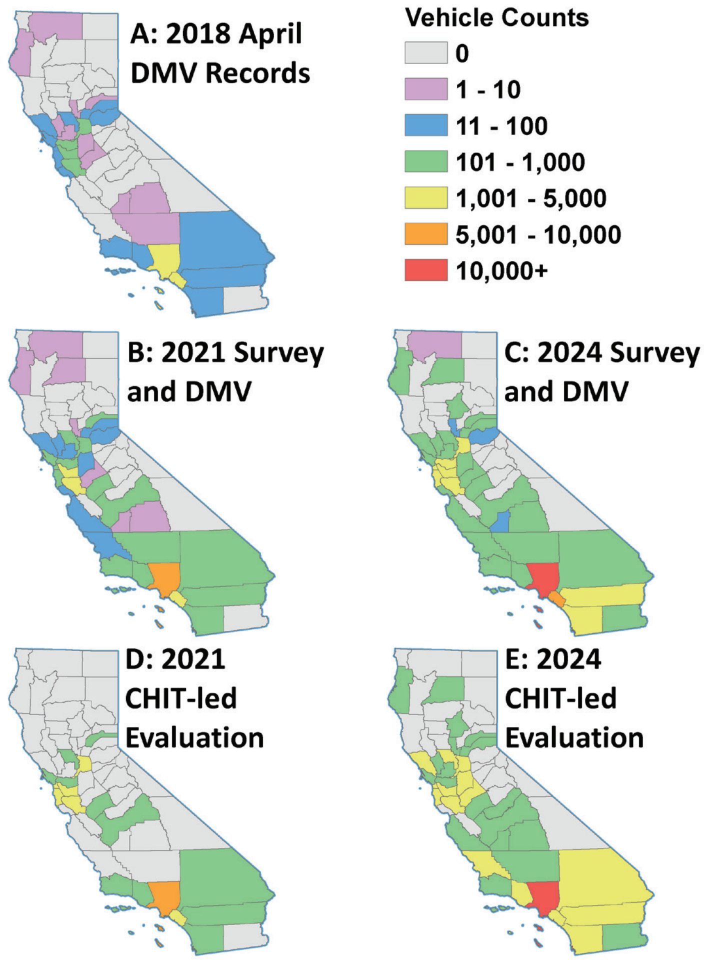
Based on the DMV registration data, as of April 4, 2018, there were 4,411 FCEVs actively registered in the state of California. The auto manufacturer members of the CaFCP have recently initiated an effort to provide updated public deployment estimates based on their sales data, and to publish these estimates through the Partnership website [1]. DMV registration data are in agreement with this industry estimate, which was reported to be 4,421 through March 2018. Panel A of Figure 3 provides the county-based distribution of the currently registered vehicles. The majority are registered in Los Angeles (35%) and Orange Counties (24%), with much of the remainder registered to Santa Clara (14%), Alameda (5%), Contra Costa (3%), Sacramento (3%), and San Mateo (2%) counties. It should be noted that there are some registrations reported in counties with no Open-Retail hydrogen stations within the county or in nearby counties. While the numbers are small, and CARB does not have a method to verify their source, it is likely these registration records may fall in one of two categories:

- Erroneous data collection and/or entry in the DMV registration database, or
- FCEV deployments that depend on private and/or research-based fueling facilities near the registered location

Global Announcements of FCEV Commitments (cont.)

- The government of Japan has also announced a strategic plan to promote the adoption of hydrogen as a transportation fuel through public-private efforts to make hydrogen cost competitive with conventional vehicle fuels [21]. Specifically, the plan calls for the price of hydrogen to reduce by 80% by 2050 and cites targets of 40,000 and 800,000 FCEV deployments by 2020 and 2030 respectively and 320 stations by 2025.
- Similar to the establishment of JHyM, auto manufacturers, energy companies, and infrastructure providers announced the formation of Hydrogen Mobility Australia [22]. While specific targets have not yet been announced, the organization's goals are to accelerate the commercialization of hydrogen and fuel cell technologies in Australia, provide a forum for collaboration, and advance the nation's shift towards renewable-sourced hydrogen fuel.
- Following the central Chinese government's publication of a 10-year plan to bolster China's manufacturing industry, the Society of Automotive Engineers of China published a roadmap for hydrogen fuel cell vehicles that outlines FCEVs' role in meeting the central government's new energy vehicle goals [23]. The roadmap sets targets of over 100 stations and 5,000 FCEVs (60% commercial; 40% passenger) by 2020, over 300 stations and 50,000 FCEVs (20% commercial; 80% passenger) by 2025, and over 1,000 stations with 50% renewable hydrogen production and over 1,000,000 FCEVs by 2030.

Figure 3: County Level Vehicle Projections Based on DMV Records and Auto Manufacturer Surveys Compared to CHIT-led Evaluations



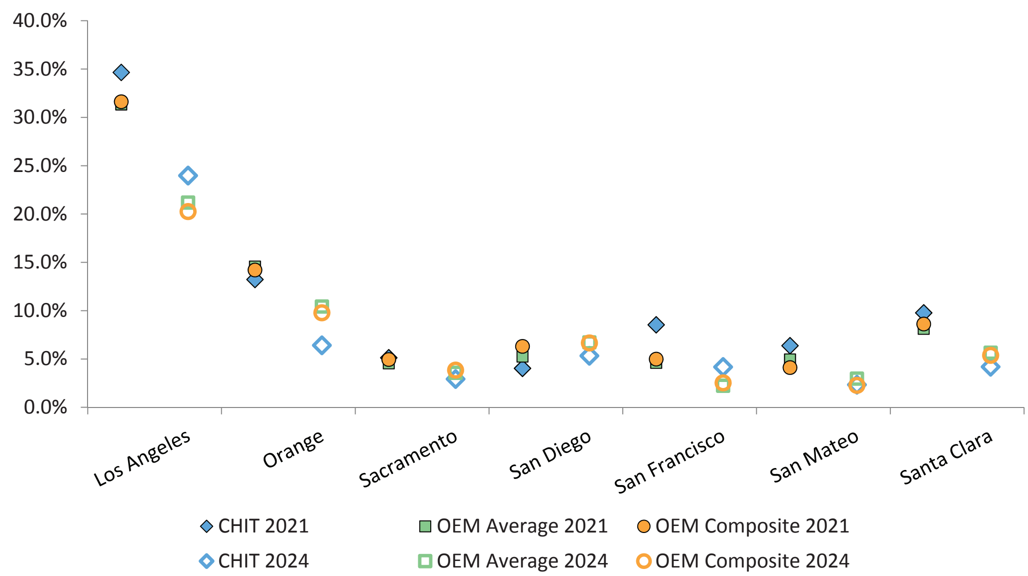
The projected FCEV deployments according to the auto manufacturer survey (which combines current DMV registrations, the CHIT evaluations shown in Figure 1, and participating respondents' modified vehicle deployment allocations by county) are shown for 2021 and 2024 in the Panels B and C of Figure 3. According to these projections, Los Angeles (2021: 33%; 2024: 28%) and Orange (2021: 18%; 2024: 15%) Counties are expected to continue to receive the greatest numbers of FCEVs through 2024. Santa Clara (2021: 11%; 2024: 9%), Alameda (2021: 7%; 2024: 6%), and San Diego (2021: 4%; 2024: 6%) Counties round out the top five counties for FCEVs projected to be on the road in both 2021 and 2024. In addition, while there is some geographic expansion of FCEV deployment projected by 2021, the expansion of the FCEV adopter market is more pronounced and with more substantial vehicles counts even outside the top five counties by 2024.

For comparison, Panels D and E in Figure 3 show projections of FCEV deployment if vehicles are allocated according to the station locations in Figure 1. In large part, the survey responses and the CHIT-led determinations are in agreement for projections to 2021, though the geographical spread of the auto manufacturer and DMV data combined is greater than projected through CHIT analyses. Still, the top 5 counties in 2021 are mostly similar: Los Angeles (35%), Orange (13%), Santa Clara (10%), San Francisco (9%), and San Mateo (6%). By 2024, the expected geographical extent of FCEV deployment is nearly identical between the two projections. However, the relative numbers of vehicles anticipated in each county differs between the scenarios. The top five counties in 2024 as projected through CHIT analysis are Los Angeles (24%), Riverside (7%), Orange (6%), San Diego (5%), and Santa Clara (4%). On a regional basis, the largest differences are in the inland southern California counties and the central San Joaquin valley. Figure 4 also provides an overview of the relative proportions of projected FCEV demand in select counties for 2021 and 2024 per CHIT evaluations and the auto manufacturer indications. Auto manufacturer data are presented in two methods: as an average where all manufacturers are considered equally, and as a composite where their input is weighted according to relative deployment projections. Los Angeles and Orange Counties represent the greatest absolute discrepancy between CHIT and auto manufacturer indications. On the whole, there is significant agreement between CHIT and auto manufacturer data, though particular counties like Los Angeles, Orange, and San Francisco do show disagreement on the order of a few percentage points.

Variations between the projection methods may be due to:

- Persistence of DMV registration counts (Panel A) into future years' projections (Panels B and C, but not Panels D and E)
- Differences in the methodology used by CHIT to assess station need compared to individual auto manufacturers' methods
- Differences between consensus (via cooperative review and comment on proposed data) vs. aggregated estimates (obtained via combination of individual data, where contributors do not communicate with one another)
- Differences in responses auto manufacturers are able to provide in confidential vs. non-confidential environments
- Participation of a wider group of stakeholders (auto manufacturers, public agencies, station developers, equipment providers, and hydrogen suppliers) in review of the CHIT-led determinations
- Some stations in either method may be envisioned to or will ultimately serve the network in a connector station role rather than to build a local fueling market; however, in all projections for Panels B through E, all stations have been assigned vehicles as though they would be serving a local market. Differences in the number of connector stations in each scenario can therefore alter the relative number of vehicles that should be attributed to each county.

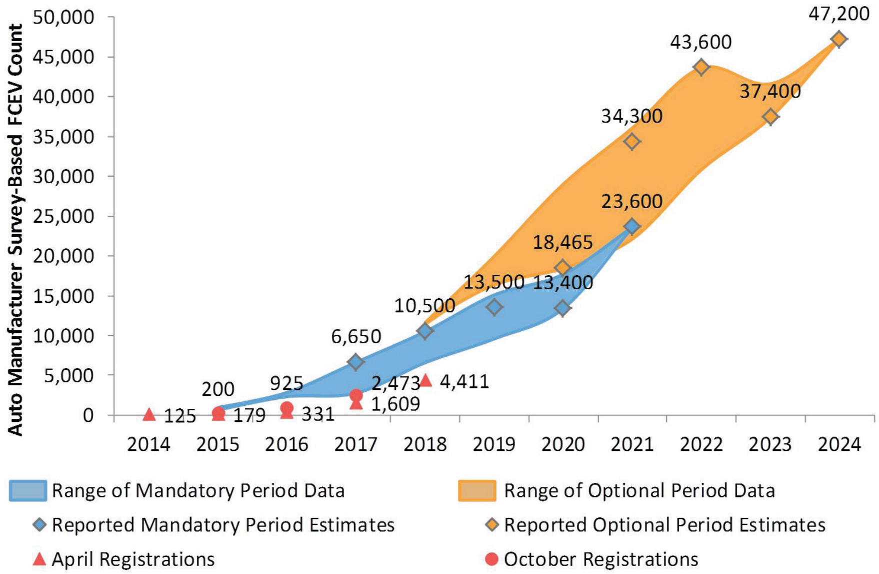
Figure 4: Comparison of CHIT and Auto Manufacturer Aggregate Predictions of FCEV Demand in Select Counties



Statewide FCEV registration and projection data for all years of Annual Evaluations (2014-2018) are provided in Figure 5. In the figure, October and April registrations based on DMV records are shown as red circles and triangles, respectively. The range of all auto manufacturer-supplied projections during survey mandatory periods is shown by the blue shaded area. The orange shaded area shows the same for the optional periods of all surveys. Diamonds within each show the end-of-period cumulative estimates reported by CARB each year.

Year-on-year registrations of FCEVs have continued to accelerate since the introduction of the first generation of consumer mass-market FCEVs in 2015. Since April of 2017, California's on-the-road FCEV fleet has gained a net 2,800 vehicles for a year-over-year growth rate of 174%. If the pace of deployment in the past year continues through the end of 2018, there may be between 6,800 and 8,300 FCEVs on California's roads before the start of 2019. These estimates would not match the highest reported projection recorded for 2018, but are well in agreement with the range of reported values over the past five years of surveys.

Figure 5: Comparison of FCEV On-The-Road Vehicle Counts in 2014-2018 Annual Evaluations



Based on the 2018 annual survey responses, the updated end-of-reporting-period FCEV estimates are 23,600 FCEVs in 2021 and 47,200 in 2024. Both of these estimates show a continuing expectation of growth in the FCEV fleet in the future. In particular, these estimates are along a deployment trajectory greater than the estimates reported in the 2017 Annual Evaluation for 2020 and 2023. This indicates a recovery in the auto manufacturers' reported expectation of the pace of FCEV deployment. CARB emphasized in its 2017 Annual Evaluation that several station network developments were contemporaneous with the distribution of the annual survey that year and these actions may have provided a temporary, downward influence on the auto manufacturers' future vehicle projections. By contrast, the past year has seen the addition of four more stations to the funded network and several other momentum-building developments in the public and private sectors related to hydrogen. Thus, it seems that the differences in the hydrogen fueling industry market conditions at the time of reporting has potentially had an effect on the auto manufacturers' vehicle projections from one year to the next.

Another positive development from the new vehicle projections is the crossover of mandatory and optional period projections shown for 2021. Prior to this year's survey, optional period estimates have consistently exceeded mandatory period estimates. In the past, this has likely been due to uncertainty in the station network development timing, though an auto manufacturer strategy of back-loading projections could not be completely ruled out. The 2021 overlap shown between mandatory and optional period projections serves as an important indication that auto manufacturers have not been artificially back-loading their reported projections.

Although the reported projections for FCEVs in the 2018 Annual Evaluation exceed those reported in 2017, the deployment schedule indicated by the auto manufacturers does not fully recover from the delay observed in 2017's Annual Evaluation. That is, compared to projections reported in 2016, this year's estimates show a continuing one-year delay over the short- and long-term. This does represent an improvement, as the 2017 estimates indicated the potential for up to a two-year delay in the long-term FCEV deployment projections compared to prior reporting.

Northeast and Zero Emission Vehicle States Optional Survey

In 2017, CARB requested information from auto manufacturers regarding their expected FCEV deployment in Northeast and other states that have adopted California's Zero Emission Vehicle regulation according to Section 177 of the Clean Air Act. CARB repeated this request for 2018, and as was the case in 2017 did not receive sufficient numbers of responses to this optional data request in order to provide detailed reporting. CARB's estimate therefore remains as described in the 2017 Annual Evaluation: for the Section 177 states, FCEV deployment projections are within the hundreds in the short-term and thousands in the long-term. Based on the experience gained in California, these projections and auto manufacturer planning likely depend heavily on the pace of hydrogen fueling infrastructure development and associated support programs within these states.

Location and Number of Hydrogen Fueling Stations

AB 8 Requirements: Evaluation of hydrogen fueling station network coverage

CARB Actions: Determine the regional distribution of hydrogen fueling stations in early target markets. Assess how well this matches projections of regional distribution of FCEVs in these markets. Develop recommendations for locations of future stations to ensure hydrogen fueling network coverage continues to match vehicle deployment.

Current Open and Funded Stations

Compared to the 2017 Annual Evaluation, there have been fewer changes in the set of open and funded hydrogen fueling stations over the past year. The most impactful changes have been[2]:

- The addition of the Beverly Hills, Mission Hills, Redwood City, and Studio City stations to the hydrogen fueling network through a second round of awards under GFO 15-605
- Three stations that encountered completion difficulties (North Hollywood, Rohnert Park, and Orange) are not included in this analysis; the removal of these stations from this analysis results in reduced assessment coverage in the respective nearby neighborhoods.

In addition to these changes, the timing of individual stations' projected opening dates have been updated, the Chino station has been added back into projected station counts, and the capacities of the stations awarded to FirstElement Fuel in GFO 15-605 have been updated to 500 kg/day [36]. With this edition of the Annual Evaluation, CARB has also transitioned to reporting all stations as Open based on their Open-Retail date. In the past, CARB has utilized a mix of Open-Retail, Open-Non-Retail, and Operational dates to indicate the start of stations' operations because there was a mix of pre-commercial and commercial-era stations in operation in California's hydrogen fueling network. Now, all pre-commercial stations have either ceased their operations, become Retail, or are currently under construction for an upgrade to Retail specification. Thus, stations that have been operational in the past but are currently undergoing upgrade construction are now reported on the basis of their expected future Open-Retail date. The first Open-Retail station in California's network was the West Sacramento station in 2015; for this reason, all station Open date reporting is now presented as 2015 or later.

The progression of hydrogen fueling station deployment by county and statewide accounting for these changes is presented in Figure 6; individual station Open dates are displayed in Figure 7. As of June 30, 2018 there are 36 Open-Retail stations statewide[1]. This includes the Newport Beach station, which had originally been co-funded by the State of California under a grant program prior to the establishment of an Open-Retail station definition. In the second quarter of 2018, the station was upgraded to full Retail operational capability. While this station as it now operates was not funded by ARFVTP, CARB includes it in reporting and analysis in order to maintain a complete picture of the current hydrogen fueling station network as available to all FCEV drivers. In the future, CARB anticipates continuing to include any stations without State co-funding in its reporting and analyses to ensure that its recommendations of needs for additional stations are fully informed and to minimize the risk of over-saturating redundancy where it may not be needed.

2 The planned network discussed and analyzed in this Annual Evaluation is current as of June 1, 2018. Changes to the planned network may occur between June 1, 2018 and the time of publication but are not represented in this Annual Evaluation.

Figure 6: End of Year Open-Retail Station Projections by County and Statewide (as of June 1, 2018)

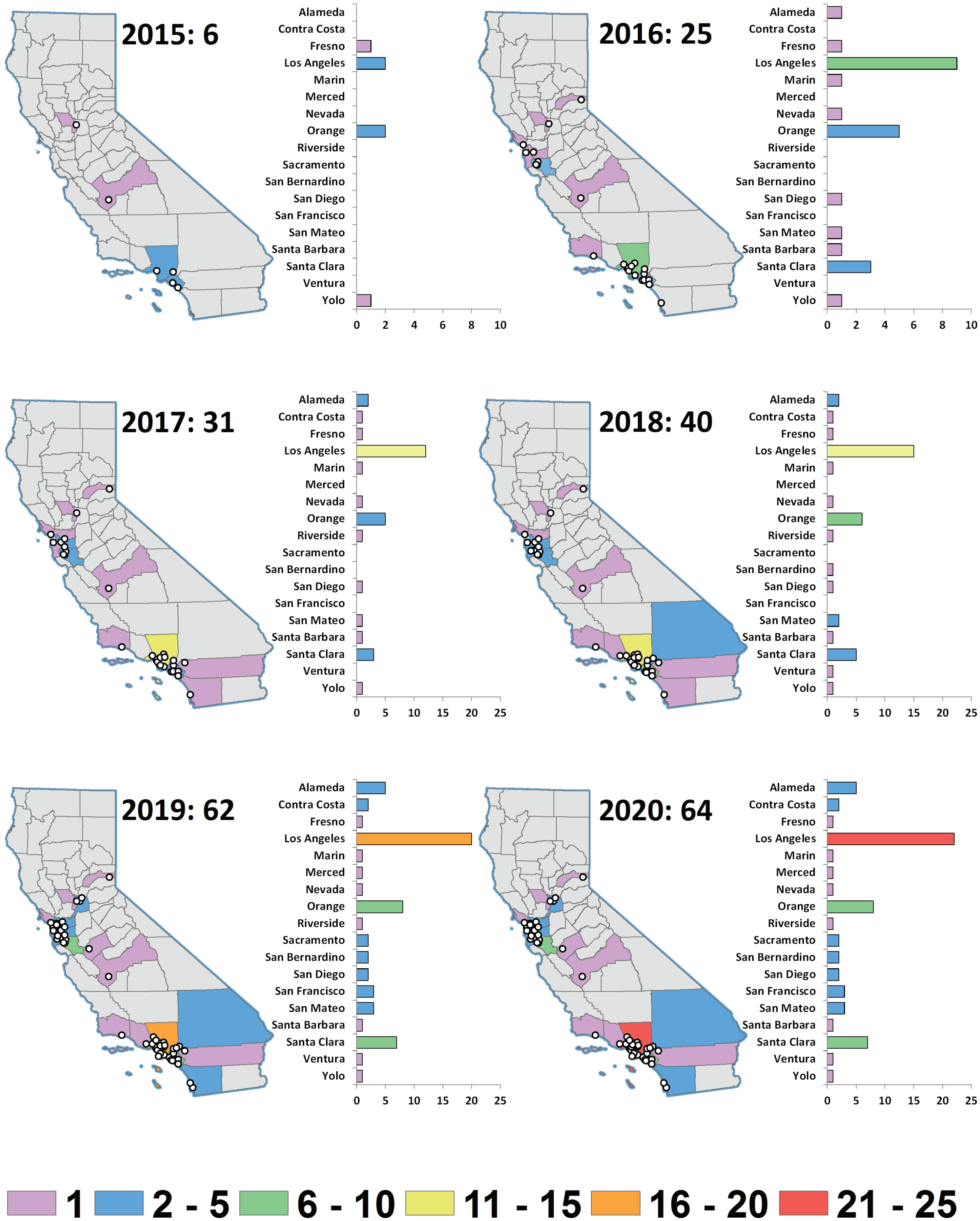
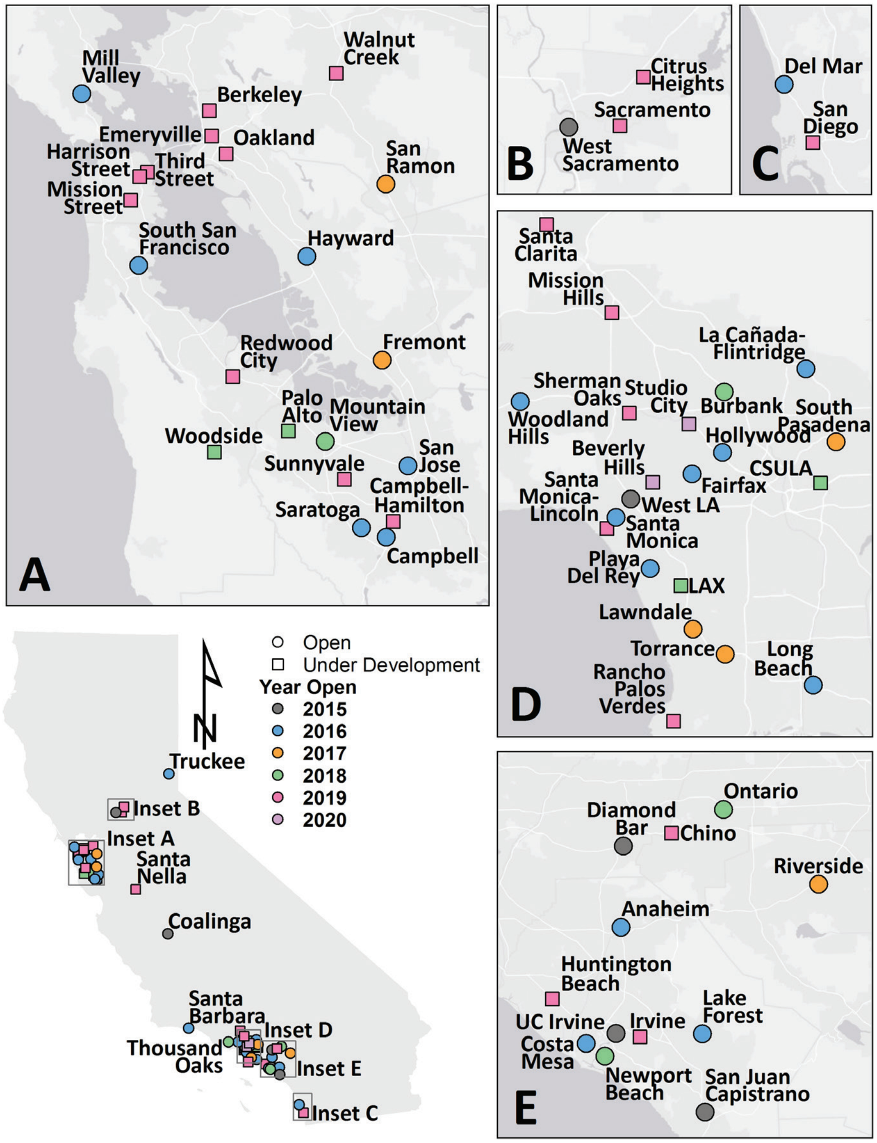


Figure 7: History and Projections for Open-Retail Stations and Funded Hydrogen Station Network

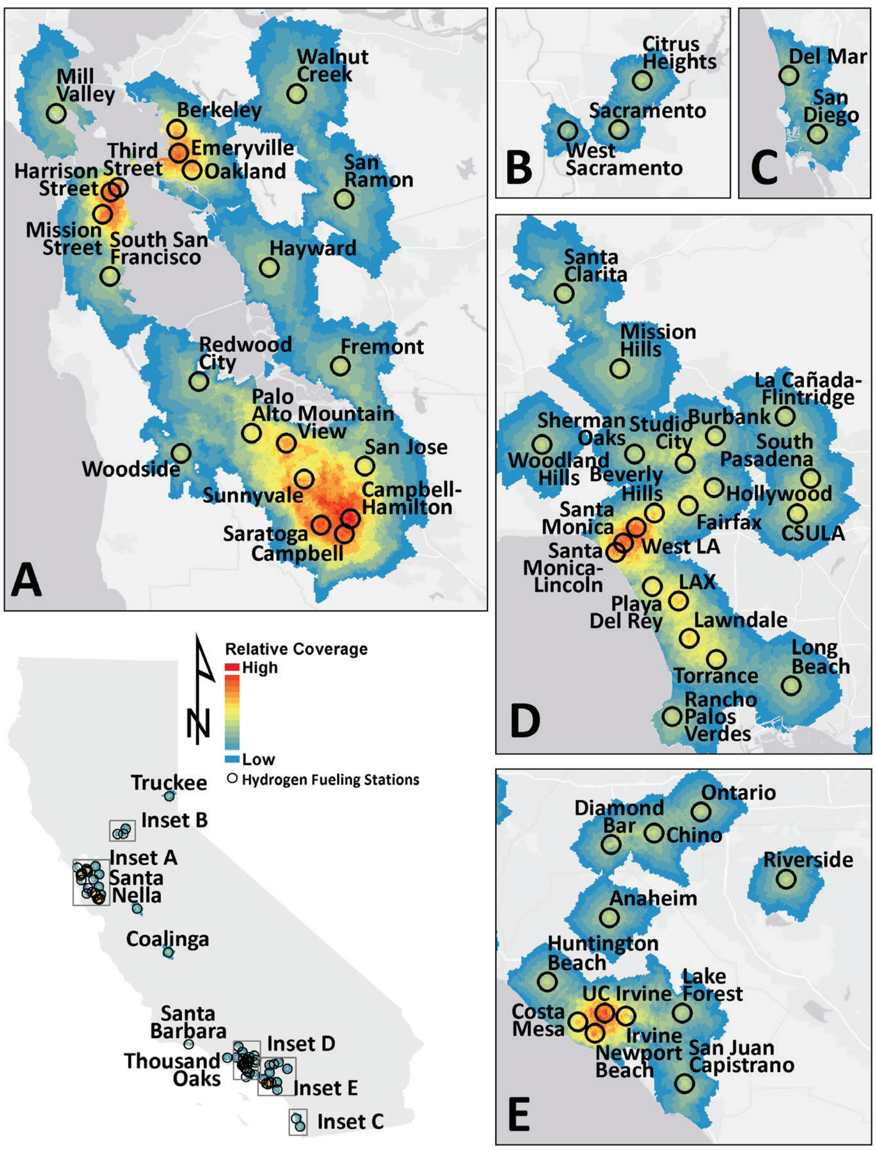


As adopted by AB 8, and initially proposed by earlier forward-thinking studies and analyses, CARB analyzes the needs for further hydrogen fueling network development on the basis of two complementary metrics: coverage and capacity. Coverage is a purely geographical metric. It defines how well a station or network of stations provides convenient fueling access throughout the state. In CARB's analyses, coverage provided by a station(s) to an area increases as the distance to a fueling station decreases and as the number of stations within a convenient distance increases. CHIT has been developed by CARB and utilized in analyses since 2015 in order to provide consistent annual assessment of network coverage according to these principles.

CARB additionally utilizes CHIT to generate an estimate of the market strength for FCEV adoption across the state and compares this geographically varying market intensity to the assessment of coverage provided by the Open and funded hydrogen fueling network. This comparison leads to the determination of a coverage gap. As the disparity between relative market strength and relative coverage increases, CHIT indicates a greater need for the addition of new hydrogen fueling stations in an area. In addition, in recent years CHIT has been further developed to help CARB assess how well capacity needs for the projected FCEV fleet are met by the Open and funded station network. Similar to coverage, the greater discrepancy between local installed capacity and local demand, the greater the capacity gap CHIT indicates for the area. The latest version of CHIT (2017 Release) is a publically-available tool, with all input and output data provided for analysis of California. The tool may be downloaded, data explored, and analyses run by any interested party[3]. In addition, the tool is flexible enough that similar data for other regions can be implemented to perform an analysis for any given jurisdiction.

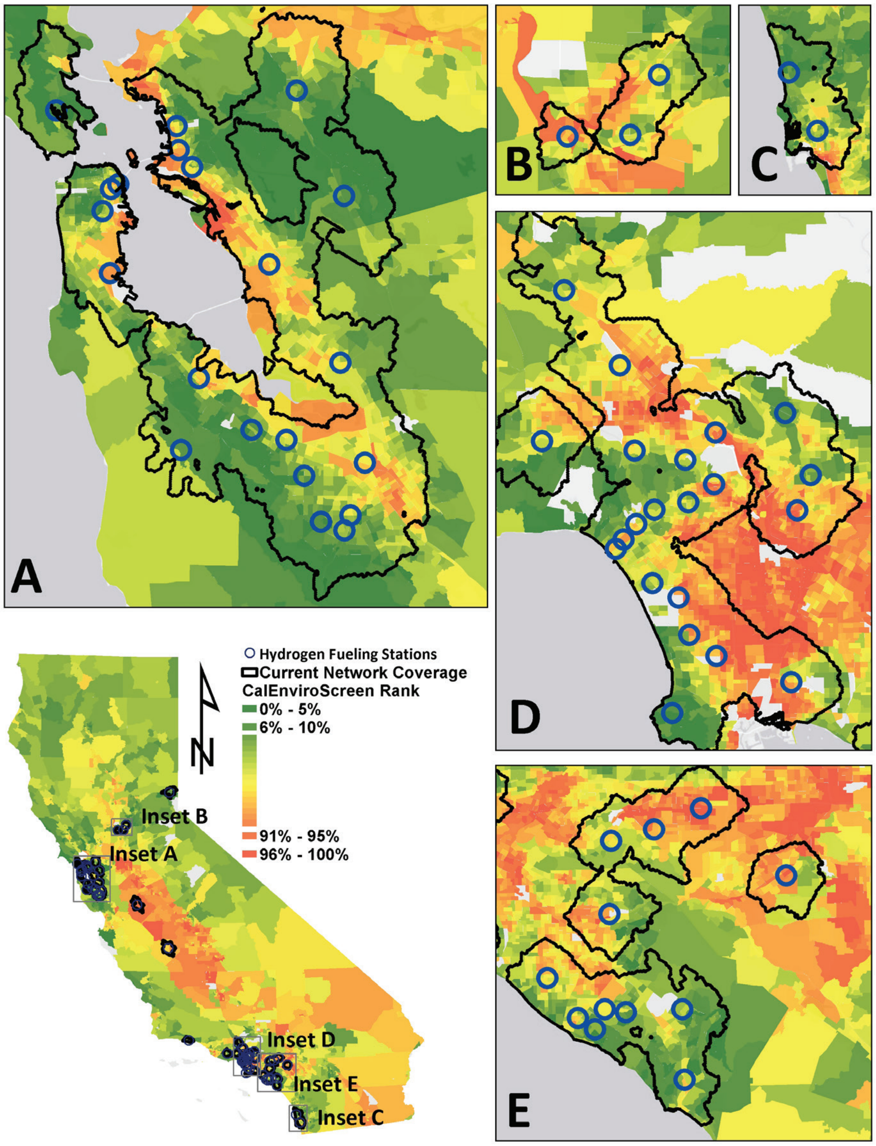
The coverage provided by the currently Open and funded hydrogen fueling network is shown in Figure 8. Areas with red shading represent locations where the hydrogen fueling network imparts a high degree of coverage because there are multiple fueling stations available to local drivers within a short drive (in terms of drive time). Areas with a light blue color are at the furthest extent that CARB considers a hydrogen fueling station provides access for FCEV drivers' daily needs. In CARB analyses, this is taken to be a 15-minute drive. Currently, the highest degrees of coverage are focused in San Francisco, between Oakland and Berkeley, in the southwest end of the San Francisco Bay near Saratoga and Campbell, in West Los Angeles between Hollywood and Santa Monica, and in Orange County near Costa Mesa and Irvine. Although there are many regions where the coverage of individual stations is coalescing to provide redundancy, there are still some regions with limited numbers of nearby fueling options. These primarily include inland parts of Orange and Riverside Counties, San Diego, the Sacramento area, and the connector and travel destination stations (Coalinga, Truckee, and Santa Barbara).

Figure 8: Assessment of Coverage Provided by Existing and Funded Stations



3 www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm. The CHIT tool and user manual are available as a 5.3GB ZIP file under the heading "Full CHIT 2017 Release Download Package." The page also contains several reference materials for users and researchers alike to become familiar with the tool's operation and its ongoing development.

Figure 9: CalEnviroScreen 3.0 [37] Identification of Environmentally Burdened and Vulnerable Communities Compared to Hydrogen Fueling Station Network



Disadvantaged Communities

Providing fueling coverage that matches well spatially and temporally to the anticipated market demand is a key part of the State's and its partners' strategy to ensuring the success of the FCEV market launch. AB 8 established as policy in California the need for hydrogen fueling infrastructure to precede FCEV deployment. Potential FCEV adopters must feel comfortable in the opportunities to fuel on their daily travels, and the most impactful way to provide sufficient assurance of fueling opportunities is to develop a network that provides coverage to the adopters' needs. However, the State also broadly maintains goals to ensure equity in the benefit gained by the deployment of advanced technologies with the potential to reduce greenhouse gas emissions and local criteria and toxic pollutant emissions.

The California Global Warming Solutions Act (SB 535; De León, Chapter 830, Statutes of 2012) directed the California Environmental Protection Agency to develop a methodology for identifying Disadvantaged Communities (DACs) [38]. Under this directive, the Office of Environmental Health Hazard Assessment (OEHHA) and CARB collaborated to develop the CalEnviroScreen (CES) tool. The tool represents geospatial analysis of localized pollution burden and demographic indicators to identify communities that face a combination of disproportionate environmental burden and socio-economic vulnerability. Within the context of CES, communities are identified by their census tract and assigned a score based on the socio-economic and pollution burden indicators. DACs are those communities with either the top 25% of scores or have a pollution burden in the top 5%.

CES scores are shown in Figure 9 with an overlay of the extent of the coverage provided by the Open and funded hydrogen station network. The locations of the hydrogen fueling stations themselves are indicated by blue rings centered on the stations' addresses. Currently, 12 (19%) of the 64 funded stations are located directly within a DAC; as shown in Table 1, 1% of all California residents living within a DAC are in these 12 particular communities. This is equivalent to the proportion of people statewide (whether within a DAC or not) that live in a census tract that hosts a hydrogen station, as 309,019 of the state's approximately 37,000,000 residents reside in the same tract as a station.

Table 1: Analysis of Coverage Provided by Funded Station Network to Disadvantaged Communities as Identified by CalEnviroScreen 3.0

CalEnviroScreen Score	Count of Stations	Population in Station Home Tract	Population in 15-Minute Coverage	Percent of CA Population in 15-Minute Coverage	Percent of Covered Population
Non-DAC Subtotals:	52	262,415	12,118,311	32.5%	79%
DAC Subtotals:	12	46,604 (~1% of all DAC)	3,238,482 (~35% of all DAC)	8.7%	21%
Totals	**64**	**309,019**	**15,356,793**	**41.2%**	**100%**
For Reference: CalEnviroScreen Indicates 9,152,024 Residents Living in Disadvantaged Communities					

However, any given fueling station likely serves a community of drivers that includes the local community and drivers in nearby communities or whose travels take them near the station. In order to assess alignment between the hydrogen station network and DACs for this wider user base, CARB also compares the geographical alignment between 15-minute coverage provided by the hydrogen station network and populations living within DACs. Although DACs are defined by census tracts, CARB bases the count of populations within the network's coverage on the locations of block population counts, which offer the greatest degree of precision available. As shown in Table 1, more than 3 million residents living within a DAC are also within convenient reach of a hydrogen fueling station. This represents slightly more than one-third of the state's full DAC population. In addition, the proportions of the covered population within and outside of DACs are respectively 21% and 79%, approaching the expected ratio per the definition of DACs.

Trends of Station Deployment Rates

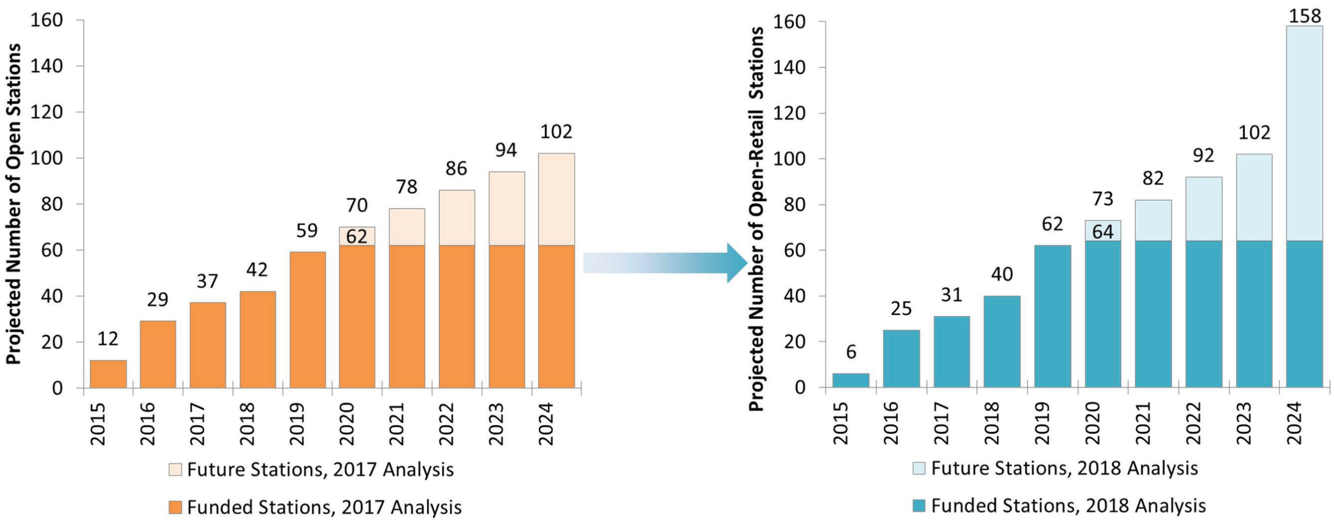
Historical and future expectations of hydrogen fueling station network growth in the 2017 and 2018 Annual Evaluations are provided in Figure 10. Historical (2015 and 2016) Open station records in the 2017 analysis exceed the 2018 analysis because 2017 data reflect a combination of Open-Retail and Non-Retail stations, whereas 2018 data are limited to Open-Retail stations. In addition, although scenarios have been developed for station development to 2030, the 2018 data in Figure 10 only include projections to 2024. This is to maintain consistency with the furthest year of FCEV deployment projections as has been the convention in previous Annual Evaluations and because this is the furthest year at which projected demand and supply can be compared.

By the end of 2017, fewer stations were open than anticipated in June of last year; however, the current number of Open stations (36) essentially matches the prior expectation for 2017, indicating that total station counts are delayed by less than a full year. This marks a clear departure from previous years' reporting, which found at least a one year delay in station network development year-on-year. There do remain stations under development that have taken much longer to develop than anticipated and the network average. However, there are now exceedingly few of these stations; as previously reported, these are mostly stations from the earliest funding programs and likely represent outliers in the data.

Looking forward, CARB had previously projected business-as-usual growth of an average of eight hydrogen fueling stations to be funded per annual allocation of $20 million. Expansion of the early commercial market and growth into full commercialization by 2030 or sooner requires a pace of station network development far exceeding this previous business-as-usual scenario. The earliest that CARB assumes any newly-funded stations could become Open-Retail is 2020, implying six rounds of station funding to reach 200 hydrogen fueling stations by 2025 (assuming all of these stations will require co-funding through AB 8). Thus, an average of approximately 23 new stations will need to become Open-Retail each year from 2020 through 2025.

This is a significantly faster pace than the historical business-as-usual case, but strong commitment in State co-funding will help incentivize industry stakeholders to make the necessary investments to meet this production pace in time. Without State initiative now, the upstream development would likely take much longer and deployment of FCEVs would be delayed beyond the projections presented in this report. Still, CARB assumes that upstream investments and production capacity growth will take a few years to reach the magnitude ultimately required for an accelerating expansion of the hydrogen fueling network.

Figure 10: Comparison of Statewide Station Projections between 2017 and 2018 Annual Evaluations[4]



Because of the time necessary for industry to ramp up to these requirements, CARB's scenario analysis assumes an up-front delay of four years before which hydrogen station deployment can significantly ramp up. This deployment schedule is also in keeping with original AB 8 requirements of 100 stations by 2023. This ramp period is likely a conservative estimate and used merely for analysis and reporting purposes. As the Energy Commission has already discussed, the revised ARFVTP Investment Plan for fiscal year 2018-2019 addresses EO B-48-18 and its accompanying proposed budget by allocating $92 million for hydrogen refueling infrastructure investment in the next year [39]. If all of these funds were to be used for light-duty hydrogen fueling stations, then more than 40 stations could be funded with fiscal year 2018-2019 funds. The actual schedule of deployment required of these stations has yet to be determined. For example, industry feedback has asked for a multi-year planning and funding program; thus, commitment of 40 stations' worth of funding in 2018 may not necessarily imply all 40 stations will be required to open in the same year. Taking all these factors together, CARB's best estimate for the next few years is as shown in Figure 10.

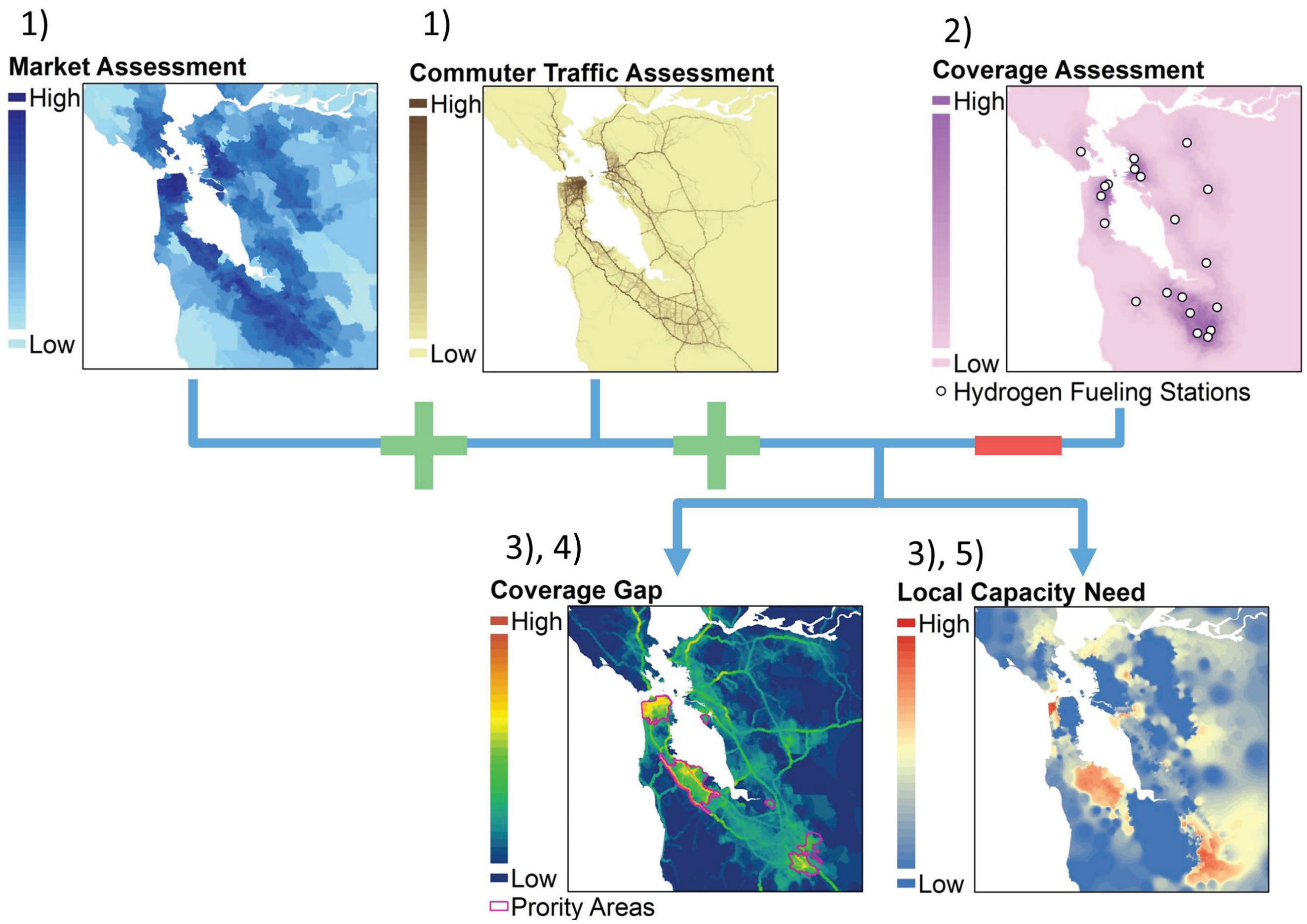
2018 CHIT Evaluation Process

In September of 2017, CARB made the latest version of its geospatial hydrogen network analysis tool, CHIT, available to the public. This latest Release version included several updates that were described in the 2017 Annual Evaluation and subsequently discussed in a November 2017 webinar. The latest version of CHIT built on the capabilities of the original tool first posted in 2015 and added key features such as

4 The 2018 rate of future station deployment in 2020-2023 for the 2018 analysis differs slightly from a projection recently shared by the Energy Commission at a May 14, 2018 workshop to discuss strategies for meeting the goals of EO B-48-18. In that workshop, the Energy Commission presented a potential rate of 11 stations per year for the same timeframe. That projection is based on an analysis of available funds, which differs from the scenario analysis presented here.

consideration of traffic data, inclusion of DMV registration and auto manufacturer survey data, and several process improvements. This same version has been utilized for 2018 analysis as the basis for determining recommended locations for future station funding.

Figure 11: CHIT Evaluation Process Comparing Market and Coverage Assessments to Determine Coverage Gaps and Capacity Need



In order to perform analyses of accelerating FCEV and hydrogen fueling market expansion, CARB has developed a new analysis framework incorporating the existing CHIT 2017 Release capabilities. Fundamental properties and processes remain as provided in the publicly-released version; however, an additional automated analysis framework has been built around these tools in order to provide the capability to project various scenarios of station network buildout. In particular, the fundamental capabilities that remain unchanged for scenario analysis are as shown in Figure 11:

1. **Market and Commuter Traffic Assessment:** Assess the relative strength of the FCEV first adopter market across the state according to various demographic and vehicle market indicators and observational data from the developing FCEV market
2. **Coverage Assessment:** Assess the relative degree of hydrogen fueling station coverage across the state
3. **Coverage Gap:** Compare coverage, market, and commuter traffic assessments to determine gaps in hydrogen fueling network coverage
4. **Priority Areas:** Utilize geostatistical methods to analyze patterns in the spatial distribution of coverage gap, and identify and prioritize greatest coverage needs
5. **Local Capacity Need:** Distribute projected vehicle population according to the market assessment, calculate localized hydrogen demand, and new capacity needs

Based on input parameters that define local market and traffic-based hydrogen fueling demand, paired with a quantified assessment of station network coverage, CHIT provides statewide determinations of localized need for increased hydrogen station network coverage and capacity. In addition, the tools in CHIT are able to perform analysis of coverage gap maps to identify priority areas (defined as the coalescence of high coverage gap scores that are statistically similar to each other but different form scores in the surrounding communities). These three determinations - coverage gap, capacity need, and priority areas- have formed the basis of CARB's analyses and recommendations for additional station location needs in prior years. The scenario analysis capability developed for this year's determinations (and covered in greater detail in Appendix D) builds on these features to iteratively:

- Combine coverage and capacity gap analyses into a single metric of overall station need to define modified priority areas
- Identify an optimized station placement within priority areas
- Quickly re-calculate coverage and capacity gaps after the inclusion of new station(s)
- Analyze the modified coverage and capacity assessments for the next iteration of station placement

Initial conditions for the iterative process were informed by the analysis of the current status of the hydrogen fueling network. In addition, the 2017 auto manufacturer-based projections for vehicle deployment by county served as an input to the market estimation process. These data are tracked and maintained in CARB's California Hydrogen Accounting Tool (CHAT). CHAT is a Microsoft Access database and collection of queries used to track DMV registrations of FCEVs, auto manufacturer responses to annual FCEV production surveys, and station operational and development status in order to project on-the-road FCEV counts, their associated hydrogen demand, and the expected available fueling capacity on a county and statewide basis. Interactions between CHIT and CHAT and their relationships with key outputs in CARB's annual analyses are shown in Figure 12.

The ultimate goal of the scenario analysis was to project the station network development necessary to meet the Governor's Executive Order goal of 200 hydrogen fueling stations by 2025 and the further goal adopted by the members of the California Fuel Cell Partnership for 1,000 hydrogen stations by 2030 that enable the deployment of 1,000,000 cumulative FCEVs. CARB relied on a collaborative process of analysis, review of results, and adjustment of analysis parameters carried out with the public and private members of CaFCP. Ultimately, CARB defined a set of station and location selection parameters that enabled the automated determination of station network growth to 2030 that meets the above stated goals. The maps shown in Figure 13 represent the status of the current hydrogen fueling network and the network projected for 2025 and 2030 through this scenario analysis framework.

These data outputs from the network development scenario, along with the intermediate data like the underlying Priority Area determinations, and post-processing of results (such as regional aggregations) form the basis of CARB's recommendations for future station locations to receive State co-funding. In particular, CARB has limited the recommendations to those applicable to reaching 200 hydrogen fueling stations by 2025. Future recommendations may continue to reference the same station network development and include the later years to 2030.

FIGURE 12: THEMATIC OVERVIEW OF CHIT/CHAT TOOLS, INPUT DATA, AND OUTPUT GOALS

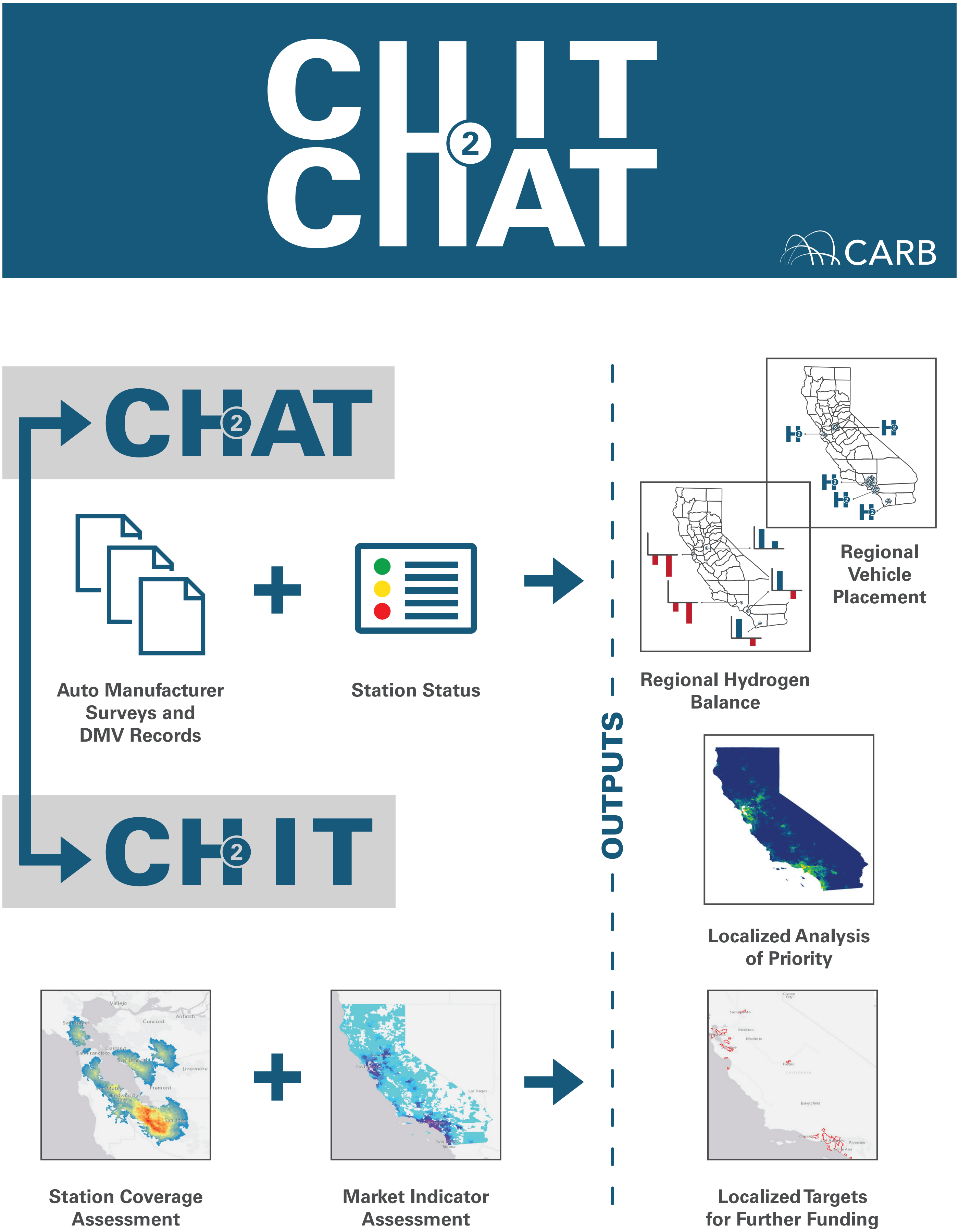
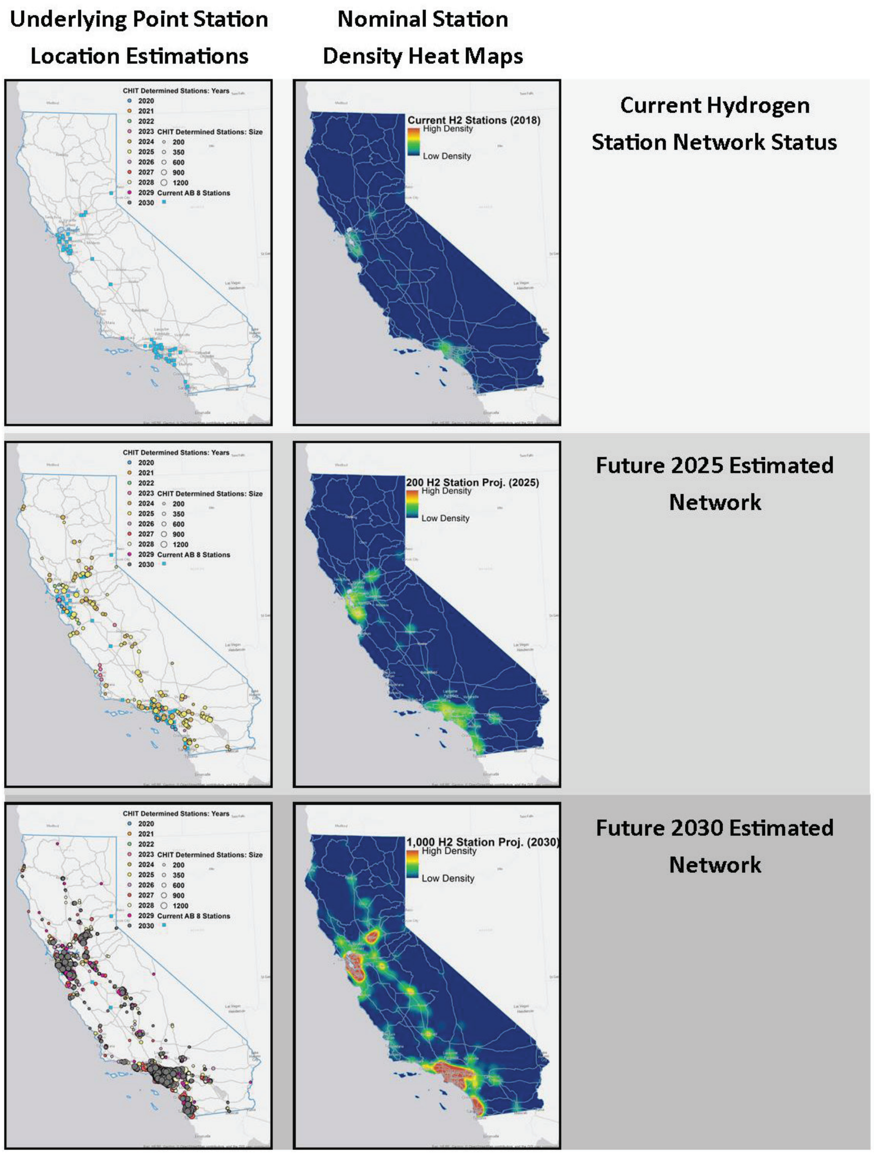


Figure 13: Projections of Potential Hydrogen Station Network Development from Present-Day to 2030 through CHIT Evaluation[5]



Suggested Station Counts and Locations for Future State Co-Funding

The station network development projected through the CaFCP Vision effort represents a quantitatively derived, ordered set of hydrogen fueling stations that is projected to meet the evolving coverage and capacity needs of an established and accelerating FCEV market. The determinations of this effort provide several opportunities for developing sets of recommended station locations for future Energy Commission Grant Funding Opportunities, such that all stakeholders and interested parties can work towards and track the common goal advanced by the CaFCP Vision. In addition, because the location determinations were largely informed by CHIT analyses, these determinations remain self-consistent with past methods used for CARB's recommendations and should remain consistent with any future adjustments.

CARB recommends that three sets of data related to the CaFCP Vision effort may serve as a suite of guiding input for the Energy Commission's next GFO. In order of recommended emphasis, these are:

- Heat maps of density of hydrogen fueling stations projected for 2025
- Priority areas bounding individual hydrogen fueling stations through 2025
- Individual locations of hydrogen fueling stations through 2025

5 See Appendix D for larger, full-resolution versions of these figures.

Heat maps of hydrogen fueling station density, such as those shown in Figure 13 and Appendix D, provide the most flexible quantitative basis for determining where new stations are necessary to support the goals of EO B-48-18. Referencing the point densities represented by the heat maps provides a sense of the urgency for an individual hydrogen fueling station in any given or proposed location. This can be useful for a high-level sense of prioritization among various regions. For example, referencing Figure 49 in Appendix D, stations in the core market areas still remain the most important (Greater Los Angeles, Orange County, San Francisco Bay Area, and Sacramento), but there are also secondary market areas (San Diego, Fresno, Desert Cities, Sacramento-San Joaquin Valley Delta cities) that can be identified as distinct from the remainder of the state. Thus, these heat maps can be used to determine relative importance of individual station locations as judged against one another.

Although the values represented by the heat maps do indicate physical and quantifiable measures (numbers of stations per square mile), they are interpolated and continuous. Thus, it is not readily determined from the heat maps alone how close stations should be to one another, the relative sequencing, nor the estimated capacity needed at each station. These can be provided by referencing the priority area and station location maps. Priority areas that determined all hydrogen fueling station locations through 2025 are provided in Figure 14, tiered by their order of determination. Tier 1 (also shown in greater detail in Figure 15) represents all stations that were identified for development in years 2020-2023, Tier 2 (Figure 16) shows all 2024 stations, and Tier 3 (Figure 17) shows all 2025 stations. CARB recommends that the tiers be used as a template and not a recipe; it is not necessary to develop all Tier 1 stations prior to any Tier 2 or Tier 3 station, but given the choice between a Tier 1 and Tier 2 station, it is likely the Tier 1 is more preferable. The numbers on each detailed map show the number of stations recommended for each priority area. Also, it should be noted that some of the priority areas between Tiers actually overlap. This demonstrates the need in some areas for continued and persistent network development to enable projected vehicle deployment rates.

These priority areas, along with stakeholder input, can be used in combination with the heat maps to determine the appropriate number of stations to place in preferential areas across the state. For example, the Greater Los Angeles area will need the greatest concentration of station development through 2025, with an estimated total 20 additional stations beyond those already funded in the region by 2025. At the same time, Sacramento County demonstrates four distinct priority areas, with an estimated need for six total stations. In both of these cases, the stations are spread among all three tiers.

Thus, while some areas within each region may be more preferential than others, it is not necessary to fund all of these stations in each region before funding any stations in other regions across the state. In fact, Figure 15 through Figure 17 demonstrate a need to spread station development across the state over the next several years, but can also provide necessary information to determine which regions should receive greater or lesser concentration of new stations to maintain statewide balance. From a market development perspective, such spread of station locations may also enable broader FCEV adoption due to the regional spread and the increased utility imparted by a geographically extensive network.

In past Annual Evaluations, CARB has provided tables of priority areas; however, they are too numerous to list and textually describe in this report with accuracy. CARB has been working with the Energy Commission on sharing CHIT-related data across agencies and with the public digitally for several years, and will continue to find ways to keep these data accessible in an interactive and digital form that remains practical and effective at communicating CARB's findings.

Finally, the individual station locations as shown in Figure 13 and Figure 48 can be referenced in cases where there is a need for fine resolution of order of preference for a station(s). Each station presented in these and similar figures throughout the report was determined sequentially and iteratively, thereby providing some information regarding their relative importance. However, these determinations are also dependent on assumptions and evaluations of the rate of FCEV market development across the state and so may require adjustment in the future should the actual market development proceed differently than estimated. Thus, CARB recommends applying the greatest scrutiny when referencing these data for station location determinations.

In addition to ordering, the individual point locations also provide information regarding the appropriate station capacity for each location (again, within the bounds of market and technology development assumptions). These data can therefore be referenced to help determine the needed capacity in any given region or the appropriateness of a proposed station's capacity to the local projected need.

FIGURE 14: PRIORITY AREAS FOR ALL APPROXIMATE STATION LOCATIONS TO 2025, TIERED BY ORDER OF SELECTION IN CHIT VISION PROCESS

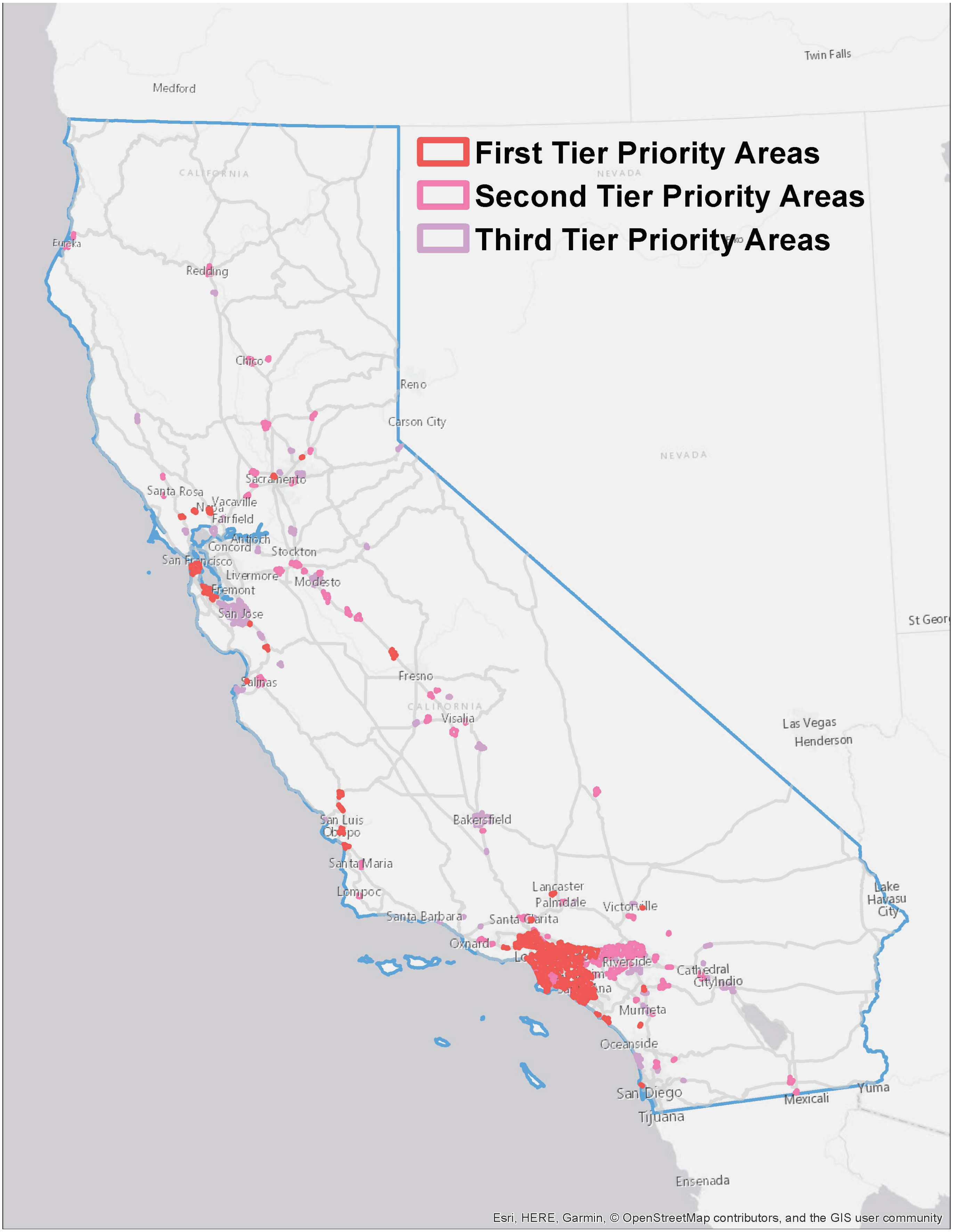
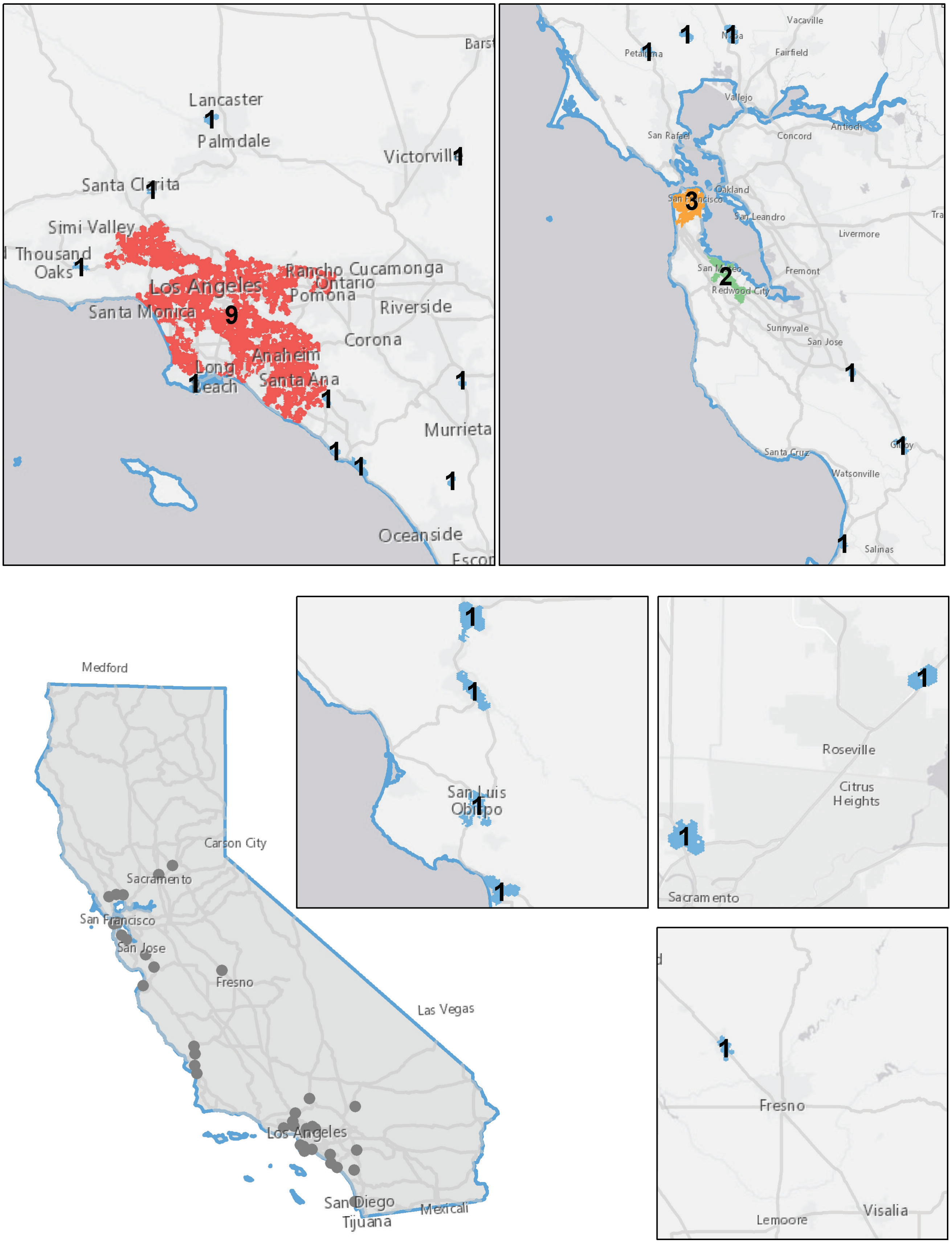
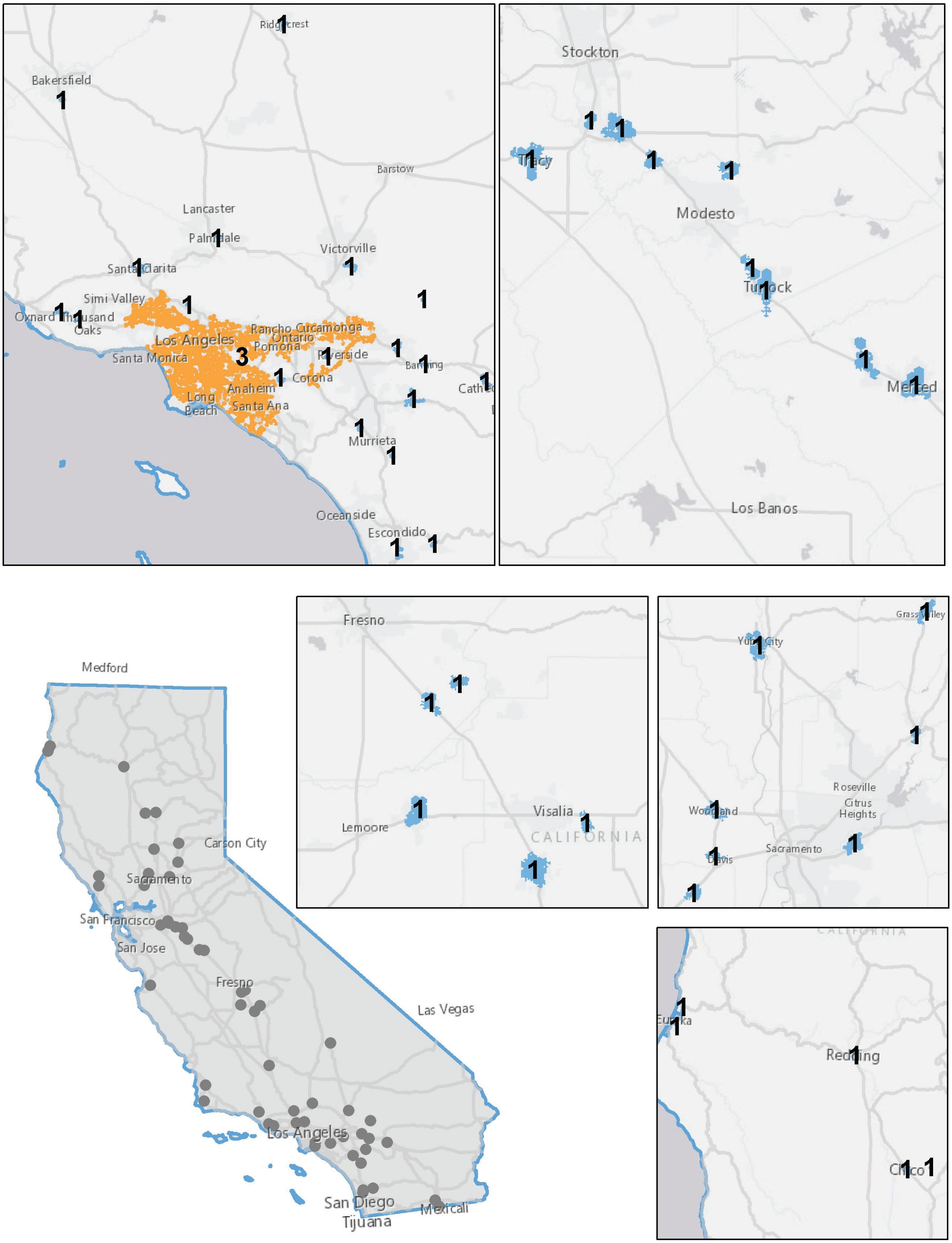


Figure 15: Tier 1 Priority Areas[6]



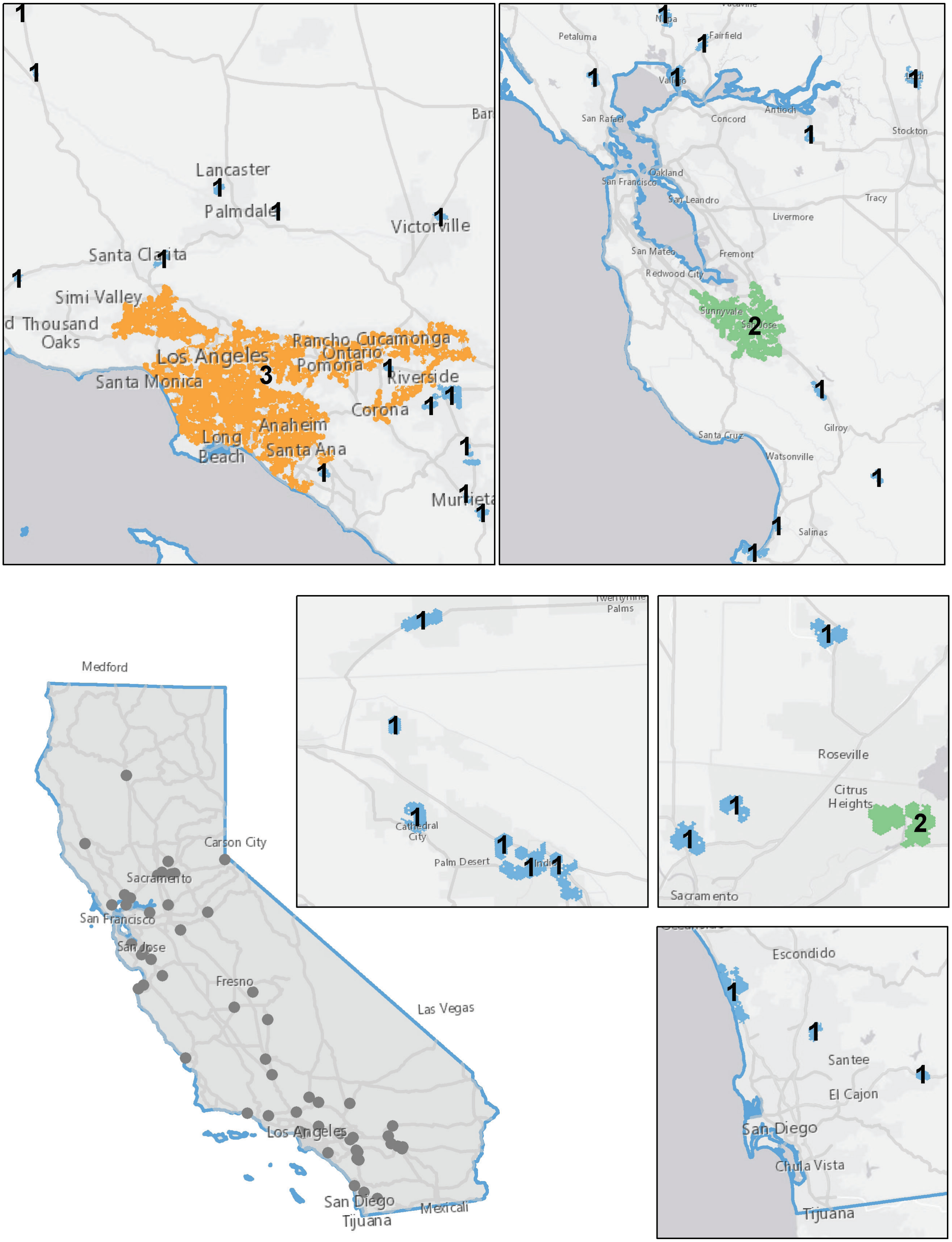
6 Numbers in Figure 15 through Figure 17 indicate the recommended count of stations within each priority area.

Figure 16: Tier 2 Priority Areas[7]



7 Numbers in Figure 15 through Figure 17 indicate the recommended count of stations within each priority area

Figure 17: Tier 3 Priority Areas[8]



8 Numbers in Figure 15 through Figure 17 indicate the recommended count of stations within each priority area

The deployment strategy for the stations shown in Figure 14 through Figure 17 and in Appendix D is fundamentally designed to anticipate network development to meet the needs of an expanding population of FCEV adopters. These figures demonstrate the spatial expansion of the user base. This is an outcome of underlying input assumptions to the scenario analysis of expanding the user base in terms of socio-economic indicators. CARB's analysis anticipates that in order to meet a 1,000,000 FCEV goal by 2030, vehicle adoption can only be restricted to first adopters for a limited period of time. The scenario analysis relaxes the first adopter constraint as progressively more stations are developed in the network in later years of the analysis.

As the FCEV adopter base broadens, so should the coverage of the hydrogen fueling network expand into the full spectrum of California's communities. CARB performed assessments of the 2025 and 2030 projected hydrogen fueling network's coverage of DACs similar to the analysis shown in Figure 9 and Table 1. The future station network's coverage of disadvantaged communities is shown in Table 2 for 2025 and Table 3 for 2030. While today's funded network can provide convenient hydrogen fueling access to a little more than a third of today's DAC populations, the anticipated 2025 and 2030 networks are able to grow the covered DAC population to two-thirds and nearly complete coverage by 2025 and 2030, respectively. In addition, the proportion of the population with convenient hydrogen fueling station coverage that also lives in a DAC grows to 22% and 25% in 2025 and 2030, respectively. Thus, by 2030, the hydrogen fueling network is anticipated to benefit DAC communities exactly proportionally to the population within DACs, per the adopted definition.

Table 2: Analysis of Coverage Provided by Projected 2025 Station Network to Disadvantaged Communities as Identified by CalEnviroScreen 3.0

CalEnviroScreen Score	Count of Stations in Future Priority Areas*	Population in Priority Areas	Population in 15-Minute Coverage	Percent of CA Population in 15-Minute Coverage	Percent of Covered Population
Non-DAC Subtotals:	90	11,132,795	19,891,957	53.4%	78%
DAC Subtotals:	60	6,173,682 (~67% of all DAC)	5,546,730 (~61% of all DAC)	14.9%	22%
Totals	**150**	**17,306,477**	**25,438,687**	**68.3%**	**100%**
For Reference: CalEnviroScreen Indicates 9,152,024 Residents Living in Disadvantaged Communities					

* Counts for Priority Areas include all Priority Areas that partially or wholly overlap a DAC. Data for populations in Priority Areas and 15-Minute Coverage are exact and only include population wholly contained within both the DACs and either Priority Areas or 15-Minute Coverage

Table 3: Analysis of Coverage Provided by Projected 2030 Station Network to Disadvantaged Communities as Identified by CalEnviroScreen 3.0

CalEnviroScreen Score	Count of Stations in Future Priority Areas*	Population in Priority Areas	Population in 15-Minute Coverage	Percent of CA Population in 15-Minute Coverage	Percent of Covered Population
Non-DAC Subtotals:	403	17,704,848	26,199,288	70.3%	75%
DAC Subtotals:	597	7,663,418 (~84% of all DAC)	8,883,966 (~97% of all DAC)	23.8%	25%
Totals	**1,000**	**25,368,266**	**35,083,254**	**94.1%**	**100%**
For Reference: CalEnviroScreen Indicates 9,152,024 Residents Living in Disadvantaged Communities					

* Counts for Priority Areas include all Priority Areas that partially or wholly overlap a DAC. Data for populations in Priority Areas and 15-Minute Coverage are exact and only include population wholly contained within both the DACs and either Priority Areas or 15-Minute Coverage.

Insights for CHIT Provided by CVRP Survey Responses

In addition to State co-funding of hydrogen fueling stations, California provides ZEV and Plug-In Hybrid Electric Vehicle (PHEV) adopters with consumer incentives through the Clean Vehicle Rebate Project. Californians who purchase or lease an eligible vehicle and choose to receive a cash rebate from the State are invited to participate in a voluntary survey process. For FCEV adopters, the available survey has thus far focused on purchase decisions and early ownership experiences. Now in its second year, 640 total responses have been received from FCEV adopters (approximately 15% of all current FCEV registrations). Responses from the survey have the potential to inform CARB's and the Energy Commission's deliberations and analyses for projected market growth of FCEVs and the actions necessary to meet drivers' needs.

In particular, CARB intends to use the CVRP survey responses as one of several information resources it leverages to guide its assessments of the developing FCEV first adopter market and the associated infrastructure needs. Survey responses may provide insights into the set of demographic indicators that are relevant to projecting the location and strength of the first adopter market across California. Responses may also be used to validate assumptions within CHIT regarding FCEV drivers' fueling preferences and behaviors. A select set of insights are presented below.

Characterizing the FCEV First Adopters

At nearly 5,000 vehicles, the FCEV adoption market is clearly in its first adopter phase. Analyses performed by CHIT have acknowledged this early stage of market development and sought to identify likely FCEV adoption markets based in part on established observations of demographic indicators for technology first adopters in general. Two key aspects of this assessment include highest educational attainment in first adopters' households and the distribution of reported income among first adopters. These are shown in Figure 18 and Figure 19, respectively. In agreement with prior observations, FCEV first adopter households tend to have high levels of educational attainment. As first reported in the 2017 Annual Evaluation, the household income of FCEV first adopters appears potentially bimodal; however, the distribution of incomes has since shifted downward, with the lower peak centered on household incomes of \$100,000 - \$125,000. This is a lower income than assumed in CHIT for market evaluations and may be influenced by the availability of CVRP rebates as well as auto manufacturer-supplied fuel cost incentives.

Figure 18: Highest Educational Attainment

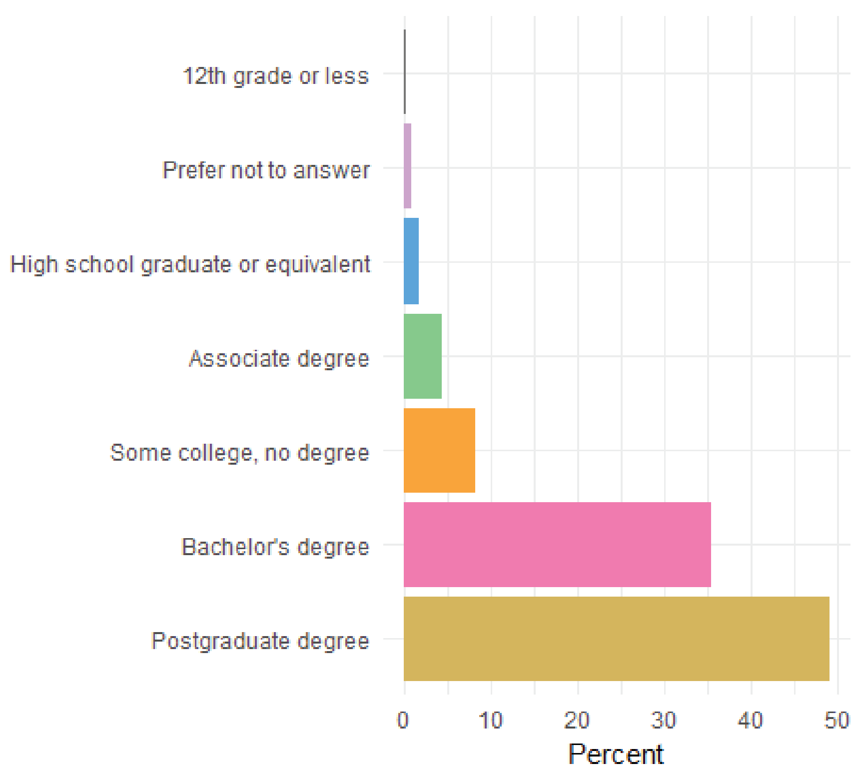
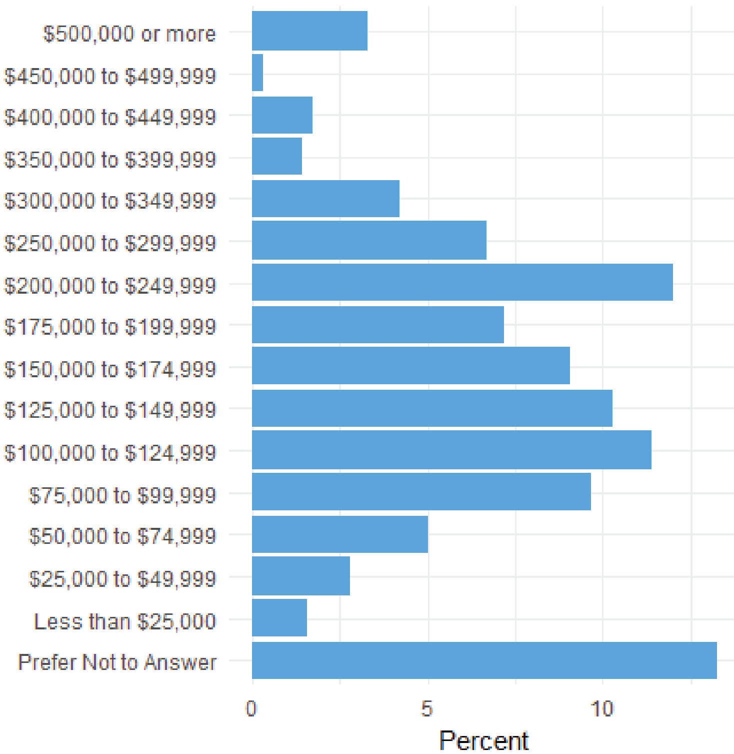
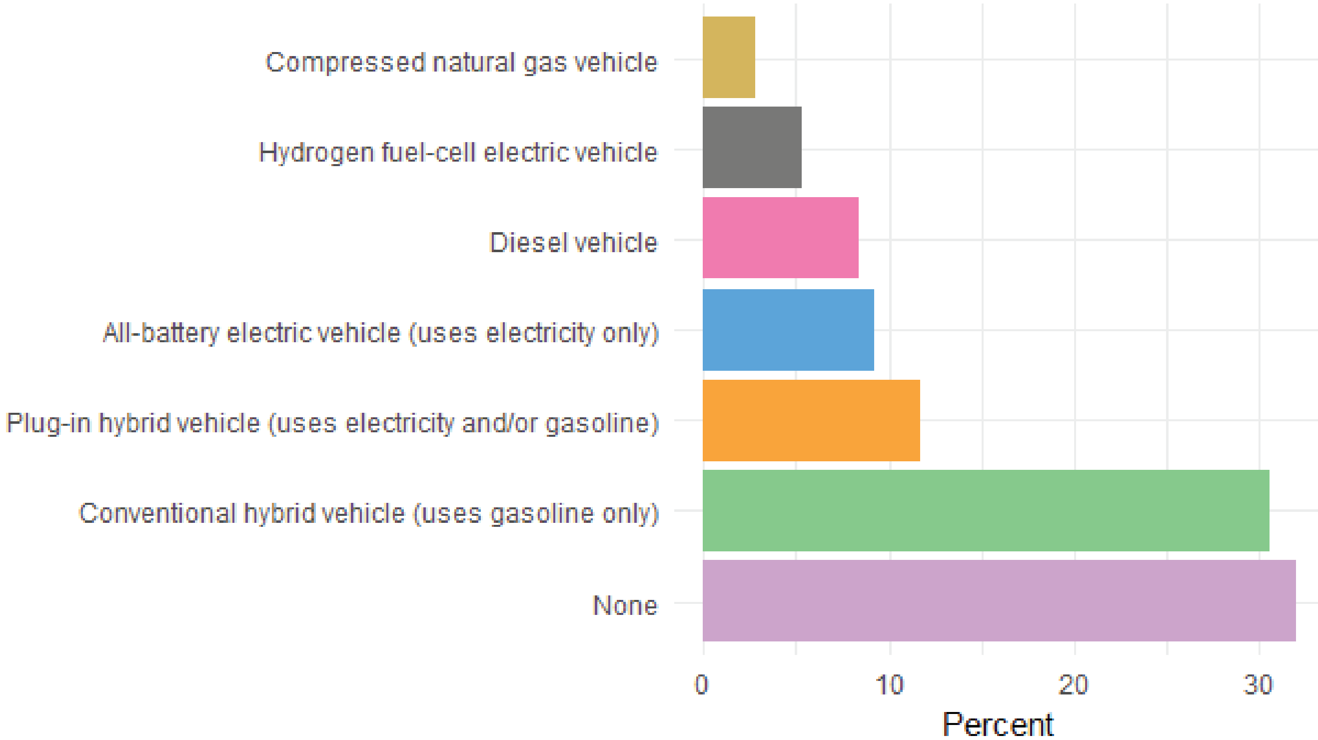


Figure 19: Distribution of Household Income



Prior studies and CARB's market analyses in CHIT have also relied on previous alternative-fueled vehicle (AFV) ownership as an indicator for potential market adoption of FCEVs. CARB's analyses through CHIT have posited that the combination of conventional hybrid (HEV) and PHEV prior adoption may be a satisfactory indicator because these two AFVs do not require a change in fueling behavior, which is the ultimate goal of FCEVs and the hydrogen fueling network. Respondents' prior AFV ownership rates are shown in Figure 20, which appears largely in agreement with CHIT's assumptions. Of those respondents who have owned an AFV in the past, HEVs are clearly the most commonly owned vehicle in FCEV drivers' prior experience. PHEVs are the second-most previously owned. The difference between PHEV and Battery Electric Vehicle (BEV) prior adoption has narrowed compared to last year's analysis. Interestingly, there are more respondents who report their current FCEV as the second they have owned than respondents that report previously owning a Compressed Natural Gas (CNG) vehicle.

Figure 20: Previous Aternative Fuel Vehicle Ownership



Understanding FCEV First Adopters' Purchase Decisions

Beyond characterizing FCEV adopters themselves, it is also important to understand the motivations and decision-making process that led them to the choice to own or lease an FCEV. Figure 21 and Figure 22 show adopters' level of interest in FCEVs at the time they were shopping for their vehicle and the other vehicle technologies they considered alongside FCEVs. According to these results, there does appear to be significant cross-shopping between FCEVs and the other zero- and low-emission technologies available to consumers, even when consumers are also considering conventional gasoline vehicles. BEVs are the most-common alternative considered. In addition, FCEV adopters tend to have at least some prior knowledge and interest developed in the technology before making their purchase decision, with a significant portion entering the purchase decision with a single vehicle in mind. Still, approximately 15% of FCEV adopters were not even aware of the technology before they began shopping for a new vehicle.

Figure 21: Interest in FCEVs

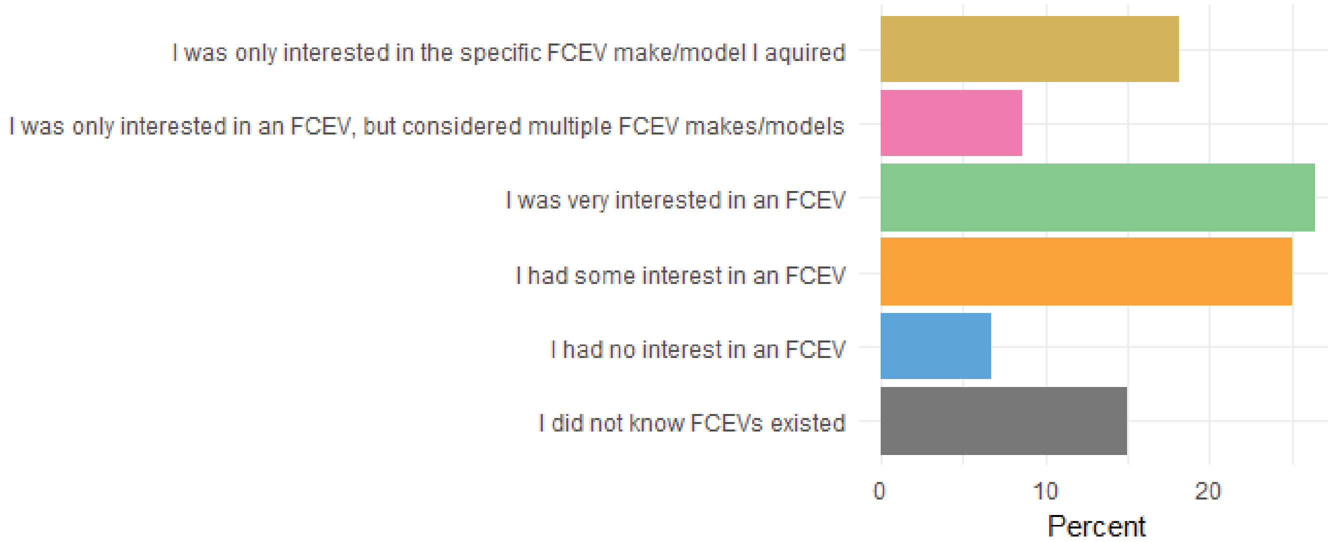
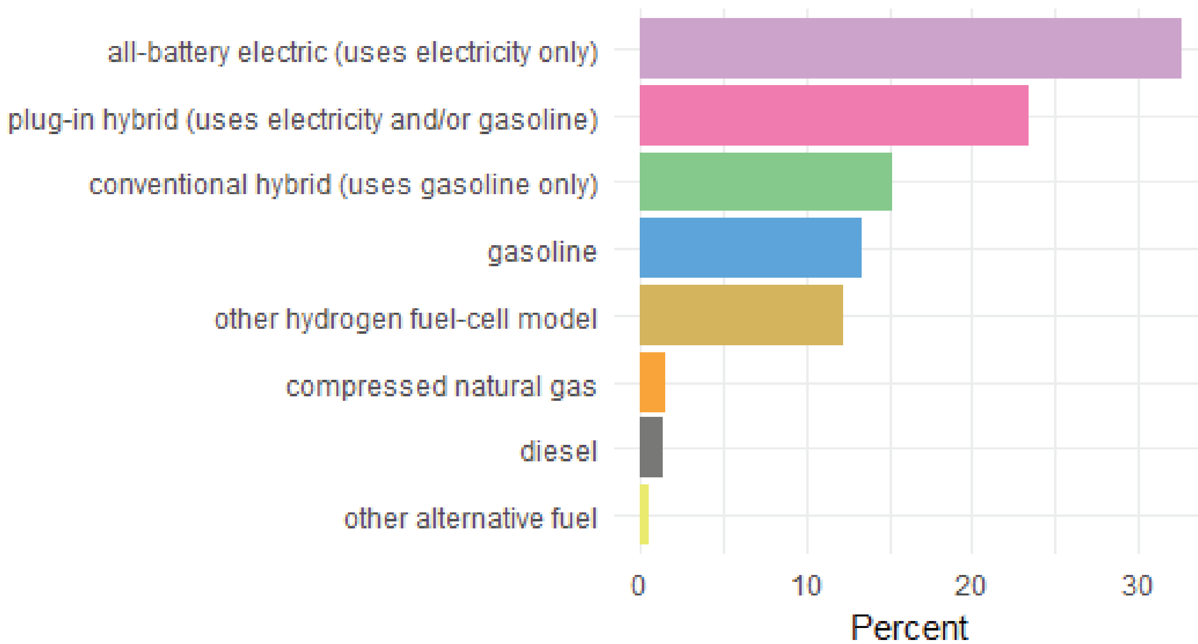


Figure 22: Other Vehicle Technologies Considered when Purchasing a FCEV[9]



FCEV adopters may be motivated by a variety of factors when making the decision to purchase their vehicle. Figure 23 shows the relative importance of several factors investigated through the CVRP survey. The most influential factor appears to remain the potential to reduce environmental impacts, providing further evidence that FCEV adopters are motivated by environmental concerns. Access to HOV lanes (a non-monetary incentive) was the second-most influential factor. This highlights the need for complementary policies to help build this new consumer market and may be an indicator of the importance of considering commute and other travel routes when assessing the need for new station locations in CHIT. Financial factors ranked approximately equivalently to a desire for new technology and energy independence. However, when asked

9 Respondents were asked to identify up to two vehicle technologies.

to identify the single most influential factor in their purchase decision, reduced environmental impacts was the most commonly-selected option but financial considerations were the second-most influential followed by HOV lane access, as shown in Figure 24.

Figure 23: Importance of Various Factors to Purchase Decision

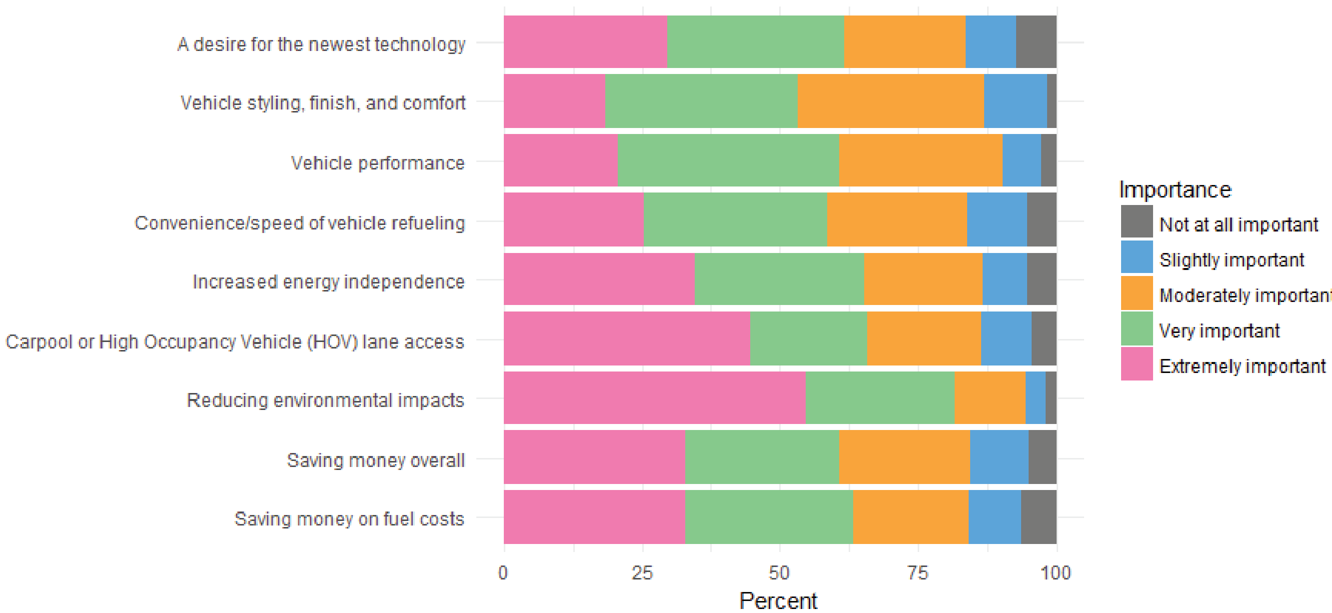
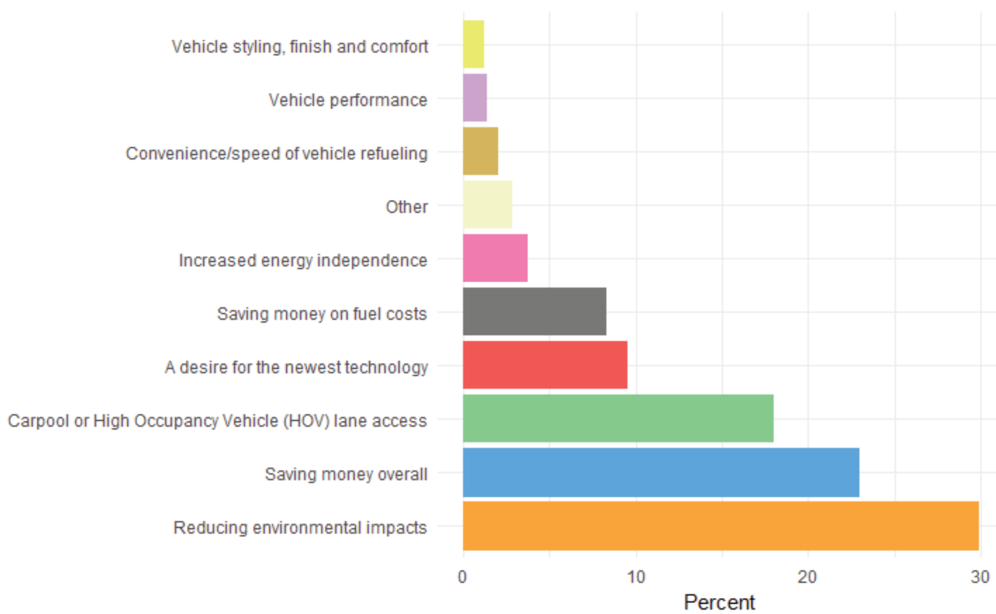


Figure 24: Most Important Factor in Purchase Decision



The CVRP survey also explores the correlation between station network development and FCEV purchase decisions. Figure 25 shows the relative importance of various categorized station locations (near home, along their commute, on the way to other frequent destinations, and on the way to or near vacation destinations) to FCEV adopters' purchase decisions. As previously reported, the availability of fueling stations near home appears to be the most strongly influential network-based consideration for purchase decisions, with fueling along commute routes having slightly less influence. The need for stations along frequent daily routes (such as on the way to errands or other daily and weekly-visited destinations) and long-distance or travel destinations continues to appear to be low-priority for FCEV adopters. These observations are in agreement with fundamental assumptions of CHIT's coverage and coverage gap calculations.

Respondents' station location importance is cross-referenced against the self-reported classification of their most-used station in Figure 26. This provides insight into any differences between purchase motivations and fueling behavior. Consistency between these behaviors is a fundamental assumption in CHIT, and the data thus far support this methodology. In these figures, categories on the right that group sets of bar charts indicate the self-reported classification of the stations used most; the labels on the left for each bar within the set provide the location classification reported as most influential for the purchase decision. Grouping responses in this way shows that there is a high degree of consistency between the reported influence on the purchase decision and respondents' actual activity. Those who reported a station near home as highly influential to the purchase decision tended to fuel more commonly near home, and the same could be said for stations along FCEV drivers' commutes.

Figure 25: Importance of Hydrogen Stations in Categorized Locations to Purchase Decision

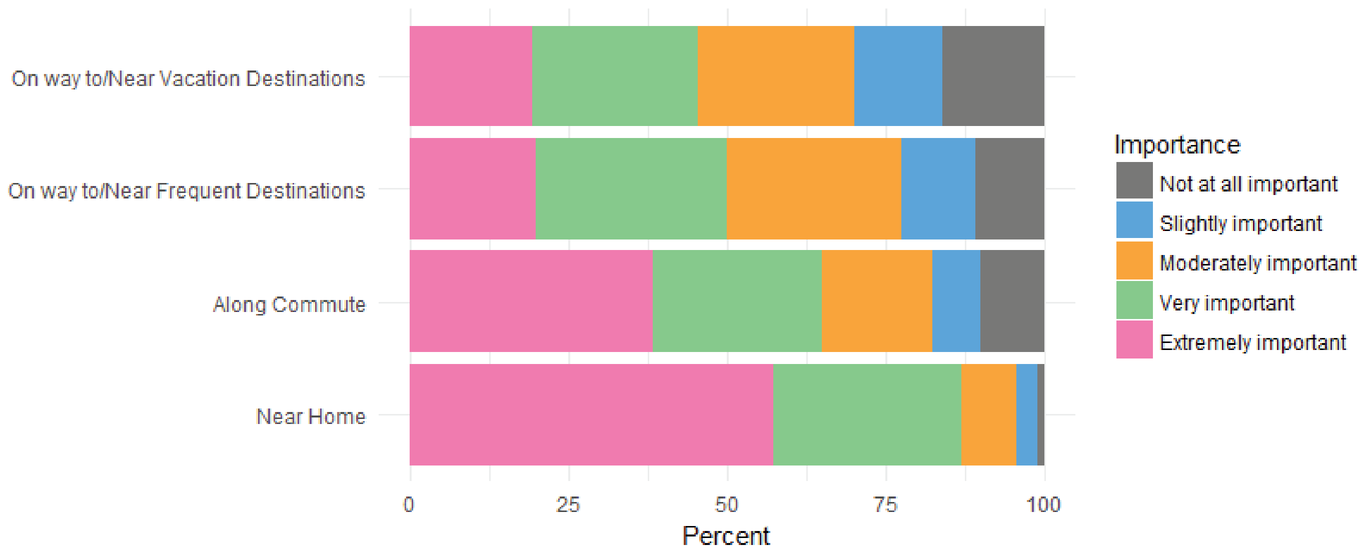
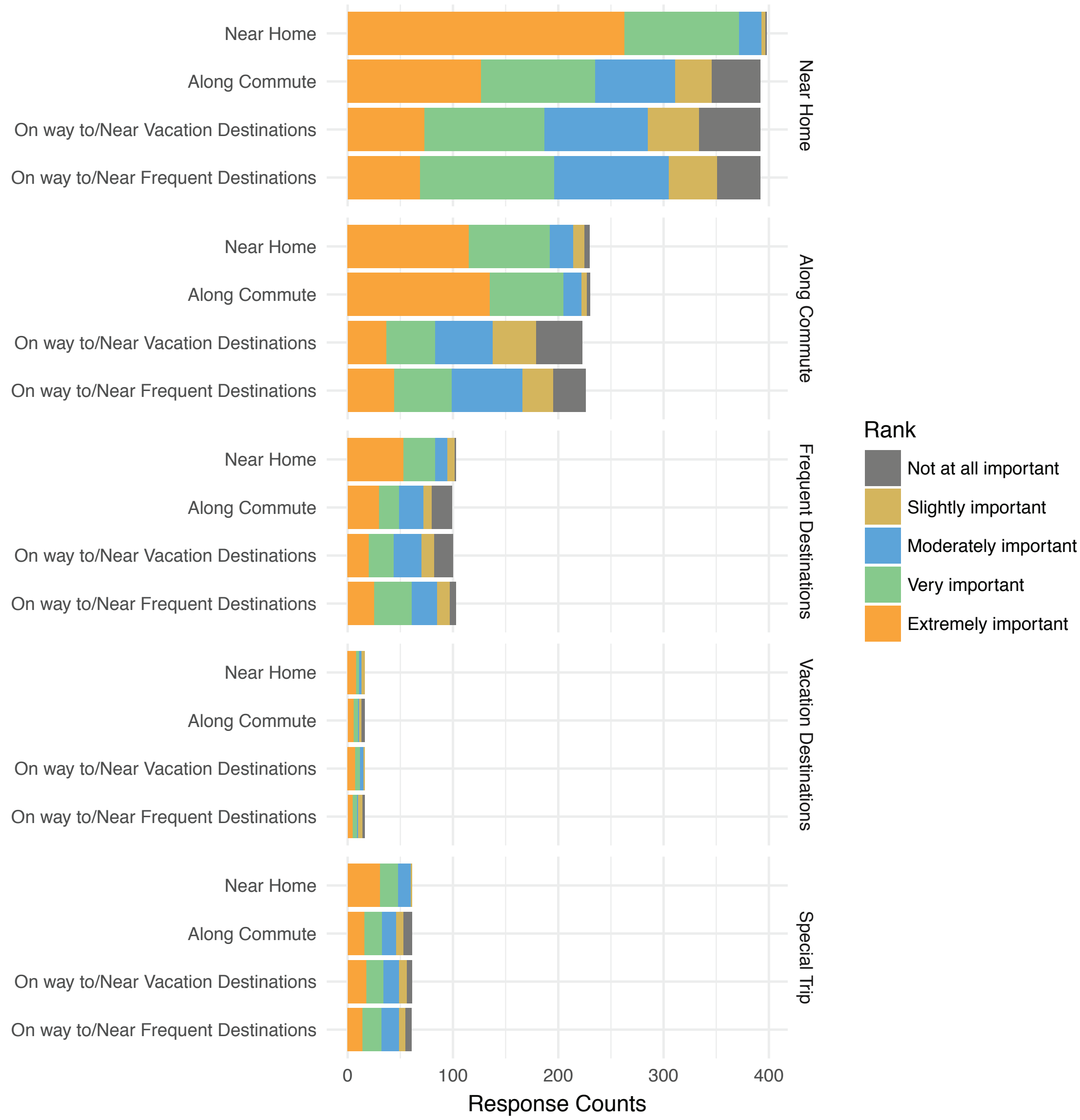


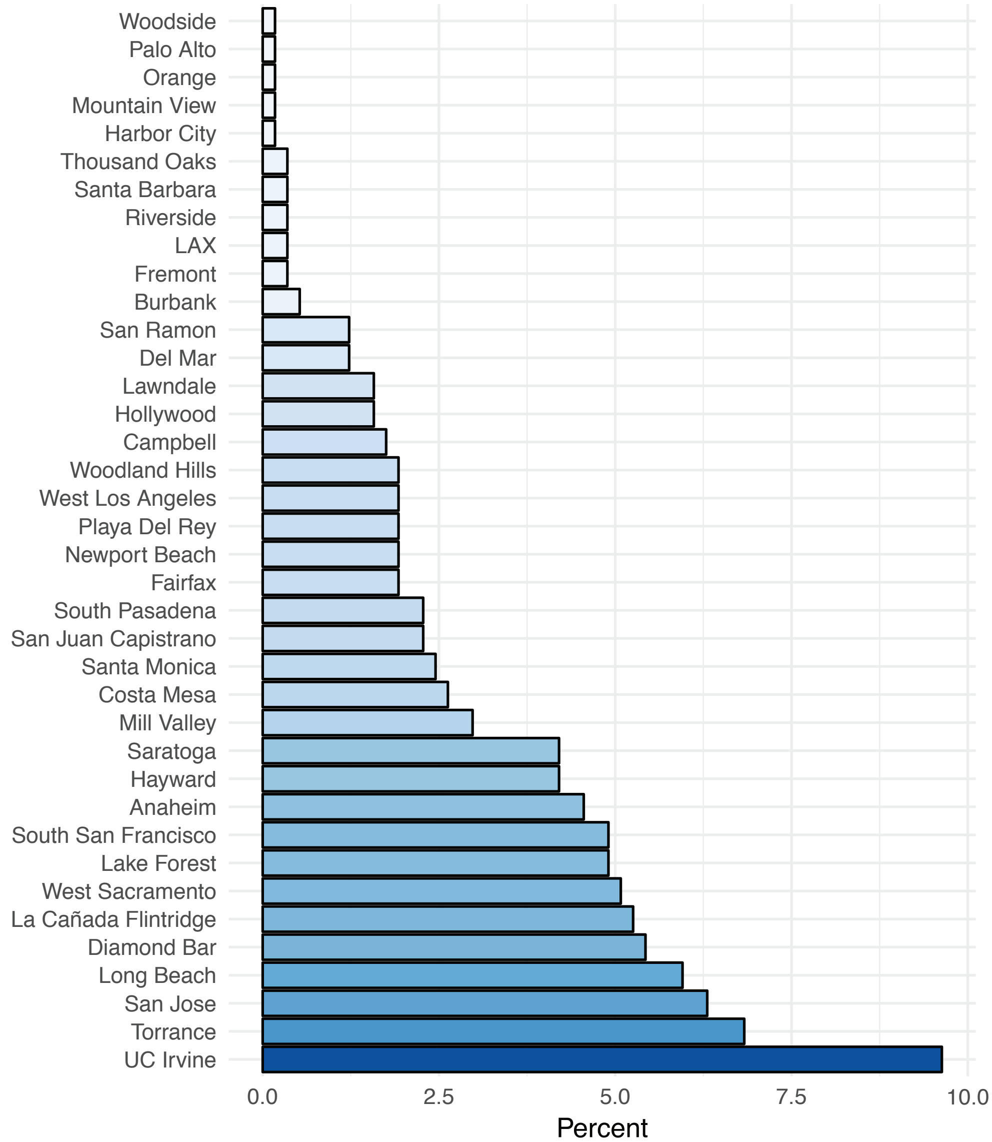
Figure 26: Importance of Hydrogen Stations in Categorized Locations to Purchase Decision Grouped by the Most Used Categorized Station Location



FCEV First Adopter Reported Fueling Behavior

An assessment of FCEV adopters' self-reported fueling behavior may enable identification of gaps in the current network's ability to meet their fueling needs and a test of the real-world reflections of CHIT analyses. Figure 27 shows the self-reported station used most by respondents; it is important to note that not all stations were Open-Retail at the time that all survey responses were provided. Stations that are the primary station for the largest number of drivers tend to be located in the areas with the largest projected network growth determined through CHIT scenario analysis, as exhibited in Figure 1.

Figure 27: Reported Most-Used Station[10]



Fueling frequency is about once per week for approximately half of FCEV drivers, as shown in Figure 28. A significant portion (approximately 30%) fuel more often than weekly, with the remainder fueling less often. Figure 29 also reveals that there appears to be a significant difference in the fueling frequency for different categorized station locations. Overall, stations near drivers' homes appear to be visited much more frequently than any other station location, including those along drivers' commutes. Comparing these data to Figure 25 and Figure 26 may point to a difference between drivers' perceived and actual needs with regard to stations along commute paths.

10 Based on station opening dates and the date recorded for survey submission, CARB identified some responses for which the indicated stations was not yet open and must therefore be mis-identified. In these cases, CARB has adjusted its analysis with respect to the ambiguous data.

Figure 28: Self-Reported Frequency of Hydrogen Fueling

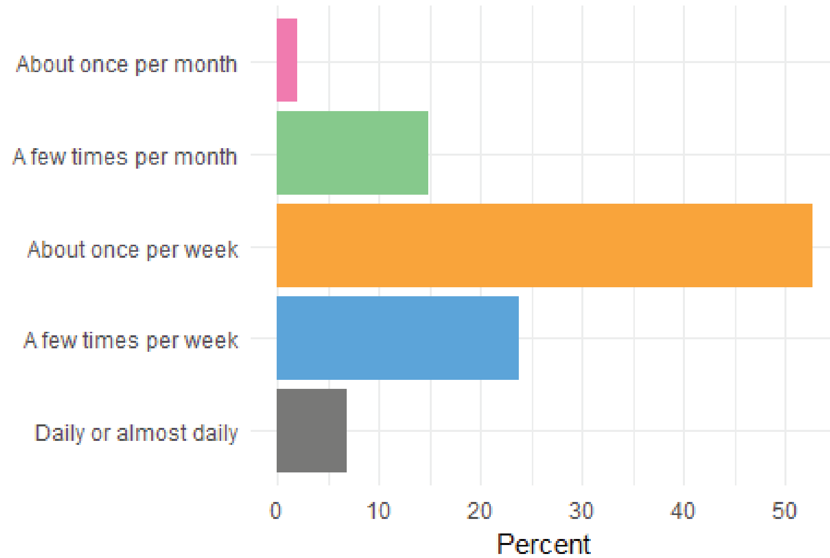
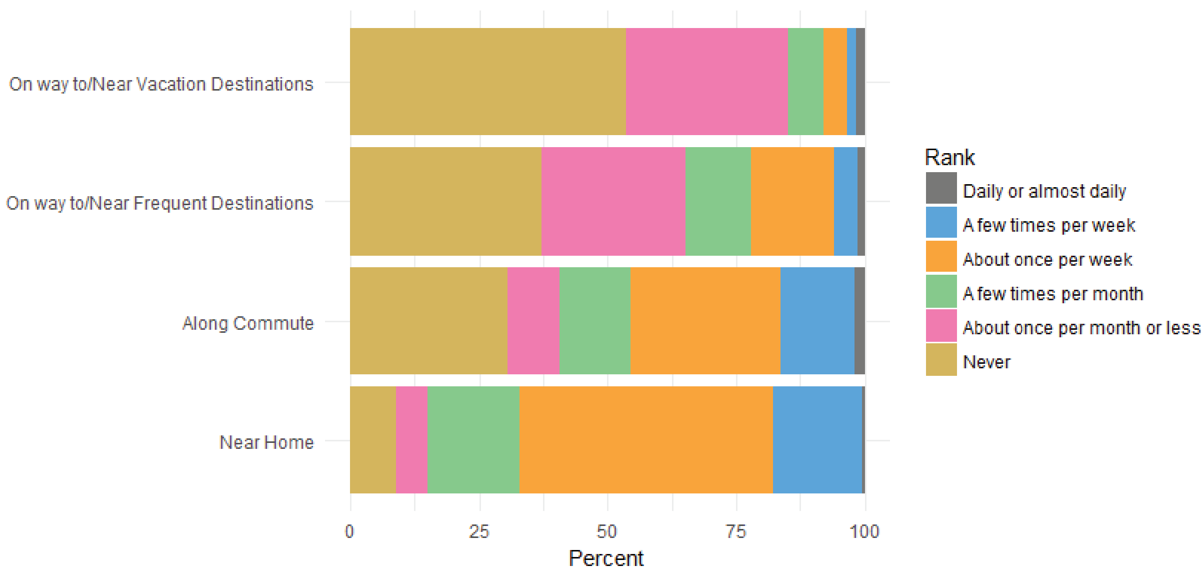


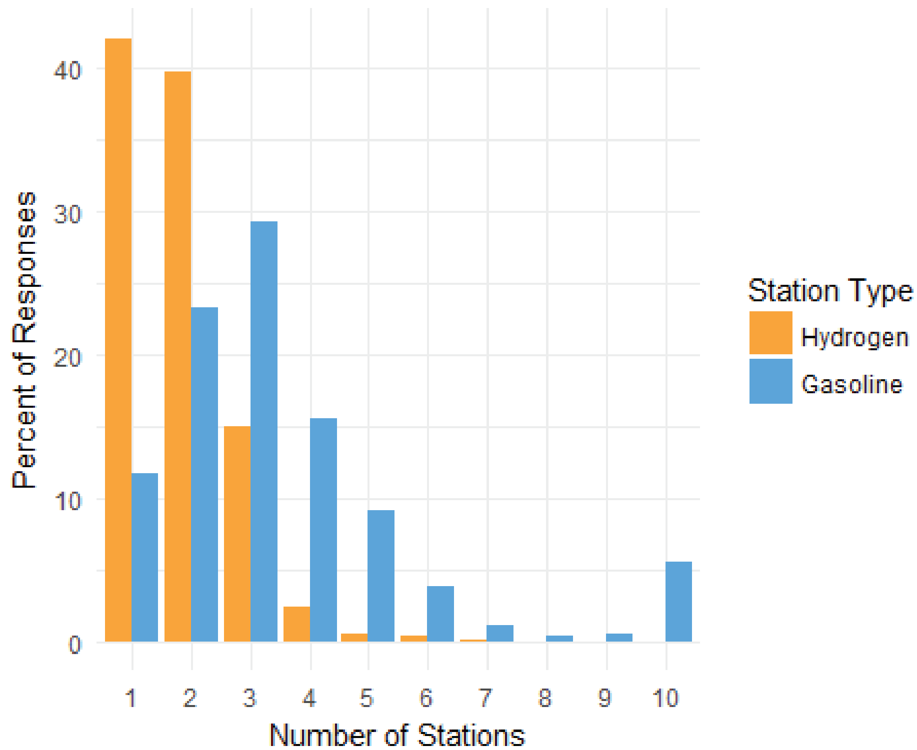
Figure 29: Frequency of Hydrogen Fueling Grouped by Categorized Station Location



Comparison of Hydrogen Fueling to Gasoline Fueling Experience

The ultimate goal of the hydrogen fueling network development in California is to provide a fueling experience that provides FCEV drivers the same utility for their vehicles as gasoline drivers experience with theirs. One potential metric for gauging the hydrogen fueling network's approach to parity with gasoline is a comparison of the number of hydrogen fueling stations that drivers may routinely rely on for their travels and the number of gasoline stations they had previously relied on. Figure 30 shows FCEV adopters' prior experience with gasoline station fueling and their current experience with hydrogen. Unsurprisingly, the data make it clear that significant hydrogen fueling station network development remains. A disproportionate amount (~42%) of FCEV drivers rely on a single station for their daily travels (compared to ~12% of prior reported gasoline experience). FCEV drivers' prior experience with the gasoline network tended towards regularly relying on two to four fueling stations, with a significant number of respondents having previously relied on up to ten stations. FCEV drivers do not yet rely on more than three stations to any appreciable degree, with the vast majority relying on only one or two stations. This highlights the need to continue developing the station network with the goal of providing service and convenience increasingly similar to the gasoline fueling network.

Figure 30: Number of Gas Stations Routinely Visited in Past Experience Compared to Hydrogen Stations Routinely Visited in Current Vehicle



Drivers' Self-Reported Needs for Hydrogen Fueling Network Growth

The CVRP survey also asks FCEV adopters to express their view of station network development necessary to enable the exclusive use of their FCEV for all their driving needs. Figure 31 shows how respondents rank various categorized station locations in order of need; Figure 32 groups these responses by the location of the station that respondents report as their most-used station. As shown by these two figures, additional stations near the home remain the most necessary additional station location. This is true regardless of drivers' reported fueling behavior. Similar to the importance of locations for influencing purchase decisions, locations along commutes stand out as the second-highest necessity, distinctly lower in priority than additional stations near the home and distinctly higher in priority than additional stations in any other location.

Discussions with stakeholders have hypothesized that the categorized location of station(s) most needed for any individual may be related to their individual driving patterns and should be reflected in CHIT analyses. For example, a person who has a longer commute that takes them further away from home may be more likely to feel they need a station located somewhere along their commute path. By contrast, an FCEV driver who largely remains in their local community on a daily basis may indicate greater need for station(s) near home.

To investigate this hypothesis, CARB performed analysis of regression models on the data shown in Figure 31 and Figure 32 .CARB assigned respondents' Rank 1 categorized station location as the most needed station location. Each respondent's reported typical daily drive distance was then paired with this station location category. Regression models were developed through the open-source R statistical analysis platform. Multinomial models were generated to determine the likelihood of choosing any given station location category compared to each of the other station location categories. In addition, a logistic model was built to determine the likelihood of choosing any given station location category against all other station location categories.

Results from the analysis of needed stations are shown in Table 4. Percentages in the table indicate the change in the odds of choosing the "Comparison" station location as the most needed station over the "Baseline" location, for each incremental increase of 10 miles in the reported daily drive distance. Cells that are shaded yellow indicate results that are statistically significant to the 5% significance level. For example, the models found a statistically significant result that, for every increase of 10 miles in a FCEV adopter's daily drive, the odds of respondents indicating that a station is needed along the commute path compared to near the home increase by 4.7%. Moreover, for every increase in 10 miles of the daily drive, the odds of FCEV adopters needing a station at any location other than near home increase by 2.5% over the choice of a station near home. By contrast, as the reported daily drive increases by 10 miles, odds decrease by 4.5% for the choice of stations at any other station location category compared to a station along the commute path.

These results therefore appear to support the stakeholder hypothesis that longer daily drives are associated with increased need for stations along drivers' commute paths. In addition, the relationships between the need for stations along commute paths compared to along the path for other common trips (such as errands) appears to emphasize that daily long-distance drivers are more concerned about fueling on the way to work than for their other regular driving needs. Commute traffic data and analysis that were implemented in the 2017 Release of CHIT therefore seem appropriate and may potentially be emphasized in future analyses as the market continues to mature.

Figure 31: Ranking of Desire for Additional Stations in Categorized Station Locations to Enable Exclusive Use of FCEV for Driving Needs

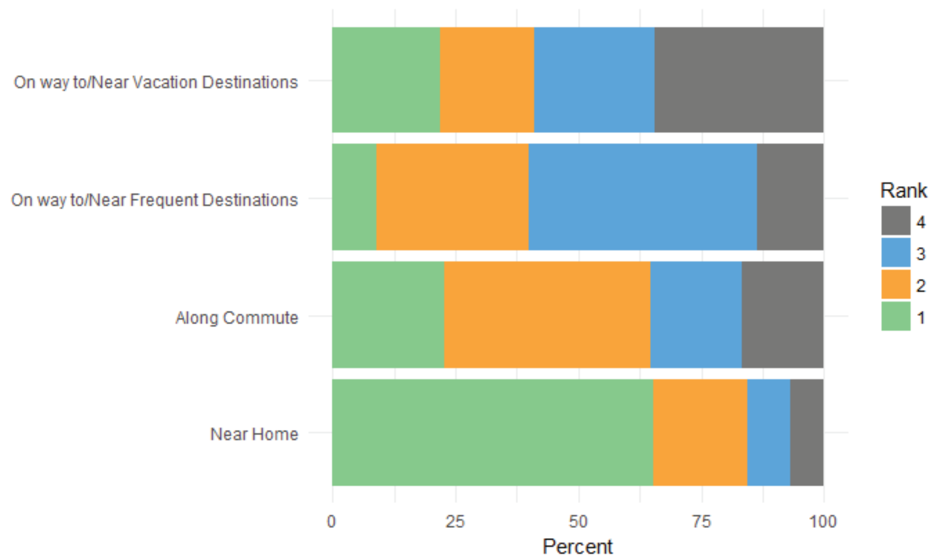


Figure 32: : Ranking of Desire for Additional Stations in Categorized Station Locations to Enable Exclusive Use of FCEV for Driving Needs, Grouped by Location of Most-Used Station

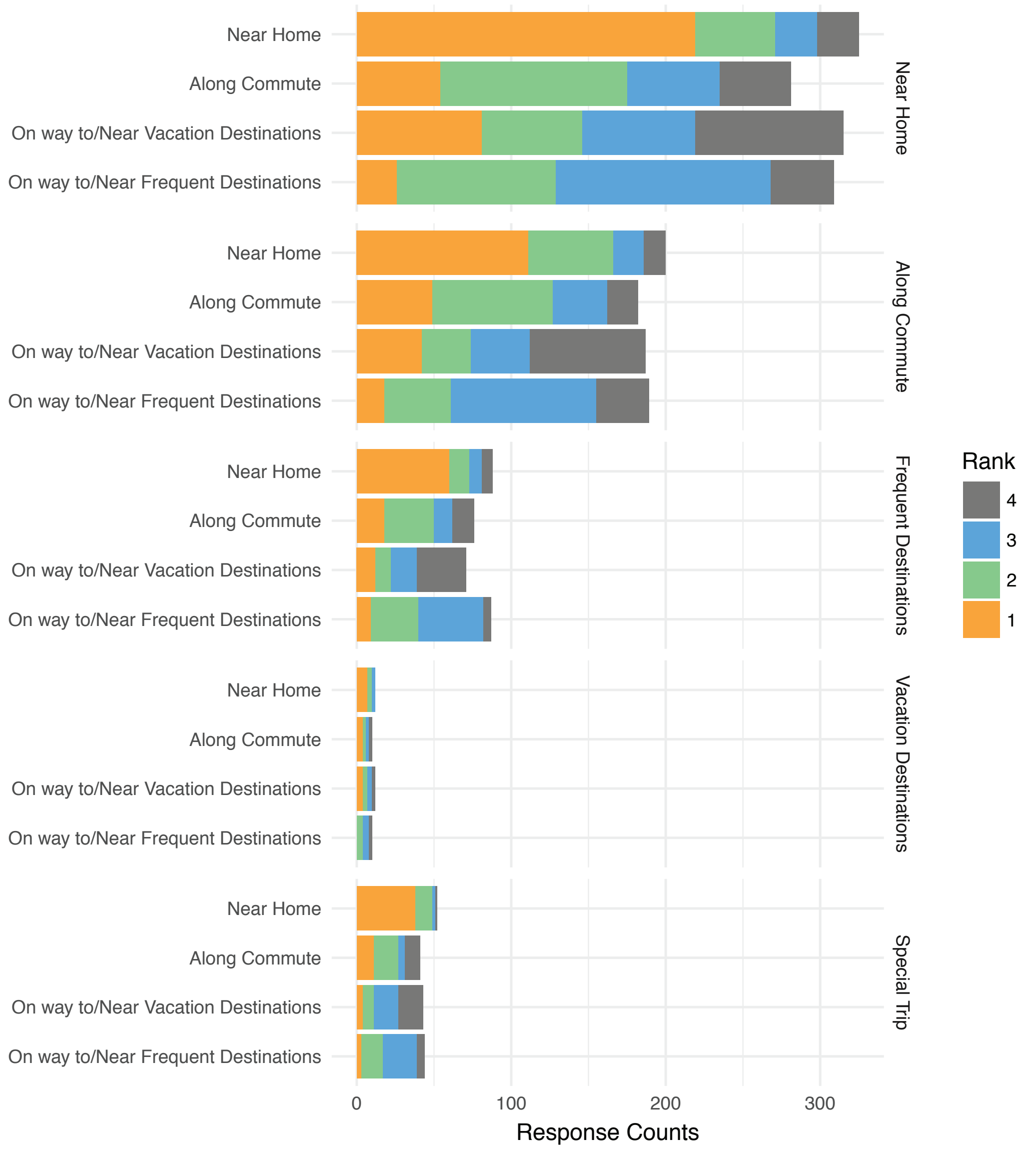


Table 4: Incremental Changes in Odds Ratio for Choosing the "Comparison" Location over the "Baseline" Location as the Most Necessary to Enable Exclusive Use of FCEV per Incremental Increase of 10 Miles in Daily Drive[11]

		Comparison Location					Descriptive Daily Drive Stats			
		H	C	D	T	All Others	Mean	Median	Min	Max
Baseline Location	H		4.7%	2.6%	-9.7%	2.5%	77.2	45.0	5	500
	C	-4.6%		-2.1%	-5.6%	-4.5%	129.5	77.5	9	450
	D	-2.6%	2.1%		-3.5%	-1.4%	100.8	50.0	14	500
	T	0.9%	5.6%	3.5%		2.4%	71.0	45.0	5	300

A similar analysis was performed to investigate changes in odds ratios as a function of distance to the nearest station to drivers' homes as opposed to their daily driving distance; however, none of the results from these models indicated statistical significance at the 5% level. In addition, analyses were completed to investigate the changes in the most influential station location category on the purchase decision. Similarly, none of the models were able to find significant relationships in the odds of choosing any one station location category over others as a function of either daily drive distance or distance to the hydrogen station closest to home. The lack of a relationship between the distance to the nearest station location to drivers' homes, their purchase decisions, and reported needs may indicate a general lack of diversity of station locations as it appears that FCEV adopters are not currently interacting with the nascent hydrogen network as would be expected under a more complete network build-out.

However, a few of the results related to the influence on purchase decisions as a function of daily driving distance could be significant at the 10% significance level, as highlighted in Table 5. In this case, it appears that longer daily drive distances may be generally associated with greater influence of stations existing along drivers' commutes on their purchase decisions. However, it should be noted that the less-stringent significance level (10%) is more likely an indication of the future potential to establish these trends rather than an indication of verified results in the current data.

Table 5: Incremental Changes in Odds Ratio and p-Value for Choosing the "Comparison" Location over the "Baseline" Location as the Most Influential in the Purchase Decision per Incremental Increase of 10 Miles in Daily Drive[11]

		Odds Ratio					p-Value				
		Comparison Location					Comparison Location				
		H	C	D	T	All Others	H	C	D	T	All Others
Baseline Location	H		1.6%	0.9%	-0.5%	9.8%		0.067	0.448	0.698	0.212
	C	-1.6%		-0.8%	-2.1%	-1.5%	0.067		0.510	0.100	0.055
	D	-0.9%	0.8%		-1.4%	-0.3%	0.448	0.510		0.356	0.752
	T	0.5%	2.1%	35.6%		1.2%	0.700	0.099	0.356		0.297

11 H: Station Near Home; C: Station Along Commute; D: Station on the way to or at a Destination/Vacation Location; T: Station Along Common Travel Routes Other than Commute (Such as for Errands). Although these tables include values for results that are not found to be statistically significant, CARB is only providing these for demonstration purposes. Results not indicated as statistically significant should not be referenced for any further analyses or interpretations.

Geospatial Analysis of FCEV First Adopter Fueling

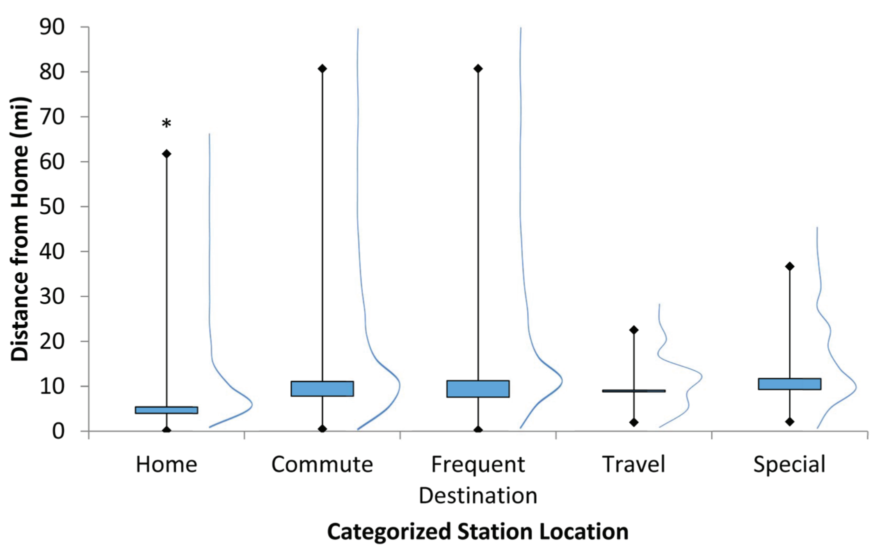
CVRP data available to CARB include information about the respondents' home census tract. CARB uses the center points of these census tracts as an approximation for the home location of respondents and can utilize these data to perform approximate analyses of FCEV drivers' spatial relationships to the Open and funded hydrogen fueling network. Cross-checking assumed behavior in CHIT against the developing network may help identify gaps in the current network, adjustments for CHIT evaluation, or both.

Figure 33 provides an analysis of the required travel distance between FCEV drivers' home census tracts and the station indicated as their most-used station, organized according to the station location classification. Today's drivers reportedly travel between two-tenths of a mile and approximately 80 miles to reach their most-used station, with average and median drive distances of 8.4 and 6 miles, respectively. Performing t-tests on the average distance between each pair of categorized station locations reveals that FCEV drivers who report their most-used station is their near-home location drive a statistically significant shorter distance to fuel than all other drivers. Differences between all remaining drivers' data do not show statistical significance. The asterisk above the Home category indicates its statistical significance as distinct from all other groups.

In order to rely on analyses and interpretation of these data to guide potential future development and analyses in CHIT, it is important to seek indications that the survey respondents interpret the questions and response options within the same conceptual framework utilized in CHIT analyses. For example, some respondents may fuel most often at a location that is along their commute and still within a reasonable distance from home, but is not the absolute closest station to their home. They may then identify this station as belonging to either one of these categories in their responses, though CHIT analyses may assume they should be reported as along their commute. A difference in interpretation such as this should be recognized in order to appropriately leverage the data from the CVRP survey.

Another example from Figure 33 is that the range of distances for those who report their most-used station is along a long-distance or vacation travel route is substantially smaller than for those that report fueling at conceptually closer categorized station locations like near home or along their commute. A similar situation is apparent regarding the drivers who report needing to make a special trip to fuel. It is possible drivers might think of these definitions in a manner different than intended through the survey or that they may classify their most-used station into multiple categorized station locations and skew the reported results. Still, given the small number of responses for these two station location categories, there is likely little need to change CHIT's analysis processes to address this situation.

Figure 33: Analysis of of Distance Between Home Census Tract and Reported Most-Used Station Grouped by Categorized Station Location[12]



12 The geospatial analyses reported here exclude a single outlier data point for a FCEV adopter who lives in the San Francisco Bay Area but reported their most-used station as the Anaheim location.

One of CHIT's fundamental assumptions is that a station near home is critically important to the purchase decision and initial fueling patterns, especially in a sparse hydrogen fueling network. Verification that actual FCEV customers both think and behave in a consistent manner with regard to these stations lends credibility to earlier observations about the self-reported influence of this station location category. Table 6 provides an analysis of the number of FCEV drivers who report their most-used station is their home-based station and are actually fueling at the estimated nearest station to their home. According to the data reported in the survey, CARB estimates that one-third of drivers who report fueling at their home-based station are actually not fueling at the station nearest their home. Aside from simple mis-reporting, potential explanations include:

- Based on the given information, CARB's estimates rely on limited spatial resolution; in some cases, the calculated nearest station may not be the true nearest station. The probability of this discrepancy increases with local density of the hydrogen station network and the size of the home census tract.
- The physically nearest station does not take into account any information regarding travel needs. The closest station may require travel in a direction opposite from the drivers' typical daily needs. A further station may still be close enough for the driver to consider it their home-based station while being located in their preferred direction of travel and therefore become their most-used station.
- FCEV drivers may be choosing to fuel at stations further than the absolute closest station for reasons other than the location, yet still considering these stations as a home-based station because it is the closest that also provides all their other desired features.

Table 6: Analysis of Most-Used Station Relative to Closest Station to Home

	Reported Generalized Location of Most-Used Station				
	Home	Commute	Frequent Destination	Travel	Special
Respondents whose most-used station is the closest to home	244	102	54	5	26
Respondents whose most-used station is NOT the closest to home	118	109	43	10	31
Percentage of respondents whose most-used station is the closest to home	67%	48%	56%	33%	46%
	Aggregated percentage of respondents whose most-used station is the closest to home.				58%

Considering all these possibilities together, CARB does not discern that there is definitively a disagreement between self-reporting and actual potential for near-home fueling. Still it is also of interest to note that for only 58% of all survey respondents, their reported most-used station is the estimated nearest station to their home. This may be somewhat lower than expected based on prior estimates and investigations.

Finally, CARB investigated the geospatial distribution of customers based on the station that respondents indicated they used most often. Maps of these customer-station relationships are shown in Figure 64 though Figure 70 of Appendix E. As shown in the legend, lines connecting customers' home census tracts to their most-used station are color-coded according to the station classification that respondents assigned to the station. In addition, the total number of respondents using that station most often is indicated in the station label (for example, 17 respondents indicated Mill Valley as their most-used station). Thicker gray lines connect respondents to their geographically nearest station (according to drive time). In this way, every figure shows three informative pieces of information:

- Drivers whose closest station is also the one they report using the most and whether or not they conceptually assign this as their home-based station
- Drivers who are nearest to the station but choose to use another station and location-based information as to why they use a different station, given the location category they assign
- Drivers who are distant from the station but still use it most often, again with the potential for location-based information as to the reason why

In some places where there is significant FCEV deployment and a handful of fueling options (such as near San Jose, and in parts of West Los Angeles), some of the fueling patterns that may be expected in a more completely built-out network seem to be developing. That is, drivers who report these stations as their near-home station do seem to be among the closest FCEV adopters. Drivers who fuel at this location for travel-based reasons, like their commute, seem to live further away and may actually pass up stations closer to their home. Conversely, drivers who live nearby but choose to fuel at another location either do so because there is a roughly equivalent second choice for a near-home station (based on proximity) or because they seem to be driving in a different direction than their closest station. The UC Irvine station is another interesting example of these observations. In particular, many drivers from somewhat further locations fuel at this station and consider it to be one of the travel-based location categories. This may contribute to its high rate of usage as shown in Figure 27.

However, inspection of other pairings and indicated station classification reveal that on an individual basis, some drivers may not be behaving as expected or may not be responding to the survey question as intended. For example, as shown in Figure 69, some FCEV drivers who live southwest of the San Juan Capistrano station report they use the Anaheim station most often, and identify it as a station near home. However, given the relative positions of the home census tract and these two stations, the San Juan Capistrano station is a more logical choice as a home-based station based on its proximity alone. In another case some drivers who live near Riverside and indicate they use the Newport Beach station most often identify it as a station along their commute path. However, the Riverside station is adjacent to the 91 highway, the major corridor between Riverside and Orange County, whereas the Newport Beach station requires substantial drive time on local streets to reach. The Riverside station thus appears to potentially be a more-convenient choice along the route or could even serve as a home-based station. However, it is not possible with the information given to make a definitive assessment of why these drivers prefer the Newport Beach station, as they may choose other routes besides the 91 for their commute, or they may choose the Newport Beach station based on attributes other than location.

There are also some fairly long-distance routes that are indicated for near-home station use. For example, some drivers apparently living near Stockton also report the South San Francisco station as a home-based and commute station. It is possible that some of these drivers might own homes in both locations, there is some degree of mis-reporting, or the driver interpretations of the survey question response options are not as expected. An example of the potential for varying respondents' interpretations may be apparent in Figure 69, where drivers with homes in two separate census tracts close to the Anaheim station reported that they instead used the Newport Beach station most often. One set of responses then classified the Newport Beach station as along their commute (which may be more aligned to the conventional expectations), but the other set reported the Newport Beach station as their near-home choice (and importantly did not also indicate it was a station along their commute). These observations point towards the possibility that the hydrogen fueling station network, even on the local sub-network scale, is not yet dense enough for FCEV drivers to interact with it in the same way as might be expected in a fully-developed hydrogen fueling station network.

Evaluation of Current and Projected Hydrogen Fueling Capacity

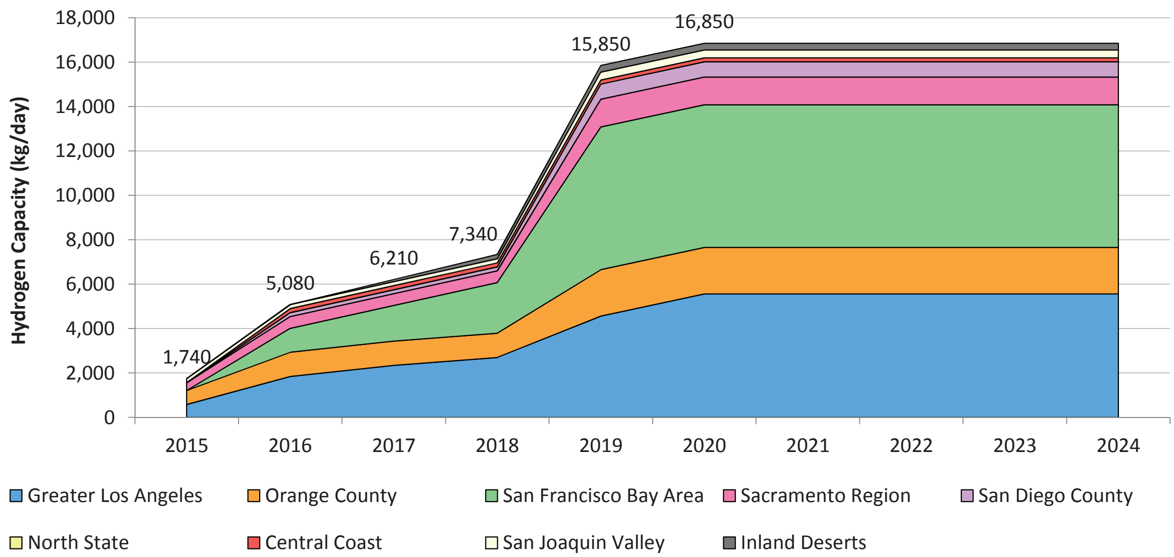
AB 8 Requirements: Evaluation of quantity of hydrogen supplied by planned hydrogen fueling network. Determination of additional quantity of hydrogen needed for future vehicles

CARB Actions: Determine statewide and regional capacity of hydrogen supply. Translate statewide and regional vehicle counts to hydrogen demand. Determine balance between capacity and demand as guideline for additional amount of capacity required.

Assessment and Projections of Hydrogen Fueling Capacity in California

The currently Open and funded hydrogen fueling network has a total nameplate daily fueling capacity of 16,850 kg/day as shown in Figure 34.

Figure 34: Capacity Growth of the Open and Funded Hydrogen Fueling Network[13]

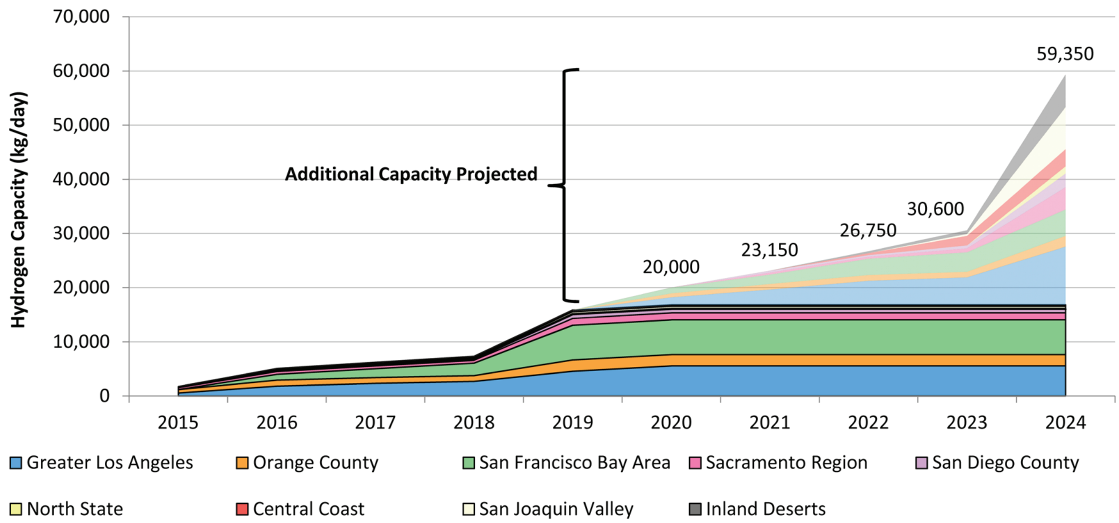


This capacity accounts for all shifts in projected hydrogen fueling station network growth, which includes additions, removals, and capacity updates for individual stations in the network. Currently, the majority of the Open station network capacity is located in the Greater Los Angeles and Orange County regions; however, when the funded station network is fully open, the San Francisco Bay area will have nearly the same total capacity as the Los Angeles and Orange County regions combined.

13 For Figure 34 through Figure 36, CARB has defined the indicated regions according to the following groups of county-wide hydrogen balances:

- Greater Los Angeles: Los Angeles and Ventura Counties
- Orange County: Orange County
- San Francisco Bay Area: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma Counties
- Sacramento Region: Butte, El Dorado, Nevada, Placer, Sacramento, Sutter, Yolo
- San Diego County: San Diego
- North State: Humboldt, Shasta, Siskiyou
- Central Coast: Monterey, San Luis Obispo, Santa Barbara
- San Joaquin Valley: Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, Tulare
- Inland Deserts: Imperial, Riverside, San Bernardino

Figure 35: Projected Capacity Growth On the Path Toward Meeting EO B-48-18[13]



Potential hydrogen fueling capacity growth by region, following the deployment schedule in Figure 1, is shown in Figure 35. As previously described, the scenario assumed is structured to be back-loaded, with the previous AB 8 goal of 100 stations met by January 1, 2024 and the new goal of 200 met by 2025. According to this scenario, total fueling capacity should more than triple by 2024, due to both the increased pace of station deployment in 2024 and the assumed growth over time in average station nameplate capacity. Although this projection is in agreement with the shared vision of the members of the CaFCP and EO B-48-18, it is all but certain that actual station deployment will differ. However, the regional growth shown in Figure 35 can be expected to roughly estimate the goals shared by the State and industry partners. Importantly, this scenario anticipates continuing growth in capacity and coverage throughout the state, but by 2024 there is a marked increase in the emphasis on developing the hydrogen fueling network outside of the core markets (Los Angeles Region, Orange County, San Diego County, and the San Francisco Bay Area).

The regional balance of hydrogen fueling capacity in 2021 and 2024 is presented in Figure 36. Scenarios where the expected capacity growth is and is not regionally allocated are shown side-by-side. Projections without allocations show the overall potential for capacity growth on a statewide level regardless of the actual station placement that may occur in the future, while projections according to the scenario of Figure 1 provide greater context for the regional development anticipated by that scenario. Comparing the currently funded network to the projections for FCEV deployment by 2021 and 2024, there is clearly a need to continue to fund hydrogen fueling stations in order to support continued and accelerated FCEV deployment. Without continued funding, every region in the state will experience a hydrogen shortfall by 2024 and all regions other than Sacramento and the San Francisco Bay Area are anticipated to experience a shortfall of hydrogen fueling capacity as early as 2021.

With continued funding to enable market expansion, CARB anticipates statewide surpluses of hydrogen fueling capacity in 2021 and 2024. While the surplus in 2021 is modest, the currently-projected 2024 statewide surplus is substantial, at approximately 26 tons per day fueling capacity. It is possible that, given the timing of the release of EO B-48-18, the auto manufacturer survey period, and the development of the private-public shared vision to 2030, the FCEV deployment projections reported here may not yet account for the anticipated acceleration of station network growth. In addition, this projected surplus should act as a signal to the FCEV auto manufacturers that there is sufficient certainty in the future hydrogen station network growth to enable more ambitious FCEV deployments than reported to date, as long as the appropriate funding support is in place to enable this growth. As acceleration of the network growth is carried out in the future, CARB will continue to assess the evolving outlook for statewide and regional hydrogen balances.

To that end, the statewide margin of hydrogen in 2024 of 26 tons per day (approximately 1.5 times the capacity of the network funded to date) indicates a substantial lead of hydrogen fueling network development ahead of reported FCEV deployment. Since the adoption of AB 8, the State and its partners have followed a philosophy that hydrogen fueling network development must precede FCEV deployment because FCEV adopters must feel comfortable that the vehicle can meet their daily fueling needs before they can decide to adopt the new technology. A network growth strategy complementary to the goals of EO B-48-18 clearly places the hydrogen station network development on a pace far exceeding the reported plans of auto manufacturers. These projections show the greatest amount of station lead since AB 8 reporting began.

Assuming the regional distribution of station development follows Figure 1, hydrogen fueling capacity is expected to be sufficient for the local FCEV adopter markets with the exception of the Inland Desert region in 2021 and Orange County in 2024. However, these deficits are relatively small (on the order of one to two stations' worth) and are more than compensated for in this same network development scenario by 2024.

Figure 36: Estimated Regional and Statewide Hydrogen Balances in 2021 and 2024 for Analyses Without and With Regional Allocation of Stations According to a Network Development Scenario to Meet EO B-48-18[13]

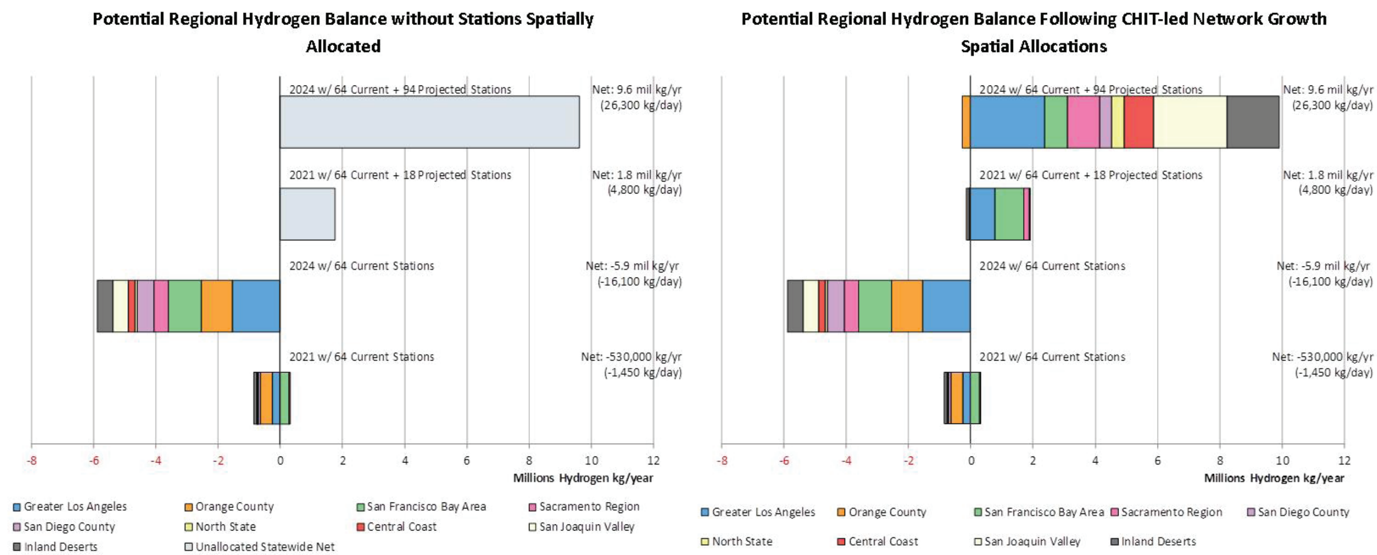
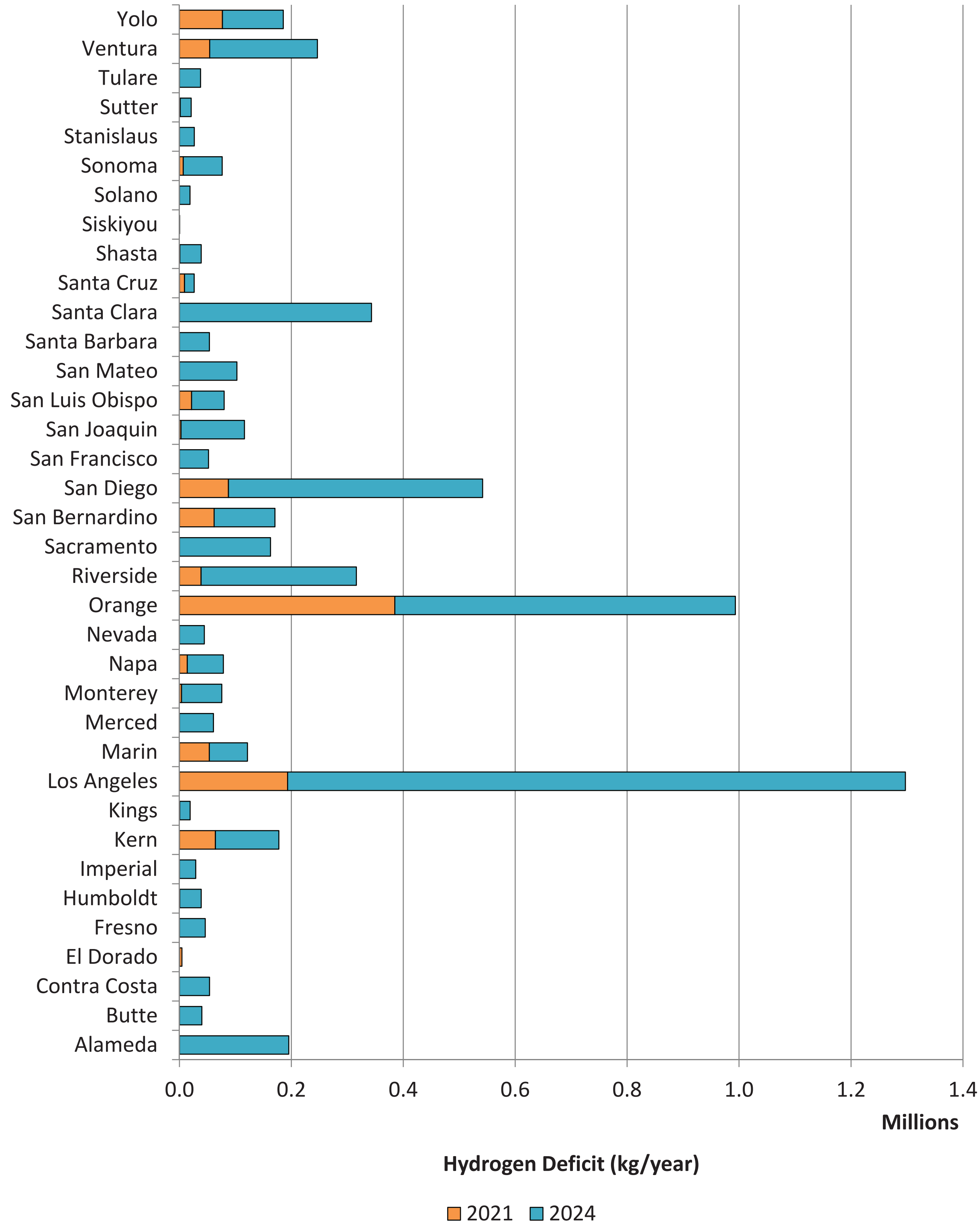


Figure 37: County-Based Hydrogen Fueling Deficit in 2021 and 2024 with 64 Currently Funded Stations



Greater resolution by county for the amount of new hydrogen fueling capacity necessary to meet projected local demand is provided in Figure 37. The most urgent needs for additional station network development to anticipate projected demand are in Los Angeles, Orange, and San Diego Counties. Secondary priorities for the near term include counties adjacent to these (such as Riverside, Ventura, San Bernardino, etc…), Marin, and Sacramento-area counties. For longer-term planning, Los Angeles and Orange Counties clearly remain the counties that will require the greatest development, followed by San Diego, Riverside, and Santa Clara Counties. Several of the anticipated secondary markets are also projected to have significant hydrogen fueling network development needs by 2024, reflecting the market expansion anticipated by the station development scenario of Figure 1.

With the assumption of steadily increasing average station capacity, and the schedule of stations required to meet the AB 8 2023 goal and the EO B-48-18 2025 goal, CARB's analyses find it likely that there will be sufficient nameplate hydrogen fueling capacity for the anticipated FCEV deployment from 2018 through 2024, as shown in Figure 38. Based on observations of daily, weekly, and seasonal demand variations at gasoline stations, it may be necessary to assume that not all of a station's nameplate capacity could be utilized while still providing reliable service to fueling customers and avoiding long lines and wait times. As previously reported [35], an 80% capacity factor may be assumed to approximate optimal feasible station operation. With this assumption accounted for, Figure 39 shows that network fueling capacity projected for 2024 still far outpaces projected FCEV fueling demand. However, there may be a need to consider accelerating station deployment faster than the scenarios shown here in the timeframe 2020-2023, as the largest near-term FCEV deployment scenarios outpace usable fueling capacity growth over that period. In order for FCEVs to outpace the likely usable hydrogen fueling capacity in this period, auto manufacturers would need to release FCEVs at the highest rates thus far reported in annual surveys. Still, it is the State's goal to enable the highest rates of FCEV deployment achievable and the State will therefore need to continue to monitor whether further station deployment acceleration is necessary.

Fuel Cell Electric Vehicle Improvements and Market Growth

- At the 2018 Consumer Electronics Show, Hyundai formally announced its new flagship fuel cell model, the NEXO [6]. The NEXO will be a dedicated platform for Hyundai's FCEV lineup and demonstrates advancements in the fuel cells system, including greater power density, efficiency, and output power. Beyond the powertrain, NEXO is also Hyundai's technological flagship, featuring several Advanced Driver Assistance Systems to showcase advances in autonomous driving capabilities. These capabilities were highlighted at the 2018 Winter Olympics in Pyeongchang, where five of the vehicles made the trip at highway speeds from Seoul to Pyeongchang (a distance of nearly 120 miles) without human controls or interruptions. These vehicles were then available for public autonomous driving demonstration near the Olympic Games facilities [7].
- Proclaiming "The end of a long wait," Daimler has reiterated its plans for release of the GLC F-Cell in 2018. The GLC F-Cell, built on the same platform as Daimler's conventional gasoline and hybrid models, will be the first plug-in hybrid FCEV offered on the market [8]. The combination of plug-in hybrid and fuel cell powertrain components allows for flexible shifting between operating modes to adapt to user-selected drive programs. [9].
- Toyota has announced a critical expansion of its fuel cell and hydrogen tank production facilities to improve mass-production capabilities [10]. The company reports a vision for global sales of FCEVs by 2020 that is an order of magnitude greater than today's sales rates. The company's planned expansions will allow it to scale from production rates of approximately 3,000 units per year to 30,000 units per year after 2020. The company cites work to develop domestic (Japanese) and global growth in demand for light-duty FCEVs and commercial vehicles such as its Sora bus in their announcement.
- Wards Auto declared the Honda Clarity Fuel Cell's propulsion system to be one of the ten best engines of 2018 [11]. This was the second time that a fuel cell won the award (Hyundai's Tucson was similarly awarded in 2015). In its announcement, the publication declared that the engine is "ready for prime time" and highlighted several fuel cell technology advancements that Honda was able to achieve in the design and manufacture of the Clarity.

Figure 38: Projected Hydrogen Demand and Potential Nameplate Fueling Capacity Growth to Meet Goals of EO B-48-18

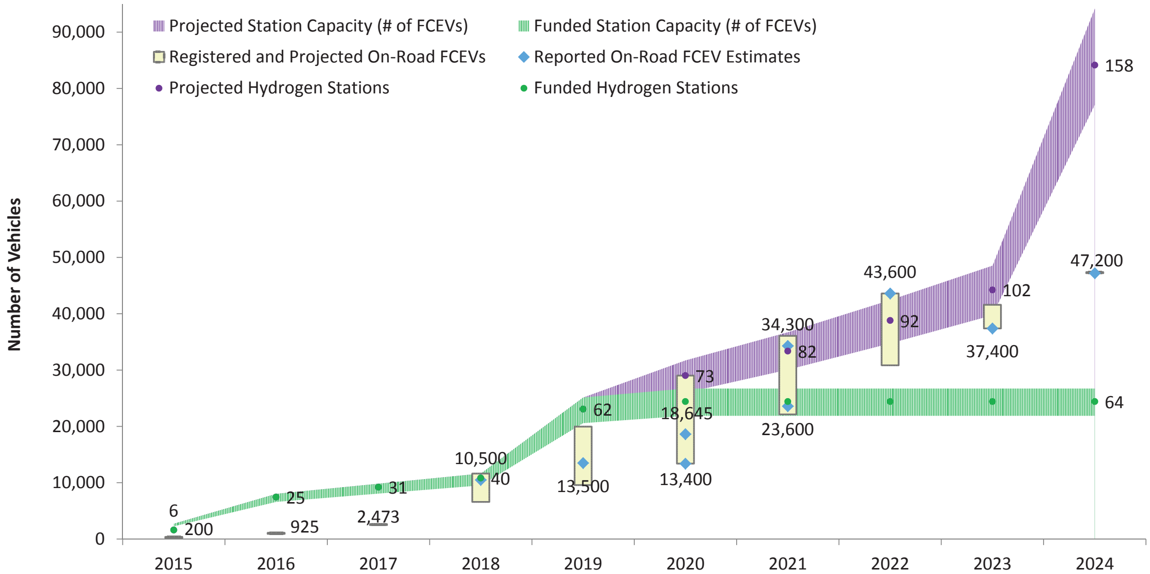
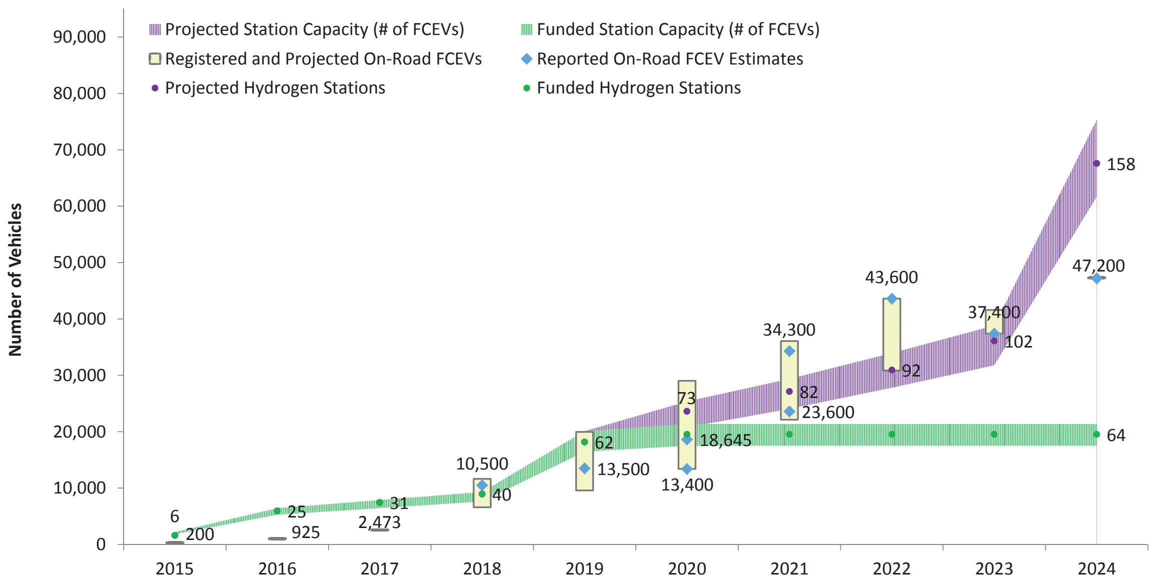


Figure 39: Projected Hydrogen Demand and Potential Usable (80% of Nameplate) Fueling Capacity Growth to Meet Goals of EO B-48-18



Hydrogen Fueling Station Performance Standards and Technology

AB 8 Requirements: Evaluation and determination of minimum operating standards for hydrogen fueling stations

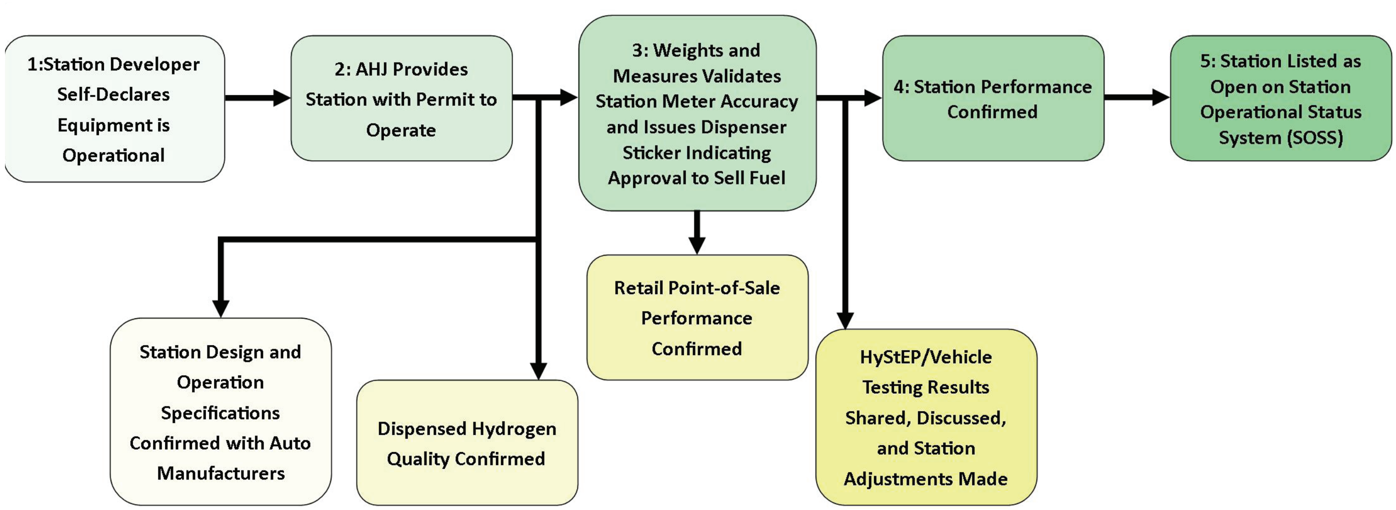
CARB Actions: Assess the current state of hydrogen fueling station standards, including planning and design aspects. Identify and recommend needed additional standards. Provide recommendations for methods to address these needs through hydrogen fueling station funding programs.

As California's hydrogen fueling station network has continued to develop, so have station components, technologies, business cases, and operational characteristics. As the market matures, it is important to ensure that State co-funded stations utilize the best-available equipment and practices and adhere to consensus-driven industry standards for retail station operations. The State's goal is to ensure safe, convenient, and reliable fueling opportunities for FCEV drivers so that adoption of the zero-emission vehicles can be maximized. In 2017, the Energy Commission hosted a series of workshops to discuss concepts for the technical requirements of stations to be funded under its next grant funding opportunity [40]. CARB's recommendations for station performance standards and technology presented below have been informed by these and other ongoing discussion throughout the past year.

Open-Retail Station Performance

With the latest developments in the hydrogen fueling station network and recent grant funding opportunities' focus on satisfying retail fueling customer needs, CARB considers the Open-Retail station to now be the de facto requirement for future hydrogen fueling station co-funding. Retail hydrogen fueling stations are defined by their ability to replicate the gasoline fueling experience, with the capability to quickly, safely, and reliably provide customers with fuel. Fueling should not be limited by any special access restrictions and payment options should replicate those available to retail gasoline fueling customers. In brief, a retail hydrogen fueling station is one that any FCEV driver can visit at any time within the host site's normal operating hours and expect to be able to receive a full tank of hydrogen within three to five minutes of starting the fueling process. Retail customers must be able to pay with their preferred method of payment, including major credit, debit, and fleet card systems. Meeting these expectations requires station developers to secure site access at the host location, integrate applicable design codes and standards into the equipment and physical layout, and ensure their station can provide fuel while meeting hydrogen quality, hydrogen metering, and fueling protocol standards. Verification of these capabilities is accomplished via a multi-step process that involves the station developer, State and local agencies having jurisdiction, auto manufacturers, and the California Fuel Cell Partnership, as shown in Figure 40.

Figure 40: Process Flow for Hydrogen Fueling Stations to Achieve Open Status



The primary codes and standards, along with the most recent publication date, that station developers in the next grant funding program must follow include:

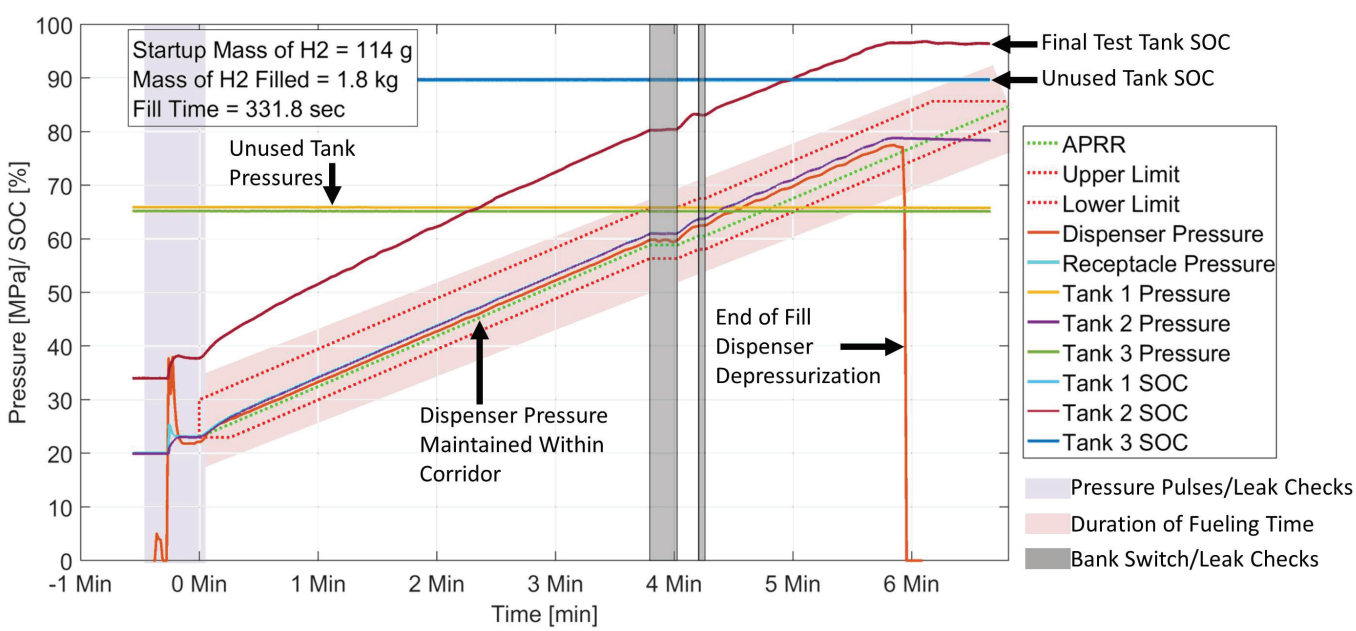
- NFPA 2-2016: Fundamental safeguards for safe generation, storage, and handling of hydrogen; requirements can affect station design considerations
- CSA HGV 4.9-2016: Design, installation, operation, and maintenance standards for hydrogen fueling stations, based on United States and international codes and standards Several component-specific standards are also incorporated into these requirements.
- SAE J2601-2016: Industry standard fueling protocol that ensures safe, fast fills are provided to customers
- SAE J2719-2015: Standards for hydrogen fuel quality for FCEVs
- SAE J2799-2014: Design requirements for interfacing with FCEV fueling receptacle, including communications standards
- ANSI/CSA HGV 4.3-2016: Test method to validate conformance to SAE J2601

These standards are typically under constant review and refinement to maintain relevance with advances in industry practices and technology. In particular, an update to CSA HGV 4.3 is expected to be released in the near future in order to address the recent development of new methods to perform fueling protocol calculations (known as the MC method). As these updated standards become available, station operators should expect requirements to advance to the latest-available versions.

Hydrogen Station Performance Confirmation

A key step in the station validation process is the verification of the hydrogen fueling station's ability to dispense hydrogen according to the SAE J2601 standard. This standard defines the process limitations (primarily in terms of dispensed hydrogen Average Pressure Ramp Rate [APRR] and temperature) to ensure vehicles are able to fill as quickly as possible while maintaining a fueling rate that ensures the longevity and continued safe operation of the vehicles' onboard hydrogen storage tanks and provides drivers with a full tank, indicated by its State of Charge (SOC). Figure 41 provides an example of a hydrogen fueling event that successfully remains within expected process bounds as defined by SAE J2601 requirements.

Figure 41: Sample Passing HyStEP Pressure Data



The experience gained in California in the past several years has made major advancements in streamlining the process of verifying hydrogen dispensers' ability to meet these fueling protocol requirements. The Hydrogen Station Equipment Performance (HyStEP[14]) device and program have enabled significant improvement in the time and process necessary to test and validate station performance. To date, the device has made 25 separate visits to 15 different stations to validate dispensers' ability to adhere to the protocols of SAE J2601 and to provide pilot testing for standards and test methods in development. The HyStEP program has been administered by CARB since 2015 and demonstrated the benefits of maintaining a predictable and reliable test device that is able to evaluate new dispenser installations as they become operational in the hydrogen fueling station network. Significant auto manufacturer time and investment has been saved by the ability of the single device to substitute for duplicate testing that would have otherwise needed to be performed by each individual auto manufacturer to confirm the dispenser's readiness to fuel retail customer vehicles.

Evolving the HyStEP Program to Meet the Expected Needs of Accelerating Station Network Development

The State and industry stakeholders, including automakers, agree that policies and technology solutions need to be developed and implemented to enable consumer acceptance of FCEVs. This will foster a robust retail hydrogen fueling market to support a growing FCEV fleet. There is therefore urgency among stakeholders to understand a near-term and long-term plan to address coming challenges in the expected transition to a rapidly-expanding hydrogen station network. Stations are currently meeting expected standards through requirements in the Energy Commission's GFOs. CARB and Energy Commission staff work closely together to ensure that the latest standards and test procedures are integrated into the designs of State co-funded hydrogen fueling stations. Although the State is involved in setting and sometimes verifying these requirements for State co-funded stations (such as the HyStEP device's ability to verify adherence to SAE J2601 according to test procedures defined by CSA HGV 4.3), the State does not have the authority to enforce these requirements on stations funded entirely through private funds. Currently, these standards and test procedures are largely unaddressed in relevant regulations, fire codes, and building codes. Therefore, it is possible that the State will need to develop regulations and programs that define and verify adherence to the required hydrogen fueling station codes and standards.

HyStEP is the first device developed to implement testing according to CSA HGV 4.3. The current software evaluates station performance according to the 2014 version of the SAE J2601 fueling protocol and CSA HGV 4.3 test method, but both the SAE J2601 fueling protocol and CSA HGV 4.3 test procedure are continuing to be modified. Development of standards and test procedures is most effective when integrating insights gained from field experience, and CARB is participating to ensure recommendations and clarifications based on field experience will be implemented to streamline the field testing and analysis processes. The most significant changes will occur in the SAE J2601-2018 version, which will include the MC method first introduced in 2016 and clarify the conditions that define the start of a fill. These changes are critical to implementing a successful program.

The CSA 4.3 committee plans to modify the testing procedure immediately after the SAE version is final, likely six to eight months after the SAE J2601-2018 publication. The modified CSA 4.3 procedure will likely include a factory testing protocol and a station verification and testing protocol. The factory testing protocol could reduce on-site testing significantly, but is not expected to eliminate on-site testing entirely.

To evaluate stations under varying future fueling protocols, the State will need to update the HyStEP device capabilities and modify the post processing software. The additional unmet testing needs will require an updated device. The new device should incorporate the following capabilities: 1) ability to complete back to back filling, 2) ability to complete test fills and vent unused tanks at the same time, and 3) ability to test flow rate directly.

As the hydrogen station market develops from demonstration to commercial scale, opportunities to further minimize the time required of auto manufacturers to participate directly in station validation have emerged. One major shift is represented by the recent interest of third party testing groups in performing station validation testing. CSA, the same organization that promulgates several hydrogen fueling station design and testing standards, has constructed its own hydrogen station equipment performance testing device. The group

14 The HyStEP device was designed and built by Sandia National Laboratories, the National Renewable Energy Laboratory, and Powertech Labs with funding provided by the DOE Fuel Cell Technology Office's H2FIRSTprogram.

is actively field-testing stations in the northeast United States and has expressed interest in testing stations located in California. In addition, factory-based evaluations could lead to reduced field-testing requirements, progress towards eliminating the need for testing by auto manufacturers, and increased station reliability.

Industry and government parties have invested in developing consensus-based performance standards and test procedures; however, government action is now needed to establish these standards and procedures in regulation. CARB will be holding meetings to identify a process that provides the most flexibility and enforceability, and encourages industry stakeholder involvement.

Ensuring Consistent Hydrogen Quality

The California Department of Food and Agriculture's Division of Measurement Standards (DMS) continues to administer the State's program to test the purity of hydrogen delivered at fueling stations intended for retail sales. DMS tests hydrogen dispensed at retail fueling stations for all contaminant species listed in SAE J2719 and shown in Table 7. The agency has indicated that their program is robust, requiring testing prior to a station opening for retail service, any time there is a maintenance event that could cause contamination within the station equipment and piping, in response to any customer complaints, and on a random spot-check basis. DMS has indicated that future requirements of a schedule for periodic testing every six months works well with their existing program and can provide sufficient assurance of continuous delivery of high-quality hydrogen in stations' normal daily operations.

Table 7: Hydrogen Contaminant Species per SAE J2719

Impurity Source	Typical Contaminant
Air	N_2, NO_X, (NO, NO_2), SO_X (SO_2, SO_3), NH_3, O_3
Reformate hydrogen	CO, CO_2, H_2S, NH_3, CH_4
Bipolar metal plates (end plates)	Fe_3+, Ni_2+, Cu_2+, Cr_3+
Membranes (Nafion)	Na+, Ca_2+
Sealing gasket	Si
Coolants, DI water	Si,Al, S, K, Fe, Cu, Cl, V, Cr
Battlefield pollutants	SO_2, NO_2, CO, propane, benzene
Compresors	Oils

In addition to periodic sampling of dispensed hydrogen, stakeholders have continued to support investigations into the development of an inexpensive and effective in-line contaminant detector. The purpose of such a detector would be to provide warning of major fuel quality issues should they arise at times that happen to fall between regularly-scheduled testing. Such a device would rely on continual sampling and detection of select species that indicate degraded fuel quality in the dispenser's supply source. With an early warning provided by such a device, a station operator can stop service at the station, limiting the number of FCEVs that may receive potentially harmful contaminants in their fuel. CARB, the Energy Commission, South Coast Air Quality Management District, and the Governor's Office of Business and Economic Development (GO-Biz) anticipate continuing the development of such a detector through a research consortium in partnership with DOE and NREL under the H2@Scale initiative.

Dispensing Meter Accuracy and the California Type Evaluation Program (CTEP)

California has also worked to streamline the testing and validation of hydrogen fueling dispensers' ability to accurately meter the amount of fuel dispensed in retail environments. As with any retail fuel transaction, accurate metering is necessary to provide confidence to both consumers (who should not be charged for hydrogen they do not receive) and station operators (who should receive payment for the full amount of hydrogen dispensed to consumers). Verification of the accuracy of hydrogen dispensers that are newly entering the California market is carried out by DMS through CTEP, in accordance with California Code of Regulations Title 4 Division 9. Under the program, DMS provides type approval for the accuracy of the dispenser's measurement of the mass of fuel dispensed. Validation for individual installations of type-approved dispensers upon installation and annual confirmation testing are then performed by DMS and/or Registered Service Agents (RSAs).

To date, six dispenser types have been certified through the program, as shown in Table 8. The accuracy classes defined under California regulation are shown in Table 9 and are largely in alignment with national guidance. The 10% accuracy class, which is no longer available for new type evaluation and dispenser installation, was developed in California to help enable the early market development of hydrogen fueling stations when dispenser components with greater accuracy were largely unavailable. Today's technology is more accurate, and the DMS program has shown that dispensers are overwhelmingly capable of meeting the 5% accuracy class and have, in some cases, demonstrated performance sufficient to meet the 3% accuracy class.

Table 8: Dispensers Currently Listed with Type Certification through CTEP[15]

Certificate Number	Company Name	Models	Effective Date
5824-18	Air Liquide Advance Technologies U.S. LLC	US-Gen I	1/22/18
5743a-15	Bennett Pump Company	H10	12/22/15
5741-15	CSULA	112892	4/29/15
5778-16	Equilon Enterprises LLC dba Shell Oil Products	RHM08 Mass Flow Sensor, RHE08 Mass Flow Transmitter	2/22/16
5774a-18 (replaces 5774-15)	Quantum Fuel Systems LLC	118586	2/14/18
5774-15	Quantum Fuel Systems Technologies Worldwide	113892	11/25/15

Table 9: Summary of CTEP Hydrogen Dispenser Accuracy Class Testing

Testing of Accuracy Classes and Tolerances for Hydrogen Gas-Measuring Devices (Two devices were re-tested after modifications)			
Accuracy Class	**Acceptance Tolerance**	**Maintenance Tolerance**	**Number of Devices in Compliance**
2	1.50%	2.00%	0
3.0[1]	2.00%	3.00%	0
5.0[1]	4.00%	5.00%	32
10.0[2]	5.00%	10.00%	3
1 The tolerance values for Accuracy Classes 3.0 and 5.0 hydrogen gas-measuring devices are applicable to devices installed prior to January 1, 2020. 2 The tolerance values for Accuracy Class 10.0 hydrogen gas-measuring devices are applicable to devices installed prior to January 1, 2018.			Total Devices in Compliance 35

Evolution of Station Design

Based on observations of station technology advancements following awards in GFO 15-605, CARB performed analyses of hydrogen station design specifications to maintain momentum in technology development for future funding programs [41]. CARB's approach sought to update prior recommendations informed by analysis completed by Nexant and the European H2Mobility private-public partnership and to contextualize requirements based on location and role of stations when introduced to the fueling network [42], [43]. These recommendations, shown in Table 10 and Table 11, focused on various measures of station performance, including capacity ratings, required fueling positions, simultaneous and back-to-back fueling

15 All certificates issued to date have been for the 5% accuracy class, with the exception of certificate 5824-18, which has been certified to the 10% accuracy class

performance, and the ability of the station to provide on-site redundancy. Feedback provided by industry stakeholders during the Energy Commission's workshop series largely validated CARB's recommendations regarding capacity recommendations in Table 10, though CARB envisions a need to require some stations in the highest-need areas to have a 24-hour capacity greater than 600 kilograms per day. This is a higher capacity than most industry requests.

In addition, indications from industry stakeholders appear to be in agreement with CARB's recommendations regarding minimum fueling positions, redundancy, and simultaneous fueling. Although not discussed with the same degree of detail, industry's requests for back-to-back fueling performance can easily be met by stations that meet the recommendations of Table 11. Some stakeholders have referenced CSA HGV 4.9, which includes a recommended testing procedure for consecutive fueling events. In these tests, CSA recommends a rest period of 4 minutes between fills and fill times of at least 4 minutes. These are well in agreement with CARB's recommendations for core market stations, which anticipate the potential for improved performance at the start of consecutive fueling events relative to the final fill events for the period. However, CARB's recommendations for stations outside the core are more lenient due to the anticipation that lower-priced component options may become available and enable station cost savings for locations where high-throughput peak performance is not a major concern in the early network development. The potential for this will be entirely dependent on the evolution of station components available in the market. If such cost savings cannot be realized and all station developers will only have dispensers available that meet the requirements of core stations, the net result will likely still be a positive benefit for customers who will be able to enjoy consistency of fill performance across the entire network, regardless of location. Thus, for the Energy Commission's next hydrogen fueling station co-funding program, CARB continues to recommend the station requirements as shown in Table 10 and Table 11.

In order to ensure that proposed stations will have the potential to meet these requirements, the State requires a standardized method of estimating station throughput capacity over the variety of time periods shown in Table 10. Such a standardized method would require key performance metrics of station equipment and knowledge of the overall station operation strategy. At the current time, no tool exists to enable such a standardized evaluation of station design capacity. The Energy Commission, in cooperation with CARB, has initiated the development of a station capacity estimation tool to be designed by engineers at the National Renewable Energy Laboratory. Under the current work plan, the tool should be available for use during the application and review period of the next Energy Commission station funding program.

Table 10: Recommendations for Station Fueling Capacity for Various Station Classifications[16]

Classification	Description	24-hour Throughput	12-hour Throughput	3-hr Peak Total Throughput	Peak Hourly Throughput
Core Market Area, Local Fueling Market Capacity Growth	Multiple local stations established; new capacity has greater priority than coverage	600+	480+	136+	48+
Core Market Area, Local Fueling Market Coverage Growth	Multiple local stations established; redundancy and coverage have greater priority than capacity	300+	240+	68+	24+
Core Market Area, Local Fueling Market Initiation	Among first 3 stations in a local fueling market	300+	240+	68+	24+
Intermittent Connector	Stations intended for long-distance fueling	200+	160+	44+	16+
Intermittent Destination	Stations intended for fueling at vacation locations	200+	160+	44+	16+

16 These specifications are intended to be nominal specifications. Stations with capacities above or below the indicated amounts may still serve the purpose described for any given station classification in this table. Consideration of the appropriate capacity for any given station will require informed consideration of several market viability factors and the status of the currently-funded hydrogen station network within the local region.

Table 11: Recommendations for Station Fueling Performance Capabilities for Various Station Classifications (back-to-back fueling specified for 4-kg fills, all fills should be less than 5 minutes)

Classification	Description	Fueling Positions	Simultaneous Fueling	On-Site Redundancy	Back-to-Back Fueling
Core Market Area, Local Fueling Market Capacity Growth	Multiple local stations established; new capacity has greater priority than coverage	2+	Required	Preferred	3 fills with 3-minute rests between, followed by 5-minute rests for 3 peak hours; <10-minute rest otherwise
Core Market Area, Local Fueling Market Coverage Growth	Multiple local stations established; redundancy and coverage have greater priority than capacity	2+	Required	Preferred	3 fills with 3-minute rest between, followed by 5-minute rests for 3 peak hours; <10-minute rest otherwise
Core Market Area, Local Fueling Market Initiation	Among first 3 stations in a local fueling market	2+	Required	Optional	5-minute rests between fills for peak 3 hours; <10-minute rest otherwise
Intermittent Connector	Stations intended for long-distance fueling	1+	Optional	Optional	5 fills with 10-minute rests between in one peak hour; <20-minute rest otherwise
Intermittent Destination	Stations intended for fueling at vacation locations	1+	Optional	Optional	5 fills with 5-minute rests between in one peak weekend hour; followed by 10-minute rests for 3 peak weekend hours; <20-minute rest otherwise

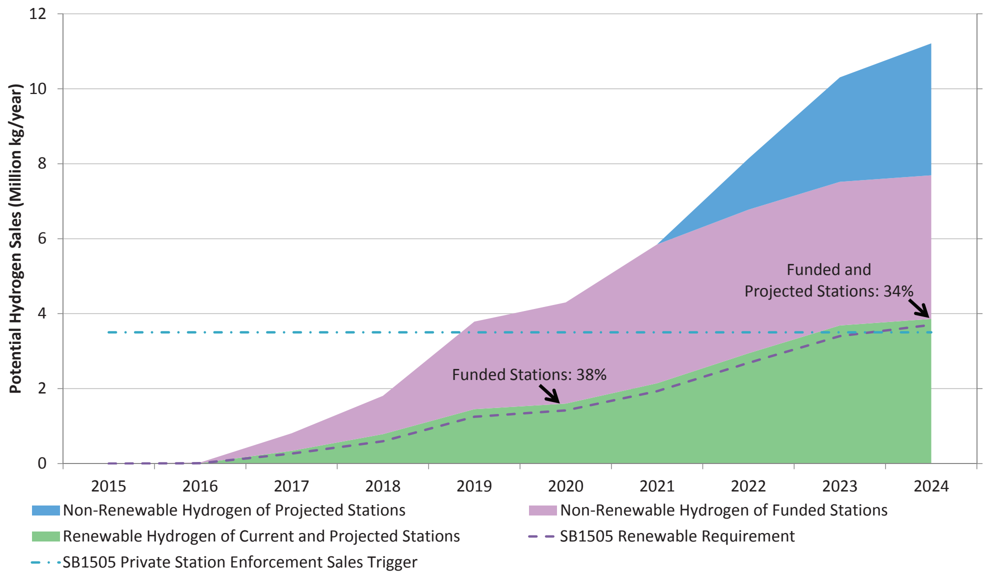
Renewable Content of California's Hydrogen Fueling Network

Based on analysis of Open-Retail station operation and the projected FCEV population, CARB estimates that the currently-funded hydrogen fueling station network will provide hydrogen with a renewable content of 38% when fully built by 2020. Including all stations through 2024 in the buildout scenario that approaches the goals of EO B-48-18, and assuming each station provides hydrogen with a 33% renewable content, CARB projects that the 2024 hydrogen station network will have an average dispensed renewable content of 34%[17]. CARB's analysis method estimates dispensed hydrogen as the lesser of total demand and total capacity in any given year. As noted earlier, the station network capacity in 2024 far exceeds the projected demand; thus, the dispensed renewable content is demand-limited in this analysis.

As shown in Figure 42, the pace of expected FCEV deployment provides a fuel demand by the end of 2019 in excess of 3.5 million kilograms per year. At this time, the 33% renewable requirement will be applicable not only to hydrogen fueling stations with State co-funding, but also to stations that are funded entirely through private sources. This estimate is based solely on LDV fueling demand; with the growing population of fuel cell electric buses (FCEBs) around the state, it is likely that the threshold will actually be crossed sooner than shown here.

17 A recent industry stakeholder proposal for a new credit generation pathway in the Low Carbon Fuel Standard program has indicated an industry-consensus baseline of 40% renewable hydrogen implementation. If enacted, and all future stations in 2020-2024 follow this requirement, the renewable content of the 2024 network would be 39%.

Figure 42: Evaluation of Compliance with SB 1505 Renewables Requirement and Trigger for Enforcement of the Requirement on Stations without State Co-funding



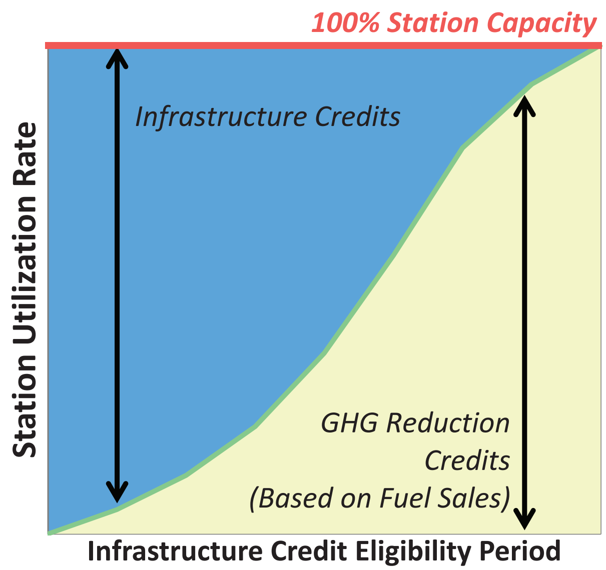
Potential Modifications to Low Carbon Fuel Standard Program

One of the provisions of EO B-48-18 was to explore methods by which the LCFS program may be leveraged to expand zero-emission infrastructure. The LCFS program is currently undergoing amendments to enable several program updates and improvements, including a number of provisions related to the generation of credits based on the sale of hydrogen as transportation fuel. At the April 27, 2018 Board Meeting, CARB staff were directed to consider implementing a method by which hydrogen fueling stations could participate in the LCFS program in a way that meets Governor Brown's directive [44].

One possibility that has been proposed by several members of the hydrogen fueling industry is the generation of "Infrastructure Credits." In the current LCFS program, fuel retailers and producers may only generate credits for dispensed fuel based on the carbon intensity of their products and the volume of those fuels sold. While hydrogen station operators are able to participate in the program through this credit generation path, the early development phase of the hydrogen fueling network limits the total fuel sales and credit generation potential. In addition, credit generation based on sales is most useful only for addressing a station's ongoing operational costs and has limited ability to offset capital costs.

The industry proposal is to develop a pathway by which hydrogen station operators can additionally generate credits based on the difference between their station capacity and the actual fuel sales rate, as shown in Figure 43. CARB staff are currently considering the proposal and any necessary additions if a similar program does become adopted. This may include appropriate methods of limiting the overall impact on the LCFS program's credit market, limits on the period of eligibility and Infrastructure Credit generation for each station, and standardized methods for determining station capacity and availability. If such a proposal is incorporated into the current amendment draft language, it will require further opportunity for public comment and Board review.

Figure 43: Demonstration of Industry-Proposed Infrastructure Credit Concept



Conclusions and Recommendations

AB 8 Requirements: Provide evaluation and recommendations to the Energy Commission to inform future funding programs

CARB Actions: Recommend funding level for next Energy Commission program. Recommend priority locations to meet coverage needs in next Energy Commission program. Recommend minimum operating requirements and station design features to incentivize in next Energy Commission program.

Perhaps more so than in any prior Annual Evaluation, CARB's analyses of the hydrogen fueling station and FCEV industries this past year indicate the most consistently sustained progress and the greatest aspirations for future growth. Hydrogen fueling station network growth has remained largely on track with expectations reported a year ago. The Open-Retail network has gained seven stations since the same time last year. Most of the funded stations that remain in development originate from the Energy Commission's most recent grant funding program, GFO 15-605. Some of these stations are reportedly expected to complete construction earlier than their original estimates and may even be Open-Retail by the close of 2018. Such an achievement would set a new precedent for rapid hydrogen fueling station development and represent a substantial accomplishment within the industry.

Moreover, the hydrogen fueling station network is rapidly evolving. The 2017 Annual Evaluation already noted that the stations funded under GFO 15-605 were larger than stations previously funded and included more sophisticated designs to enhance station performance and availability. In the past year, one of the station developers has even updated the expected nameplate capacity of their awarded stations, further demonstrating the continued advancements within industry and the anticipation of greater numbers of FCEVs on the road in the near future. Today's hydrogen fueling station network continues to meet growing customer demand for fuel. The average utilization has grown from merely 3% at the start of 2016 to over 36% (nearly 2,100 kilograms per day on average, enabling an estimated 10 million miles in zero-emission travel) in the first quarter of 2018, thanks to a constant deployment of FCEVs. Industry estimates now indicate 4,819 FCEVs have been deployed in California.

This pace of development is expected to continue and must accelerate in order to fully realize the potential of a widespread commercial FCEV market. A pathway to achieving these market maturation goals can be achieved that also meets the complementary goals of 200 hydrogen fueling stations by 2025 (advanced by Governor Brown's EO B-48-18) and 1,000 stations supporting 1,000,000 FCEVs by (as envisioned by the members of the CaFCP). Meeting these goals will require significant acceleration in station development and FCEV deployment beyond business-as-usual and any projections reported to date. However, as noted by the members of the CaFCP, it can be done.

Taking these developments and related insights gained from ongoing discussions with public and private industry partners, CARB makes the following set of recommendations:

- While the past year has seen significant progress and a renewed vision for the future of hydrogen transportation in the state, the most recent goals set forth require continued acceleration of station deployment. The Energy Commission has put in place methods to improve station development timelines in its grant funding programs and should maintain its focus on faster station development. In addition, the Energy Commission has put forth an aggressive plan to shorten the time required to develop, release, evaluate, and make awards under the next grant funding program. Such a plan is timely and can provide station developers with increased assurance of a steady stream of available grant funds. Moreover, as first presented in Governor Brown's budget request to support EO B-48-18, and embodied in the Energy Commission's ARFVTP Investment Plan for fiscal year 2018/2019, a total of $92 million has been proposed for hydrogen infrastructure under the next funding program. CARB recommends that the Energy Commission maximize the proportion of these funds that it dedicates to light-duty and/or co-located (with medium- and heavy-duty) hydrogen fueling stations. This investment would represent nearly a four-fold increase beyond the pace in recent years and will be necessary to give the hydrogen community a head-start on meeting the ambitious 2025 and 2030 goals.
- Although the pace of station development will be a key factor to the success of the hydrogen fueling network and FCEV deployment, individual station design considerations will also play an impactful role. CARB recommends that the Energy Commission's next funding program build on progress made to date in continuing to elevate the minimum requirements for stations, especially

those located in the largest first-adopter markets and where the density of funded hydrogen fueling stations is most rapidly increasing. Minimum station capacities should be increased, multiple dispensers capable of fueling vehicles simultaneously should become standard requirements for most locations, and back-to-back fueling performance should continue to be held to requirements as specified earlier in this report and in agreement with H2Mobility and other industry input. In addition, as more drivers adopt FCEVs and the user base for fueling stations broadens, stations will need to increasingly have the look and feel of a familiar retail fueling experience. Considerations for adequate lighting, cover from rain, accessibility, and easy-to-understand dispenser operation should continue to be a part of the Energy Commission's funding decisions.

- Significant analysis and public-private cooperative effort has been leveraged to develop a year-by-year vision of potential station network development to meet both Governor Brown's 2025 target of 200 hydrogen fueling stations and the CaFCP's 2030 target of 1,000 hydrogen fueling stations. CARB's recommendations for guidance in selecting appropriate sites for future funding program awards reference this scenario analysis. Over the next few years, most of the station network will need to continue to develop in the areas with the greatest potential first-adopter market. Higher-capacity stations on average will also need to be focused in these areas as long as station-specific site design and local permitting processes are amenable to the requirements of larger stations. In addition, the next few years of development should enable the commencement of significant network expansion into secondary markets and filling in key long-distance travel routes and more options for vacation and destination travel.
- Recently, the Energy Commission also made significant progress to address a projected gap in hydrogen production capacity by funding an additional two tons per day of 100% renewable hydrogen production capacity at a planned three-ton per day facility. This was a first in California and an important milestone to achieve. As reported in the previous Annual Evaluation, significantly larger volumes of hydrogen production will be needed to meet the demand of the projected FCEV fleet. With the accelerated goals developed in the past year, this has only become an even more consequential consideration. The ARFVTP Investment Plan for fiscal year 2018-2019 includes $25 million for low-carbon fuel production and supply; CARB recommends that the Energy Commission continue to build on the progress made with the recent award and consider maximizing the proportion of the $25 million that can be devoted to further developing in-state 100% renewable hydrogen production capacity.

The expectations going forward of the hydrogen fueling network and FCEV deployment represent acceleration of progress by at least an order of magnitude by 2030. Meeting these ambitions will require all stakeholders, public and private, to redouble their efforts and maintain commitment to a shared vision of hydrogen and FCEVs' role in the transition to a zero-emission vehicle fleet. Public financial commitments secured for the short term will provide a necessary boost to the momentum already gained within industry and have the potential to launch the FCEV and hydrogen markets on a trajectory not only towards success, but also towards eventual financial self-reliance. The investments determined in the next year will be consequential; they have the potential to more clearly define the trajectory for a hydrogen fueling network that allows any California resident to not only realize easy adoption of FCEVs into their daily lives, but also enables them to economically take any trip that they can currently make with conventional fuels. Those drivers will be able to accomplish all this while significantly reducing the greenhouse gas and criteria pollutant emissions associated with their travel.

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Appendix A: AB 8 Excerpt

The following is an excerpt of AB 8, with the language from section 43018.9 relevant to this report.

Section 43018.9 is added to the Health and Safety Code, to read:

43018.9.

(a) For purposes of this section, the following terms have the following meanings:

(1) "Commission" means the State Energy Resources Conservation and Development Commission.

(2) "Publicly available hydrogen-fueling station" means the equipment used to store and dispense hydrogen fuel to vehicles according to industry codes and standards that is open to the public.

(b) Notwithstanding any other law, the state board shall have no authority to enforce any element of its existing clean fuels outlet regulation or of any other regulation that requires or has the effect of requiring that any supplier, as defined in Section 7338 of the Revenue and Taxation Code as in effect on May 22, 2013, construct, operate, or provide funding for the construction or operation of any publicly available hydrogen-fueling station.

(c) On or before June 30, 2014, and every year thereafter, the state board shall aggregate and make available all of the following:

(1) The number of hydrogen-fueled vehicles that motor vehicle manufacturers project to be sold or leased over the next three years as reported to the state board pursuant to the Low Emission Vehicle regulations, as currently established in Sections 1961 to 1961.2, inclusive, of Title 13 of the California Code of Regulations.

(2) The total number of hydrogen-fueled vehicles registered with the Department of Motor Vehicles through April 30.

(d) On or before June 30, 2014, and every year thereafter, the state board, based on the information made available pursuant to subdivision (c), shall do both of the following:

(1) Evaluate the need for additional publicly available hydrogen-fueling stations for the subsequent three years in terms of quantity of fuel needed for the actual and projected number of hydrogen-fueled vehicles, geographic areas where fuel will be needed, and station coverage.

(2) Report findings to the commission on the need for additional publicly available hydrogen-fueling stations in terms of number of stations, geographic areas where additional stations will be needed, and minimum operating standards, such as number of dispensers, filling protocols, and pressures.

(e) (1) The commission shall allocate twenty million dollars ($20,000,000) annually to fund the number of stations identified pursuant to subdivision (d), not to exceed 20 percent of the moneys appropriated by the Legislature from the Alternative and Renewable Fuel and Vehicle Technology Fund, established pursuant to Section 44273, until there are at least 100 publicly available hydrogen-fueling stations in operation in California.

(2) If the commission, in consultation with the state board, determines that the full amount identified in paragraph (1) is not needed to fund the number of stations identified by the state board pursuant to subdivision (d), the commission may allocate any remaining moneys to other projects, subject to the requirements of the Alternative and Renewable Fuel and Vehicle Technology Program pursuant to Article 2 (commencing with Section 44272) of Chapter 8.9.

(3) Allocations by the commission pursuant to this subdivision shall be subject to all of the requirements applicable to allocations from the Alternative and Renewable Fuel and Vehicle Technology Program pursuant to Article 2 (commencing with Section 44272) of Chapter 8.9.

(4) The commission, in consultation with the state board, shall award moneys allocated in paragraph (1) based on best available data, including information made available pursuant to subdivision (d), and input from relevant stakeholders, including motor vehicle manufacturers that have planned deployments of hydrogen-fueled vehicles, according to a strategy that supports the deployment of an effective and efficient hydrogen-fueling station network in a way that maximizes benefits to the public while minimizing costs to the state.

(5) Notwithstanding paragraph (1), once the commission determines, in consultation with the state board, that the private sector is establishing publicly available hydrogen-fueling stations without the need for government support, the commission may cease providing funding for those stations.

(6) On or before December 31, 2015, and annually thereafter, the commission and the state board shall jointly review and report on progress toward establishing a hydrogen-fueling network that provides the coverage and capacity to fuel vehicles requiring hydrogen fuel that are being placed into operation in the state. The commission and the state board shall consider the following, including, but not limited to, the available plans of automobile manufacturers to deploy hydrogen-fueled vehicles in California and their progress toward achieving those plans, the rate of deployment of hydrogen-fueled vehicles, the length of time required to permit and construct hydrogen-fueling stations, the coverage and capacity of the existing hydrogen-fueling station network, and the amount and timing of growth in the fueling network to ensure fuel is available to these vehicles. The review shall also determine the remaining cost and timing to establish a network of 100 publicly available hydrogen-fueling stations and whether funding from the Alternative and Renewable Fuel and Vehicle Technology Program remains necessary to achieve this goal.

(f) To assist in the implementation of this section and maximize the ability to deploy fueling infrastructure as rapidly as possible with the assistance of private capital, the commission may design grants, loan incentive programs, revolving loan programs, and other forms of financial assistance. The commission also may enter into an agreement with the Treasurer to provide financial assistance to further the purposes of this section.

(g) Funds appropriated to the commission for the purposes of this section shall be available for encumbrance by the commission for up to four years from the date of the appropriation and for liquidation up to four years after expiration of the deadline to encumber.

(h) Notwithstanding any other law, the state board, in consultation with districts, no later than July 1, 2014, shall convene working groups to evaluate the policies and goals contained within the Carl Moyer Memorial Air Quality Standards Attainment Program, pursuant to Section 44280, and Assembly Bill 923 (Chapter 707 of the Statutes of 2004).

(i) This section shall remain in effect only until January 1, 2024, and as of that date is repealed, unless a later enacted statute, that is enacted before January 1, 2024, deletes or extends that date.

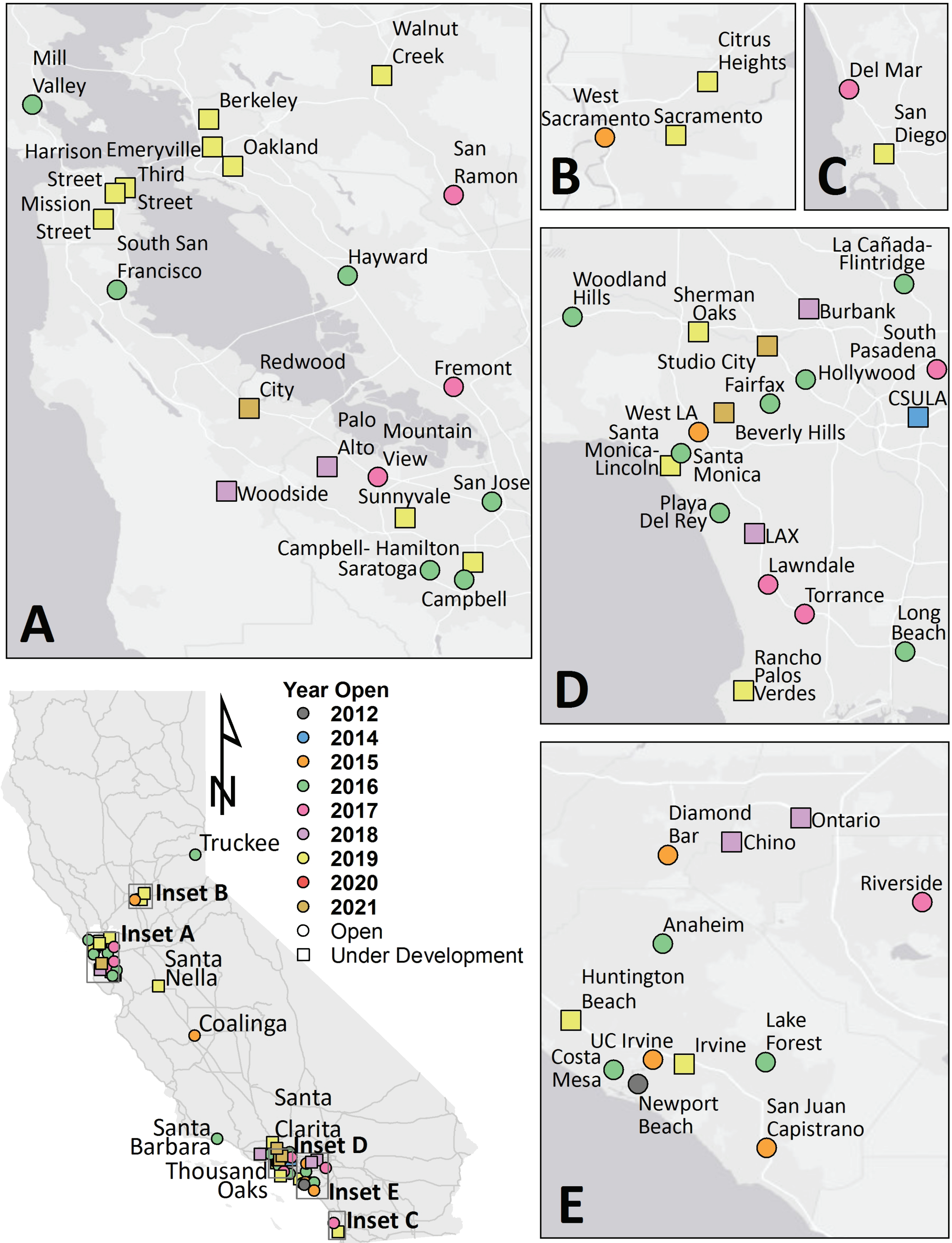
Appendix B: Station Status Summary

List of Known and Projected Hydrogen Fueling Station Retail Open Dates (2015-2020), as of June 1, 2018

Name	Address	City	Capacity (kg/day)	County	Retail Open Date	Renewable %
West Sacramento	1515 South River Rd	West Sacramento	350	Yolo	2015, Q2	33
Diamond Bar	21865 E Copley Dr	Diamond Bar	180	Los Angeles	2015, Q3	33
Coalinga	24505 W Dorris Ave	Coalinga	180	Fresno	2015, Q4	0
San Juan Capistrano	26572 Junipero Serra Rd	San Juan Capistrano	350	Orange	2015, Q4	33
UC Irvine	19172 Jamboree Road	Irvine	180	Orange	2015, Q4	33
West LA	11261 Santa Monica Blvd	Los Angeles	180	Los Angeles	2015, Q4	33
Costa Mesa	2050 Harbor Blvd	Costa Mesa	180	Orange	2016, Q1	100
La Cañada-Flintridge	550 Foothill Blvd	La Canada Flintridge	180	Los Angeles	2016, Q1	100
Lake Forest	20731 Lake Forest Dr	Lake Forest	180	Orange	2016, Q1	100
Long Beach	3401 Long Beach Blvd	Long Beach	180	Los Angeles	2016, Q1	100
San Jose	2101 North First St	San Jose	180	Santa Clara	2016, Q1	0
Santa Monica	1819 Cloverfield Blvd	Los Angeles	180	Los Angeles	2016, Q1	33
Saratoga	12600 Saratoga Ave	Saratoga	180	Santa Clara	2016, Q1	0
South San Francisco	248 S Airport Blvd	South San Francisco	180	San Mateo	2016, Q1	0
Campbell	2855 Winchester Blvd	Campbell	180	Santa Clara	2016, Q2	0
Fairfax	7751 Beverly Blvd	Los Angeles	180	Los Angeles	2016, Q2	33
Hayward	391 West A St	Hayward	180	Alameda	2016, Q2	0
Mill Valley	570 Redwood Highway	Mill Valley	180	Marin	2016, Q2	0
Santa Barbara	150 S La Cumbre Rd	Santa Barbara	180	Santa Barbara	2016, Q2	100
Truckee	12105 Donner Pass Rd	Truckee	180	Nevada	2016, Q2	0
Playa Del Rey	8126 Lincoln Blvd	Los Angeles	180	Los Angeles	2016, Q3	100
Anaheim	3731 E La Palma Ave	Anaheim	100	Orange	2016, Q4	33
Del Mar	3060 Carmel Valley Rd	San Diego	180	San Diego	2016, Q4	100
Hollywood	5700 Hollywood Blvd	Los Angeles	180	Los Angeles	2016, Q4	100
Woodland Hills	5314 Topanga Canyon Blvd	Woodland Hills	180	Los Angeles	2016, Q4	33
Riverside	8095 Lincoln Avenue	Riverside	100	Riverside	2017, Q1	33
Lawndale	15606 Inglewood Avenue	Lawndale	180	Los Angeles	2017, Q2	33
South Pasadena	1200 Fair Oaks Ave	South Pasadena	180	Los Angeles	2017, Q2	100
Fremont	41700 Grimmer Blvd	Fremont	180	Alameda	2017, Q3	0
San Ramon	2451 Bishop Drive	San Ramon	350	Contra Costa	2017, Q3	33
Torrance	2051 W 190th St	Torrance	200	Los Angeles	2017, Q3	33
Thousand Oaks	3102 Thousand Oaks Blvd	Thousand Oaks	180	Ventura	2018, Q1	100
Mountain View	830 Leong Drive	Mountain View	350	Santa Clara	2018, Q2	33
Newport Beach	1600 Jamboree Road	Newport Beach	100	Orange	2018, Q2	33
Ontario	1850 Holt Blvd	Ontario	100	San Bernardino	2018, Q2	100
Burbank	145 W Verdugo Rd	Burbank	100	Los Angeles	2018, Q3	33

Name	Address	City	Capacity (kg/day)	County	Retail Open Date	Renewable %
CSULA	5151 State University Dr	Los Angeles	60	Los Angeles	2018, Q4	100
LAX	10400 Aviation Drive	Los Angeles	180	Los Angeles	2018, Q4	33
Palo Alto	3601 El Camino Real	Palo Alto	180	Santa Clara	2018, Q4	33
Woodside	17287 Skyline Blvd	Woodside	140	San Mateo	2018, Q4	33
Berkeley	1250 University Avenue	Berkeley	360	Alameda	2019, Q1	33
Citrus Heights	6141 Greenback Lane	Citrus Heights	360	Sacramento	2019, Q1	33
Huntington Beach	16001 Beach Blvd	Huntington Beach	500	Orange	2019, Q1	33
Sacramento	3510 Fair Oaks Blvd	Sacramento	360	Sacramento	2019, Q1	33
Santa Clarita	24551 Lyons Ave	Santa Clarita	180	Los Angeles	2019, Q1	33
Santa Nella	12754 State Hwy 33	Santa Nella	180	Merced	2019, Q1	33
SF Harrison Street	1201 Harrison St	San Francisco	360	San Francisco	2019, Q1	33
SF Mission Street	3550 Mission St	San Francisco	360	San Francisco	2019, Q1	33
SF Third Street	551 Third St	San Francisco	360	San Francisco	2019, Q1	33
Sunnyvale	1296 Sunnyvale Saratoga Rd	Sunnyvale	500	Santa Clara	2019, Q1	33
Walnut Creek	2900 N Main St	Walnut Creek	360	Contra Costa	2019, Q1	33
Campbell-Hamilton	337 East Hamilton	Campbell	500	Santa Clara	2019, Q2	33
Emeryville	1152 45th Street	Emeryville	350	Alameda	2019, Q2	33
Rancho Palos Verdes	28103 Hawthorne Blvd	Rancho Palos Verdes	180	Los Angeles	2019, Q2	33
Sherman Oaks	14478 Ventura Blvd	Sherman Oaks	500	Los Angeles	2019, Q2	33
Irvine	5333 University Dr	Irvine	500	Orange	2019, Q3	33
Mission Hills	15544 San Fernando Mission Blvd	Mission Hills	500	Los Angeles	2019, Q3	33
Oakland	350 Grand Ave	Oakland	500	Alameda	2019, Q3	33
Chino	12610 East End Ave	Chino	100	San Bernardino	2019, Q4	100
Redwood City	503 Whipple Ave	Redwood City	500	San Mateo	2019, Q4	33
San Diego	5494 Mission Center Rd	San Diego	500	San Diego	2019, Q4	33
Santa Monica-Lincoln	1866 Lincoln Blvd	Los Angeles	500	Los Angeles	2019, Q4	33
Beverly Hills	9988 Wilshire Boulevard	Beverly Hills	500	Los Angeles	2020, Q1	33
Studio City	3780 Cahuenga Blvd	Studio City	500	Los Angeles	2020, Q1	33

Appendix C: Auto Manufacturer Survey Material



Appendix D: Vision 2030 Development and Reference Materials

The Location and Number of Hydrogen Fueling Stations portion of this report provides CARB's recommendations for priorities in the next set of hydrogen fueling station locations to be co-funded under an Energy Commission GFO. As described in that chapter, the determination of these locations is guided by and in accordance with a similar effort undertaken by the California Fuel Cell Partnership to provide a vision of the potential hydrogen fueling network development to reach the goals of the Governor's EO B-48-18 (200 stations by 2025) and establish a fueling network of 1,000 stations able to support 1,000,000 FCEVs on the road by 2030. CARB participated in the activities to help define the potential structure and development process of this network. Key determinations included the number, timing, capacity, and general location of individual station deployments in years 2020 through 2030. These were informed primarily by an automated evaluation process that utilized the CARB-developed CHIT 2017 Release and stakeholder input to account for considerations not entirely captured by CHIT.

This appendix provides a detailed overview of the evaluation process that led to the determination of the vision to 1,000 hydrogen fueling stations by 2030, including exploratory evaluations that ultimately led to development of the network buildout scenario presented here and in the Partnership's latest publication, "The California Fuel Cell Revolution: A Vision for Advancing Economic, Social, and Environmental Priorities" [4].

Overview of Finalized Evaluation for Vision to 1,000 Stations by 2030

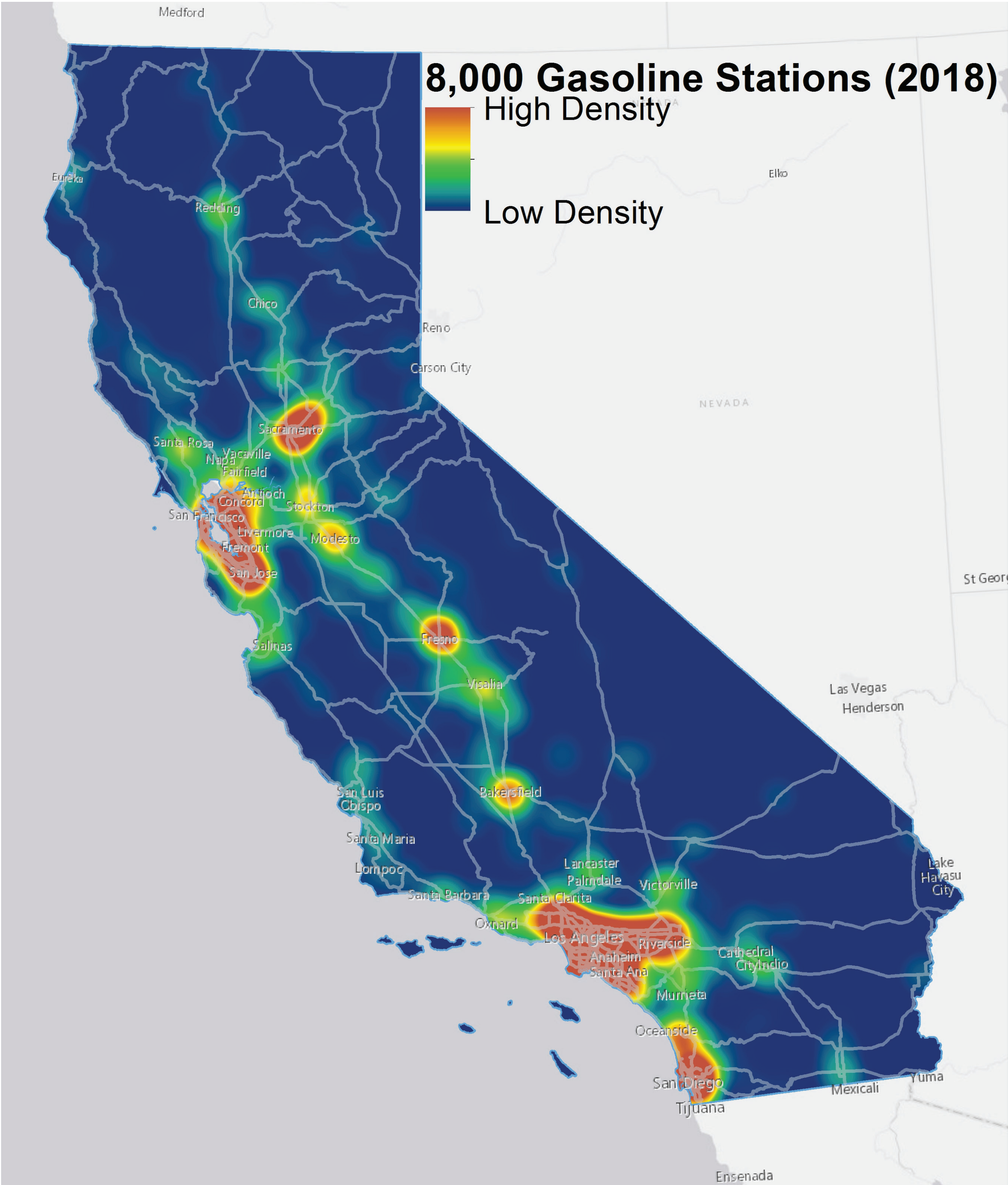
The evaluation process utilized by CARB relied heavily on previously existing capabilities and data within the 2017 Release CHIT toolbox. Additional developments consisted primarily of two parts:

- Development of a Python script incorporating the arcpy library[18] and CHIT functions to automate the process of selecting locations for stations and accounting for the effect of successive station placements on the need for further new station deployment
- Development of a hydrogen station distribution tuning template based on the distribution of gasoline fueling stations and gasoline fueling station throughput

The script developed for this work automates the iterative process of executing arcpy and CHIT functions to determine appropriate station placement by referencing and manipulating coverage gap and capacity need data files. Some of the CHIT functions used in this effort are modified versions of those distributed with CHIT 2017 Release, primarily for the express purpose of faster execution and to enable additional functions necessary for the considerations included in this work beyond the base CHIT toolbox. In addition, some input files were synthesized from input and output data files provided with CHIT 2017 Release; thus, they are created from the same analysis basis but are new files not yet available in a public release.

18 Python is an open-source object-oriented programming language; arcpy is a custom library of ArcGIS functions provided by ESRI, the makers of the ArcGIS software that CHIT is built upon.

Figure 44: Gasoline Station Density Heat Map Reference[19]



19 Source: Air Resources Board analysis of Energy Commission PIIRA form CEC-A15 results. For California Energy Commission form CEC-A15, see website: *www.energy.ca.gov/almanac/transportation_data/gasoline/piira_retail_survey.html* and *www.energy.ca.gov/piira/forms_instructions/index.html*

The development of the arcpy script was itself an iterative process, with successive creation and manipulation of scenario-defining parameters to include and/or remove considerations that might be integral to a station developer's decision-making process when choosing a viable hydrogen fueling station location. One of the key parameters that arose out of this iterative development process was the tuning of hydrogen fueling station density to the distribution of gasoline station density across the state. (A further parameter for also tuning hydrogen station viability estimates to gasoline throughput was considered though not included in the finalized vision to 1,000 hydrogen stations). The justification for this tuning parameter lies in the assumption that the ultimate goal of a fully-developed hydrogen fueling network is to provide fueling access that mimics the availability of gasoline fueling; this will be a critical aspect of maximizing the viability of drivers seamlessly replacing today's gasoline-powered vehicles with FCEVs without the need to alter their fueling behaviors.

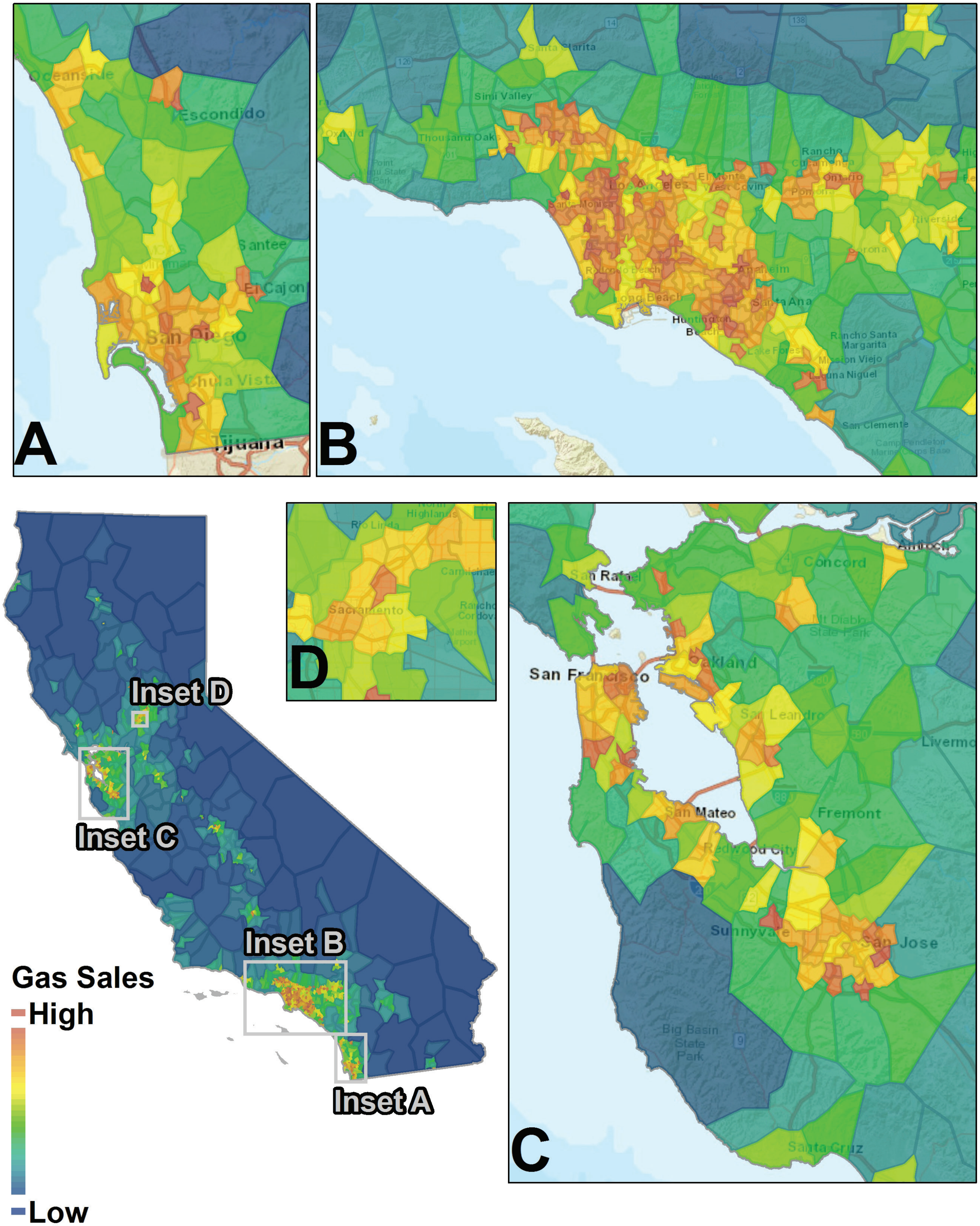
With over a century of operational history, it can be assumed that the gasoline fueling station industry is keenly tuned to the market forces of supply and demand; thus, the locations and geographic distribution of gasoline fueling stations are likely a reasonable facsimile for the eventual goal of a fully-developed hydrogen fueling network. Therefore, the spatial distribution of gasoline stations can likely serve as a template for the spatial density of hydrogen fueling stations, given a large enough hydrogen network. Figure 44 presents a heat map of the density of approximately 8,000[20] retail gasoline fueling stations in operation today. Data for these station locations were obtained through the Energy Commission's PIIRA form CEC-A15. In order to maintain the integrity of sensitive business confidential information, no individual gasoline station data may be shared publicly, though aggregate data such as the heat map in Figure 44 are allowed.

While a hydrogen station distribution mirroring the gasoline station distribution may be achievable in the future, it is important to acknowledge that even with 1,000 hydrogen fueling stations there should not be an expectation of exactly meeting the same density and coverage as provided by 8,000 gasoline stations. Rather, the goal when identifying 1,000 hydrogen stations is to use gasoline station data as a template to indicate when any given local area may become overbuilt with excessive hydrogen fueling stations. This can occur through CHIT evaluations in areas where hydrogen market indicators are particularly strong and population density is particularly high, as was noted in the 2017 Annual Evaluation.

In order to meet data confidentiality requirements, CARB developed the gasoline station density geometry template shown in Figure 45. The polygon boundaries shown in the figure represent a semi-optimized set such that each polygon is as small as possible while also guaranteeing that each polygon contains at a minimum ten gasoline stations. This was achieved by calculating each of the 8,000 gasoline stations' Thiessen polygons and then iteratively combining sets of ten (or more) in order of increasing average distance between the central nodes. These requirements balance the desire for sufficient spatial resolution of gasoline station density and the need to aggregate sufficient numbers of gasoline stations' data such that no individual station's location or performance can be precisely determined from the template. Although ultimately not used for the finalized 1,000 hydrogen station scenario, the color shading of the map also shows the relative areal density of gasoline sales (based on the most recent year of recorded sales for each station in the Energy Commission data) within each polygon.

20 The original data from the Energy Commission contains a greater number of stations. CARB performed some data filtering to remove station sites classified for purposes other than retail sales for light duty vehicles (such as truck and marine fueling) and to remove locations for which the address information no longer appears current or the station has not reported operations in the past three years of reporting.

Figure 45: Gasoline Fueling Station Density Template and Sales Volumes[20]



The arcpy script utilized this gasoline density template as an additional input layer. Counts of hydrogen stations within each polygon were tracked as successive hydrogen stations were placed according to the CHIT-based evaluations. When the number of hydrogen stations in any gasoline station density polygon reached a predetermined limit, all remaining candidate locations within that polygon were eliminated from consideration for additional station placement. In addition to this template, CARB also constrained the extent of candidate station locations to a limited area around existing gasoline stations. This helped ensure that not only were the relative amounts of hydrogen stations assigned to various regions commensurate with the gasoline station distribution but also that their individual locations were informed by both the expected and estimated future hydrogen fueling market and the current observed gasoline fueling market. Further details are provided later in this appendix.

Figure 46 through Figure 51 provide snapshots in time of the CHIT-determined path towards 1,000 stations by 2030, both in terms of "point" locations and densities as represented by heat maps. Determination of the 1,000 station statewide distribution began with the known locations of today's funded and open hydrogen fueling stations (Figure 46). It is clear that today's initial network of stations has developed in order to provide a basic level of fueling opportunity concentrated most heavily in urbanized core market areas and at critical points along long-distance travel corridors to allow FCEV drivers to utilize the long range provided by their vehicles. Although there are apparent hot spots of current station density shown in Figure 47, it should be noted that the contrast has been enhanced in this figure; if drawn on the same scale as today's gasoline stations or the eventual goal of 1,000 hydrogen stations, even these core areas today would not be distinguishable.

Figure 48 and Figure 49 display the projected growth of the network out to 2025, the point at which EO B-48-18 requires at least 200 hydrogen fueling stations to be developed. Including the currently-funded stations, the scenario presented here includes slightly more stations (212); however, as will be discussed further in this appendix, the growth rate of hydrogen fueling stations was designed to be commensurate with meeting the capacity needed as time passes through 2030. Compared to today's network, by 2025 the network is clearly expected to have transitioned out of a core market-focused phase and into expanded accessibility. This includes a marked increase beginning in 2024 in development along travel corridors, in medium-population vacation and sightseeing destinations (such as several cities in the central coast and the desert cities), and in the likely second wave of high-market areas (such as Fresno, Bakersfield, Redding, and others).

By 2030, hydrogen fueling network development is anticipated in this scenario to have entered yet a third phase. As the scenario envisions a spectrum of available station capacities, growing demand for fueling opportunities, and broadening of the consumer market base, Figure 50 reveals that network development becomes increasingly multi-faceted. Large-capacity stations become concentrated primarily in the high-adopter, high-population urban core markets. Smaller stations are utilized to expand the geographical reach of the network and enable travel to increasing numbers of vacation and sightseeing destinations as well as the potential to connect to station networks in neighboring states. Second-wave markets initiated in 2024 and 2025 continue to gain mid-sized stations, commensurate with their likely total demand for FCEVs and hydrogen fuel. By 2030, the statewide distribution of hydrogen (Figure 51) closely mirrors the gasoline station network, though there are clearly some remote regions with limited fueling options and many of the second-wave markets, especially along CA-99, will require further focused development relative to the primary core markets.

Figure 46: Point Locations of Stations Currently Funded Under AB 8

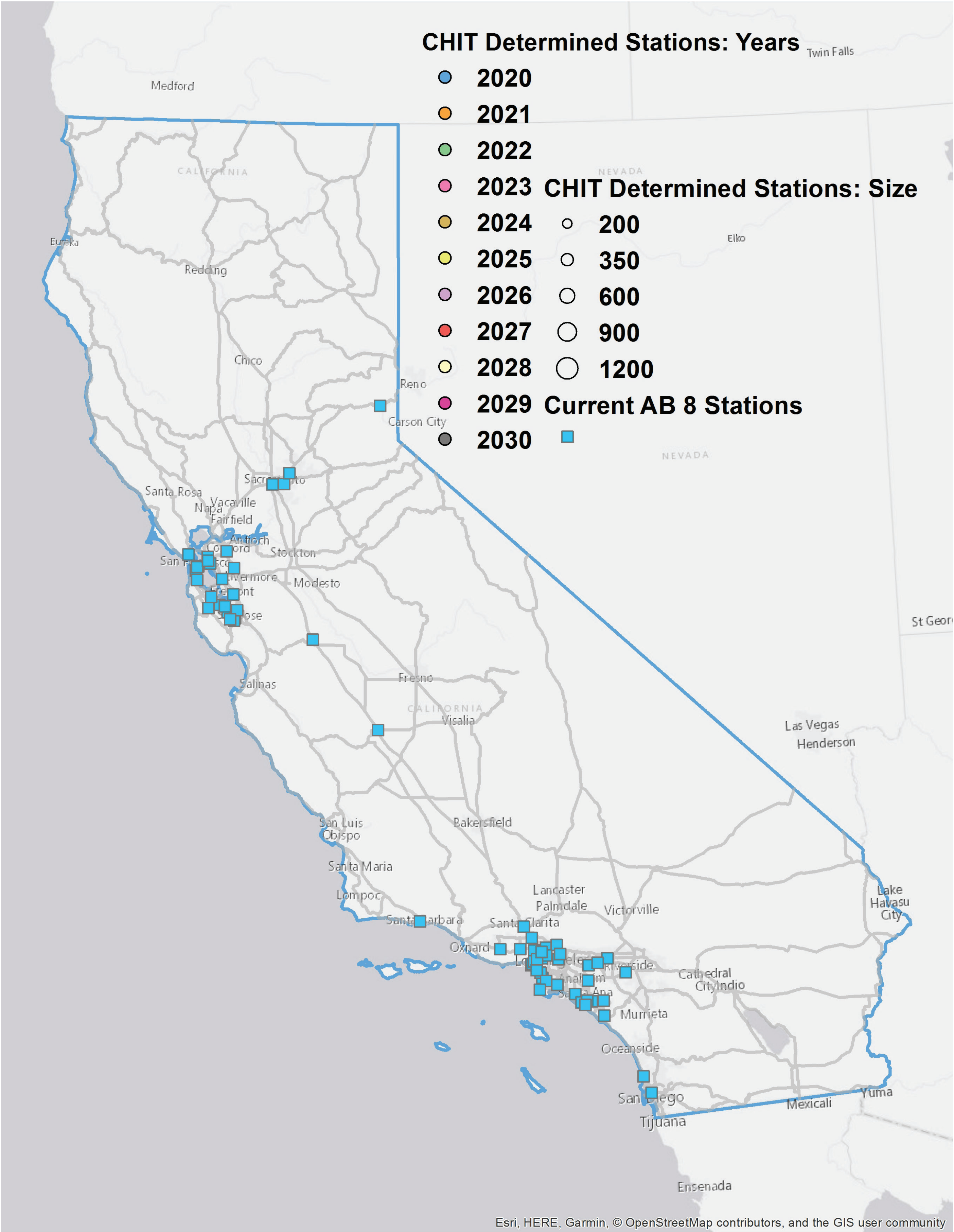


Figure 47: Current Hydrogen Station Density Heat Map (Contrast Enhanced)

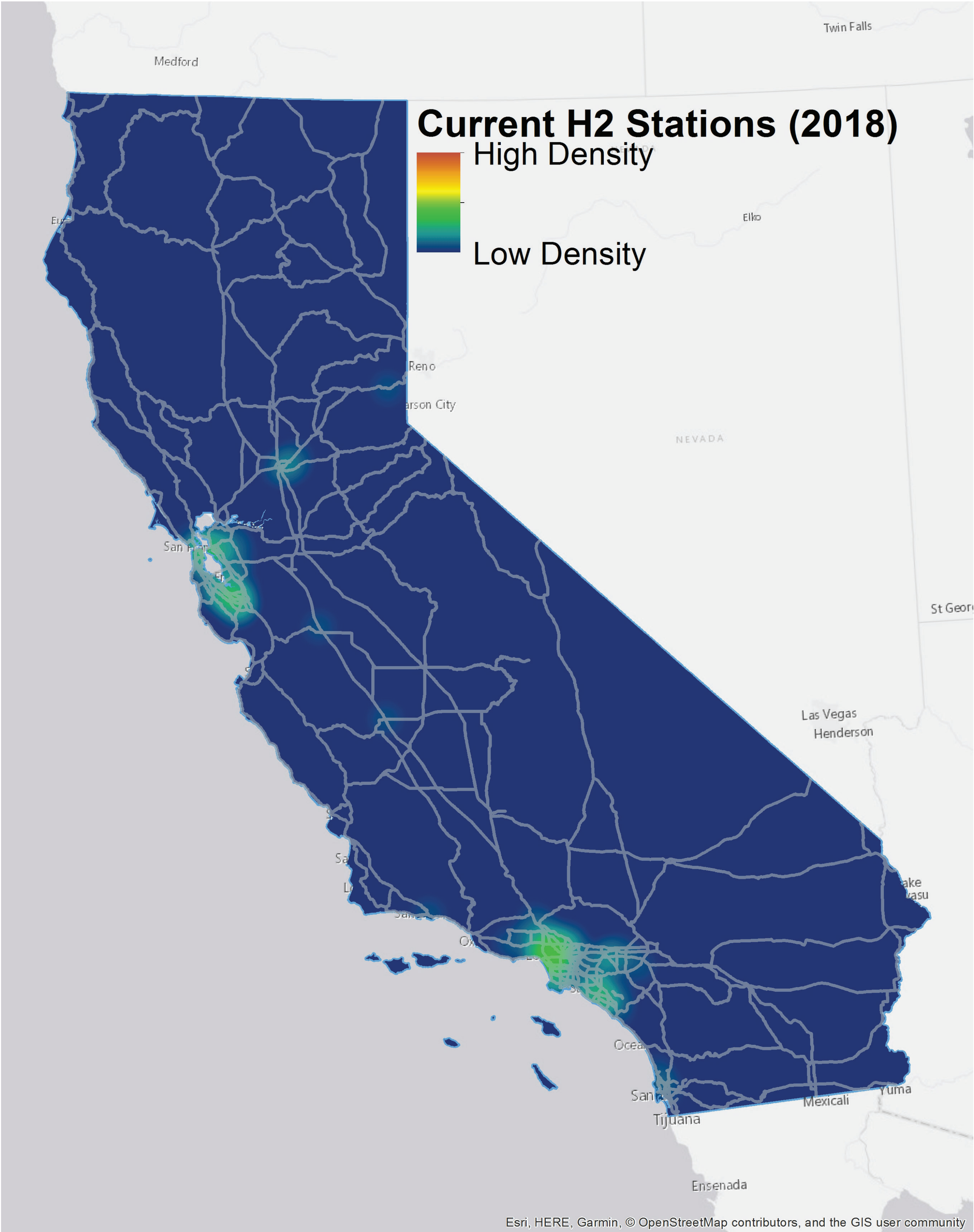


Figure 48: Point Locations of Hydrogen Station Network in 2025 as Determined by CHIT Evaluation

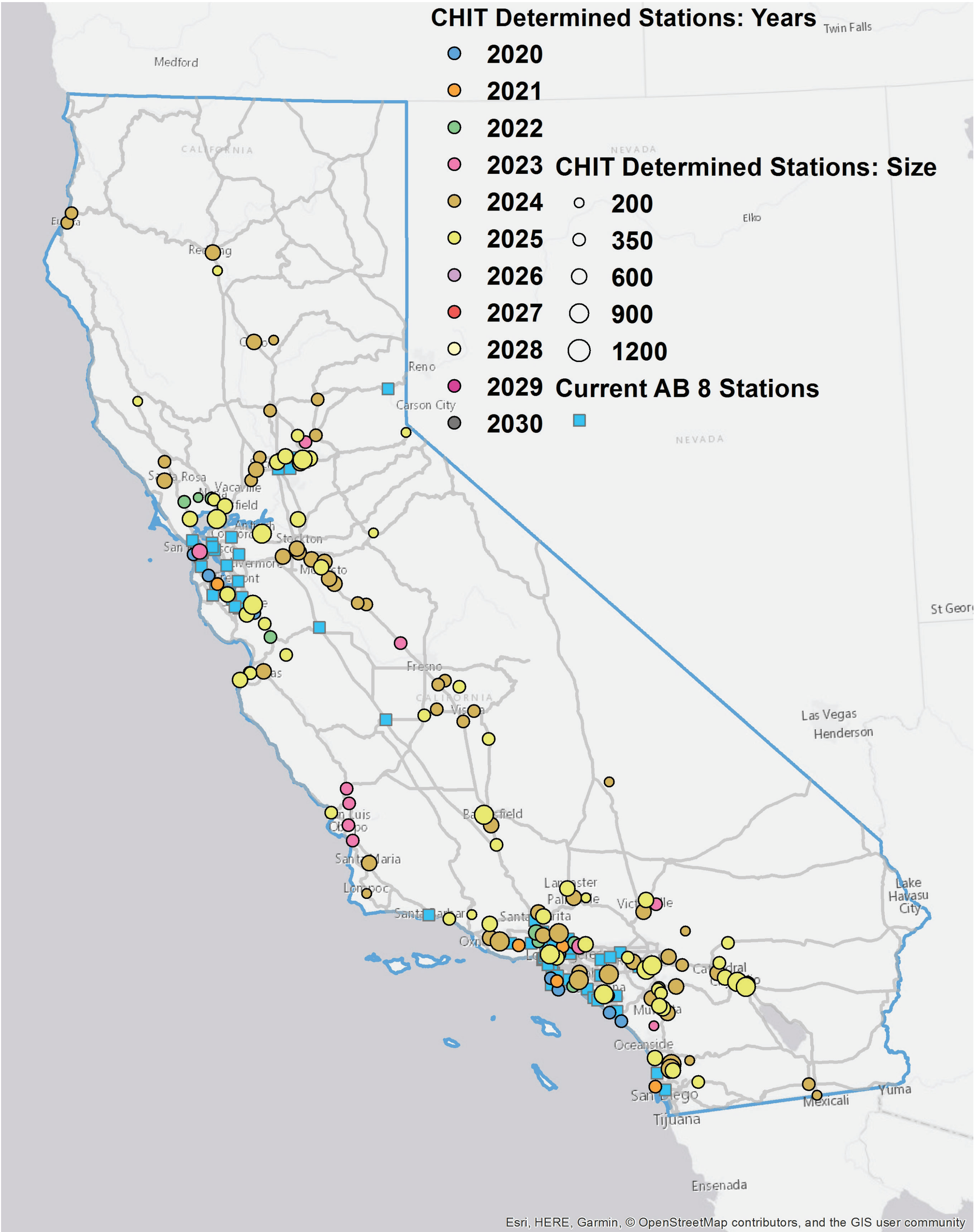


Figure 49: Hydrogen Station Point Density Heat Map for 2025

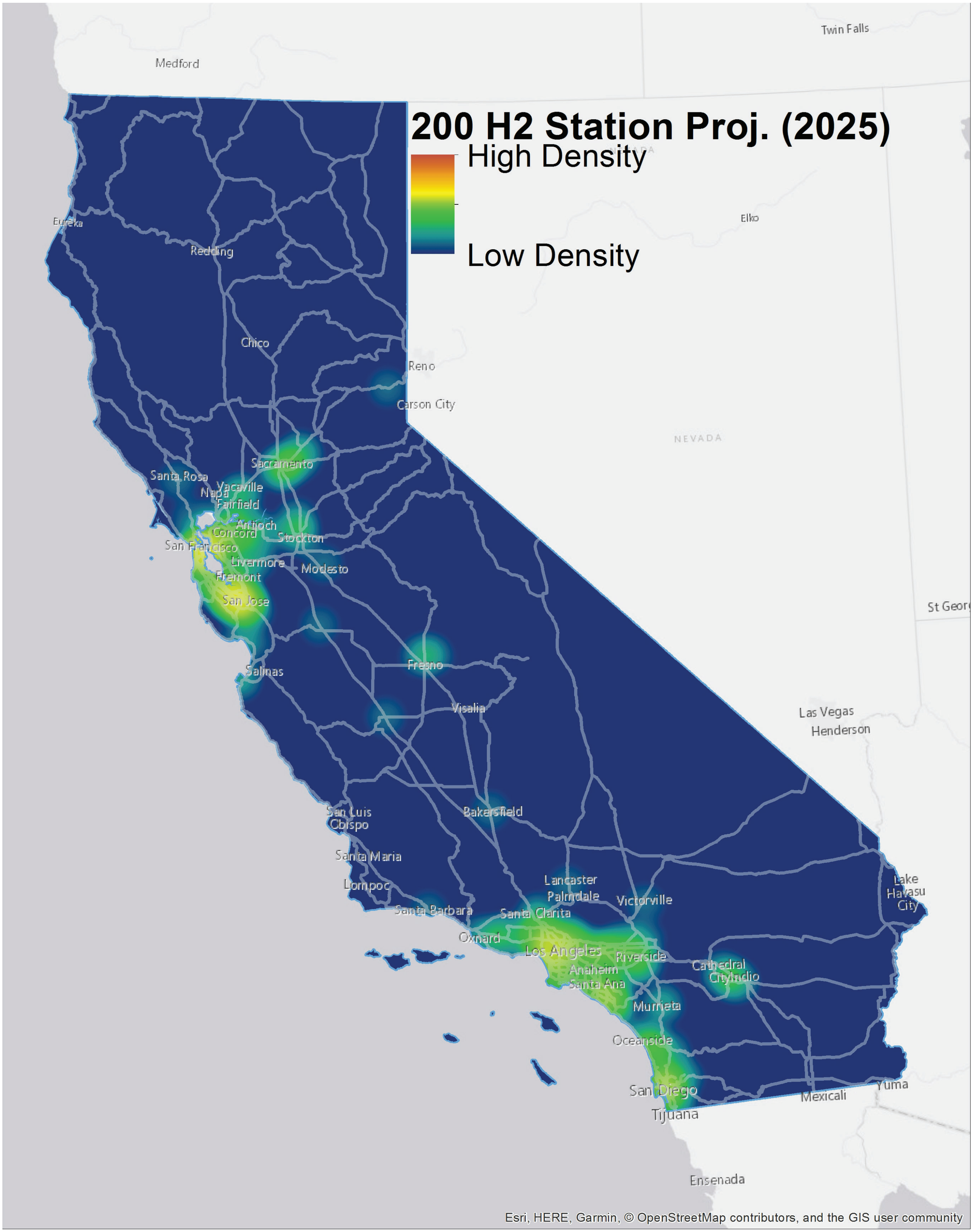


Figure 50: Point Locations of Hydrogen Station Network in 2030 as Determined by CHIT Evaluation

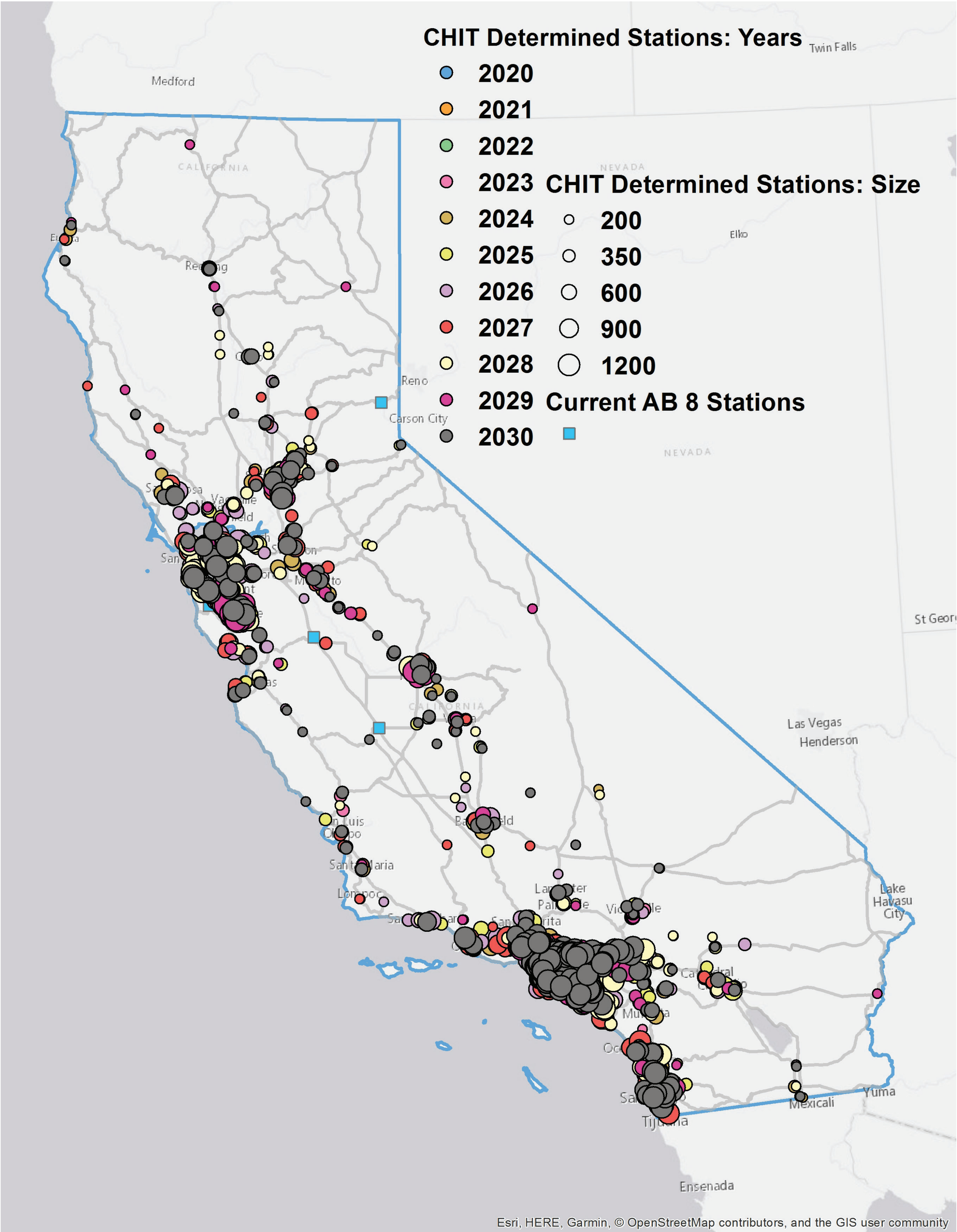
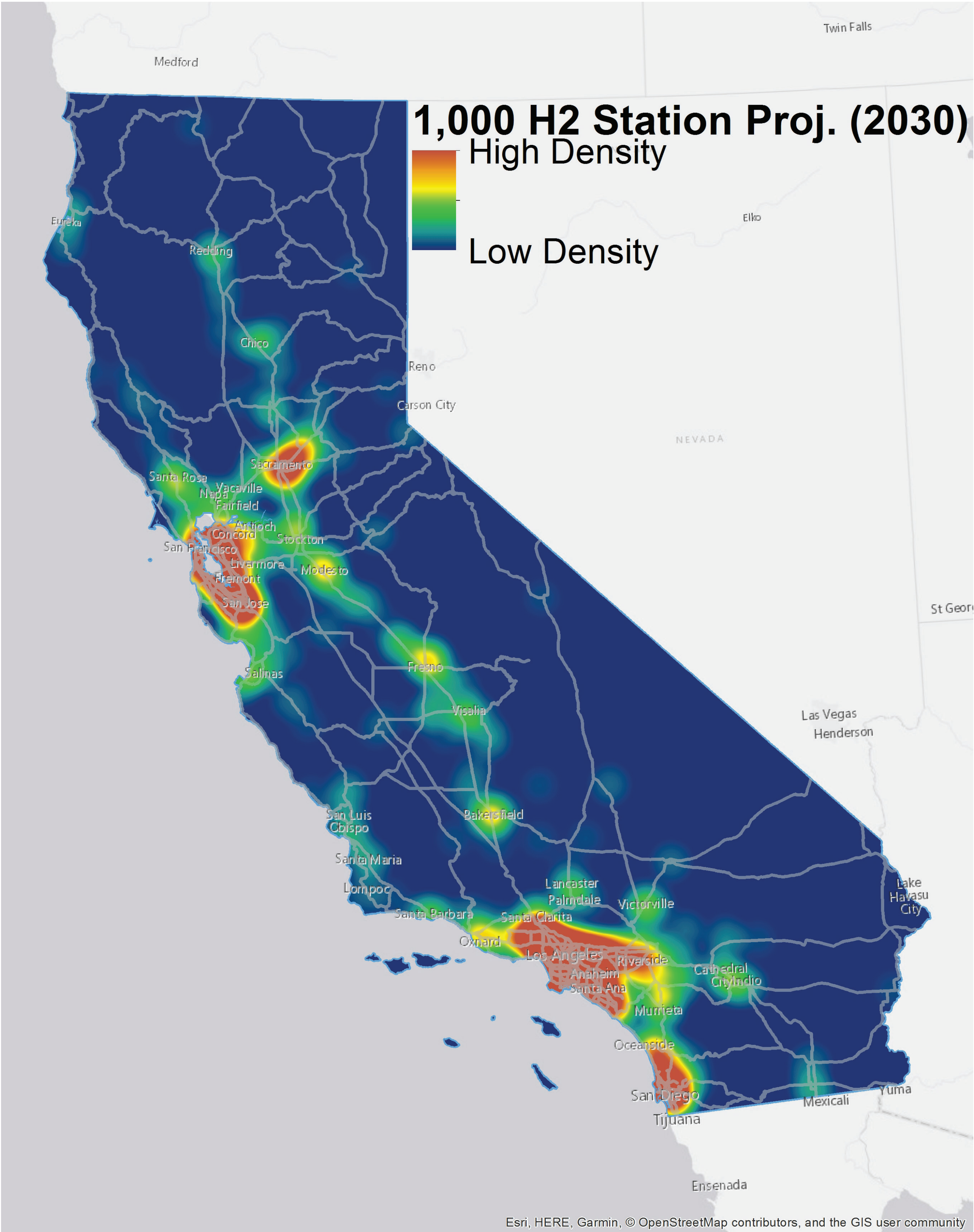


Figure 51: Hydrogen Station Point Density Heat Map for 2030



Development of the Scenario for 1,000 Stations and 1,000,000 FCEVs by 2030

The first step in defining the hydrogen station network development scenario shown in Figure 46 through Figure 51 was to define the ultimate goal of the number of on-road FCEVs and commensurate hydrogen fueling stations in California in 2030. In order to develop these goals, CARB and collaborating stakeholders considered past electrified vehicle adoption data, projections for future adoption, and the implications of other FCEV-related studies and announcements released in the past year. The ultimate goals of 1,000,000 FCEVs and 1,000 fueling stations were primarily informed by four points of reference.

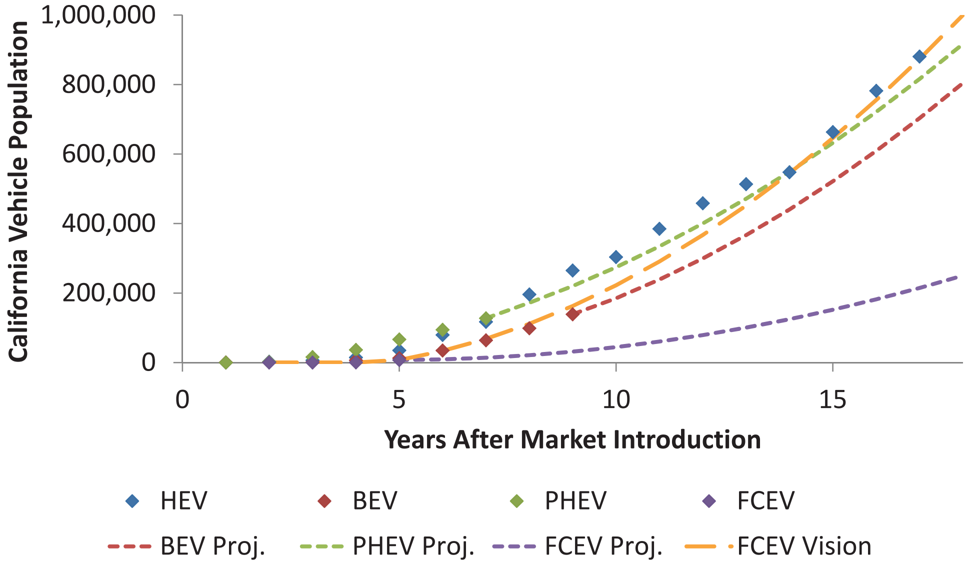
From a more speculative initial basis, CARB investigated past sales and projections of electrified vehicles, including conventional hybrid (HEV), battery electric (BEV), plug-in hybrid (PHEV), and fuel cell electric vehicles (FCEV). Figure 52 shows California-specific deployment trends for each of these vehicle types as a function of the number of years after initial market introduction of the technology. HEVs have had the longest history of deployment and have successfully achieved market penetration in today's passenger vehicle marketplace. These vehicles have been able to achieve a California population of one million vehicles approximately eighteen to nineteen years after introduction, closely following a parabolic trend.

Given the demonstrated success of HEV technology, this may serve as an aspirational goal for other electrified vehicle technologies to mirror in order to similarly achieve enduring market share. Early deployment volumes of PHEVs seem to be nearly identical to the historical HEV data. Projections of PHEV deployment similarly following a parabolic trend tuned to the early deployment data anticipates essentially the same market share potential for PHEVs as HEVs at eighteen years following introduction.

Early market data and projections for BEVs anticipate a future market potential roughly 80% the size of HEV and PHEV deployment at the same stage of market introduction. By contrast, past FCEV adoption rates indicate a much smaller future market of only 200,000 vehicles. Such a vehicle deployment scenario, after nearly two decades of market development, likely does not indicate a successful market launch. Such limited vehicle deployment would also not be in agreement with the necessary co-development of hydrogen fueling and FCEV markets to justify ongoing State and private investment. If HEV deployment is to serve as the example then a shift in the expected FCEV deployment trend, accelerated from the anticipated parabolic curve, would need to be realized. This is shown by the FCEV Vision curve, which represents an aspirational and hypothetical trend of FCEV adoption to achieve a transition to success much like the HEV experience.

The data and projections of Figure 52 provide the conceptual framework for identifying a vehicle deployment trend that is based on markers of success. In order to assess the feasibility of this aspirational goal, studies and announcements from third-party organizations can prove useful. One particularly informative resource is the publication "Hydrogen Scaling Up", written by McKinsey & Company for the Hydrogen Council [18]. The Hydrogen Council is a "global initiative of leading energy, transport, and industry companies with a united vision and ambition for hydrogen to foster the energy transition" [45]. The Council's members are focused on identifying necessary developments and making investments to transition hydrogen into a widely used transportation fuel, energy resource, and industrial process gas.

Figure 52: Electrified Vehicle Adoption Histories, Projections, and Speculative Scenarios for California



In "Hydrogen Scaling Up," the authors investigated the potential global size of the hydrogen-related industry in the future out to 2050. The report also provided insights into projected hydrogen markets in various industrial segments and for selected nation-level markets. The report anticipates ten to fifteen million FCEVs globally on the road by 2030 (and further equates this to a sales rate in California of one in every twelve new vehicle sales). In order to infer what a global population of ten to fifteen million FCEVs might mean for California's population, CARB compared Plug-In Electric Vehicle (PEV, which consists of BEVs and PHEVs) registration data to national and global cumulative sales data maintained by the website InsideEVs[21]. For the years 2014 through 2016, California PEV sales have been between 9% and 18% of global sales. Applying these rates to the Hydrogen Council's projection of ten to fifteen million global FCEVs infers a minimum of one million FCEVs on the road in California by 2030. On the national level, this would likely represent 30% to 60% of the United States' total FCEV deployment, which is in agreement with current and expected hydrogen fueling station deployment rates in California as compared to the rest of the nation.

The third reference point for developing the 2030 California goals is the H2USA Location Roadmap Working Group's publication "National Hydrogen Scenarios" [24]. Informed by scenario evaluation performed by NREL with its Scenario Evaluation and Regionalization Analysis (SERA) tool, the report outlines potential national and regional FCEV and hydrogen station deployment under varying cases of market success (with market success driven both by supportive policy and consumer acceptance). Figure 53 shows the projected deployments in 2025, 2035, and 2050 under the three scenarios evaluated. In 2025, on-road FCEVs in California could be between 75,000 and 150,000; by 2035, between 1.3 million and 3 million FCEVs are projected. A target of one million FCEVs by 2030 therefore lies well within the range of cumulative deployments anticipated by these scenarios and most closely agrees with the mid-range "State Success" scenario.

Finally, EO B-48-18 calls for five million ZEVs on the road by 2030. This was a slightly higher target than the Clean Technologies and Fuels scenario adopted in CARB's Mobile Source Strategy for achieving Greenhouse Gas Emission Reduction goals. One million FCEVs represents one-fifth of the target ZEV deployment, which is qualitatively deemed to be a necessary proportion in order for FCEVs to play a significant role in decarbonization of light-duty transportation. These four considerations therefore support the 2030 target of one million FCEVs on the road.

With determination of a 2030 FCEV population goal, it is possible to determine the number of hydrogen fueling stations necessary to ensure sufficient fueling capacity. Individual station capacities sized appropriately for local markets are also important, but these issues can be (and were) addressed through CHIT's individual station evaluation processes. Therefore, a top-down approach was utilized to estimate

21 *https://insideevs.com/monthly-plug-in-sales-scorecard/*

the number of hydrogen fueling stations necessary. To perform this analysis, CARB assumed that individual vehicles would consume an average of 0.7 kilograms of hydrogen per day, and the on-road FCEV population would grow according to the FCEV Vision curve in Figure 52.

CARB further assumed a progressive growth over time of the average new hydrogen fueling station capacity. Today's technology up to 350 kilograms per day capacity was assumed to remain the most common through 2023, after which average station size would grow from 600 kilograms per day to 1,200 kilograms per day by 2030. CARB further assessed two different options for growing the station network. The first assumed that the number of hydrogen stations built in any year would exactly satisfy the following year's anticipated incremental additional hydrogen fueling demand (due to the continued deployment of FCEVs). A second scenario assumed the new fueling capacity deployment would be back-loaded towards later years. This scenario therefore seeks to take greater advantage of larger station capacities in later years (thereby reducing the total number needed) and anticipates the potential that the industry will likely require time to build upstream manufacturing capabilities in order to meet growing demand.

Figure 53: Scenario Evaluation Results for Numbers of FCEVs and Hydrogen Stations in Various Regions of the United States According to the H2USA National Scenarios Roadmap [24]

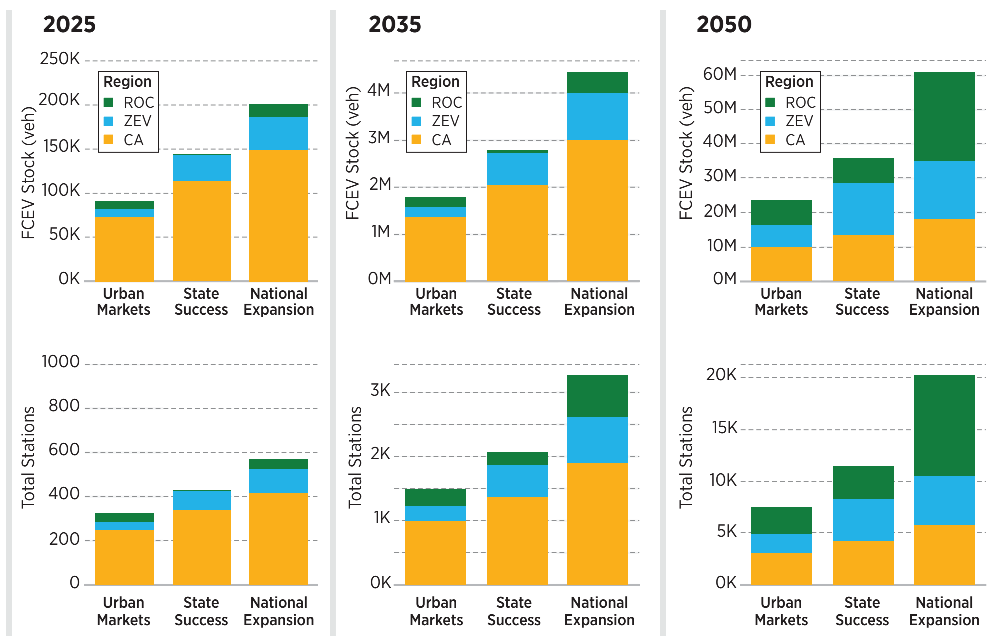


Figure 9. Number of FCEVs on the road and total HRSs by scenario and region

Note: The scale of the vertical axis changes between each of the three periods.

Under these two scenarios, between 1,000 and 1,200 hydrogen fueling stations would need to be developed by 2030 in order to provide sufficient hydrogen fueling capacity for one million FCEVs. This analysis is confirmed by the "National Hydrogen Scenarios" report, which similarly shows approximately 1,000 stations necessary to support the projected FCEV populations by 2030 (Figure 53). The finalized hydrogen station network development scenario did deviate to a small degree from these evaluated scenarios in terms of the numbers of stations deployed in each year and the timing of hydrogen fueling station capacity growth. However, the final resulting hydrogen fueling capacity of the modeled 1,000 station network remains valid. The total capacity of the network shown in Figure 50 is 742,500 kilograms per day, effectively equivalent to the demand represented by one million FCEVs each consuming an average of 0.7 kilograms per day.

Comparison of 2030 Vision Station Distribution to Minimum Drivability Requirements

The finalized hydrogen station network vision is informed by considerations central to CHIT analyses. Namely, assessments of appropriate iterative station placement were driven by estimates of the spatial distribution of FCEV market strength as revealed by a set of FCEV adoption indicators and population distribution data. Thus, station placement is inherently tuned and optimized (within constraints) to the evaluation of potential future market needs, both in terms of coverage and capacity. In addition to the need to meet market-based considerations of station placement, it is also instructive to understand how these determinations compare to scenarios built around purely geographic coverage principles in order to understand the basic needs of drivability. Drivability of a hydrogen fueling network in this context may have two aspects: 1) the extent to which the network's station placements enable FCEV adopters to make full use of the 300+ mile range of their vehicles by enabling travel on extended stretches of roadway, and 2) the extent to which the network's station placements provide fueling access at some maximum acceptable distance (likely a greater distance than would be considered convenient in most cases for daily usage but close enough to enable medium-distance travel) to all residents of the state.

Evaluating the optimal station placement for drivability can be achieved through native functions in the ArcGIS Network Analyst Extension; no market data or functions from the CHIT 2017 Release are necessary to perform such an evaluation. CARB performed a set of exploratory geographic optimizations primarily to understand the needs of a hydrogen fueling network that guarantees access to residents within defined limits of coverage and/or guaranteed fueling opportunities within a given distance along travel paths. CARB performed two types of analyses to probe the requirements of drivability:

- Optimize Coverage: Define the 8,000 existing gasoline stations as prospective hydrogen fueling locations. Define 800 city centers[22] as demand points. Define a limit of coverage in terms of X miles. Define a number Y of hydrogen stations to locate. Hydrogen stations provide coverage to any city(ies) within an X mile drive. The set of Y stations selected will be the set that provides coverage to the most city centers possible within the coverage extent constraint X. Therefore, this optimum is subject to the number of stations Y allowed to be chosen; if X is not commensurately large enough to counterbalance a small value of Y then the solution of selected stations will not provide coverage to all city centers. X is defined as 25, 50, or 100 miles; Y is defined as 50, 100, or 200 stations.
- Minimize Stations: Define the 8,000 existing gasoline stations as prospective hydrogen fueling locations. Define 800 city centersU as demand points. Define a limit of coverage in terms of X miles. Find the set of stations that includes the fewest members such that coverage of city centers is maximized. Addition of any more stations to this set will not further improve the coverage of city centers. X is defined as 25, 50, or 100 miles.

22 Derived from the California Cities (2015) dataset maintained by the California Department of Transportation. See *www.dot.ca.gov/hq/tsip/gis/datalibrary/Metadata/cities.html*.

Figure 54: Geographically Optimized Station Placements to Optimize Coverage of City Centers with Y Stations Subject to an X-Mile Limit of Coverage

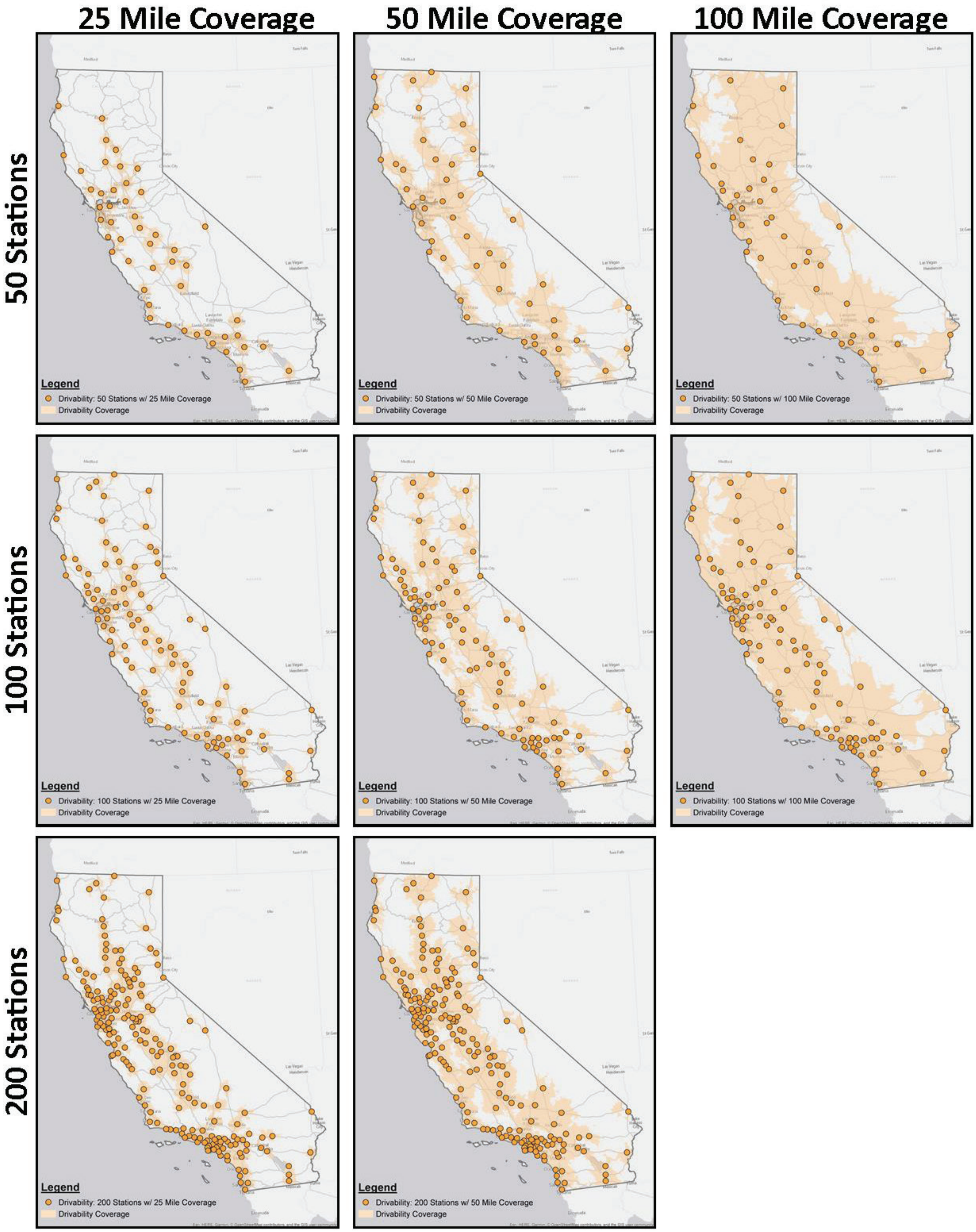


Figure 54 shows the optimized station network layout within the Optimize Coverage problem for all combinations of station counts and coverage extents investigated. In the figures, dots represent the approximate locations of chosen stations and the orange shading shows the extent of coverage provided by the network within the indicated limit. Table 12 provides several metrics that can be utilized to assess the degree of drivability represented by each of these station networks. In terms of equitable access to hydrogen fueling stations, Table 12 makes it readily apparent that a high degree of basic drivability coverage for the state's population is achievable with relatively few stations. With an optimized set of 50 stations, nearly 90% of the state's population can be located within a 25-mile drive of a station, enabling medium-distance travel for a large portion of the state. Meanwhile, over 90% of the state's population is covered by every other combination of number of stations and coverage distance metric, indicating that medium-distance drivability can be guaranteed for nearly all residents with 100-200 stations and long-distance drivability can be guaranteed with as few as 50 well-placed stations. On the other hand, the limits of these networks as convenient daily fueling opportunities is apparent by the low percentages of roadway miles covered within a 25 and even 50 mile distance (which are larger distances than necessary for a conveniently accessible daily fueling network).

Table 12: Evaluation Metrics to Assess Drivability Afforded by Optimized Station Sets Shown in Figure 54

★	90%+
★	75%-90%
☆	<75%

% of ZIP Codes Crossed		Drive Distance		
		25	50	100
# of Stations	50	73%	91%	98%
	100	86%	95%	99%
	200	88%	96%	

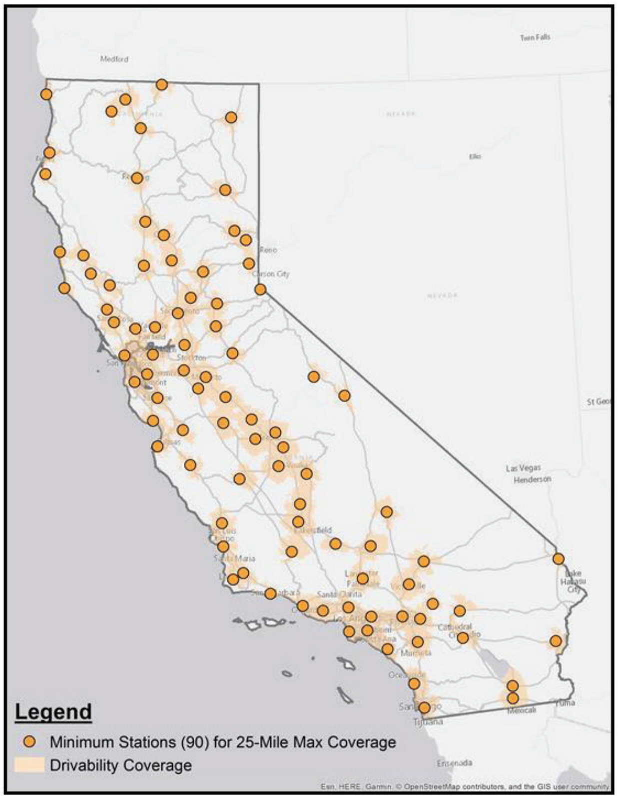
% of Census Blockgroups Contained		Drive Distance		
		25	50	100
# of Stations	50	84%	94%	97%
	100	91%	94%	97%
	200	94%	96%	

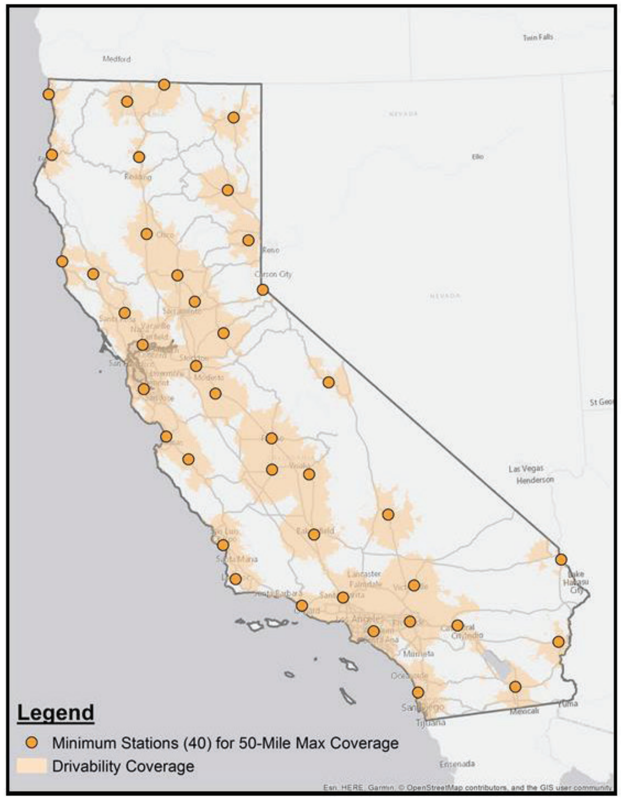
% of Population Covered		Drive Distance		
		25	50	100
# of Stations	50	89.4%	98.5%	99.8%
	100	96.1%	99.2%	99.9%
	200	98.7%	99.5%	

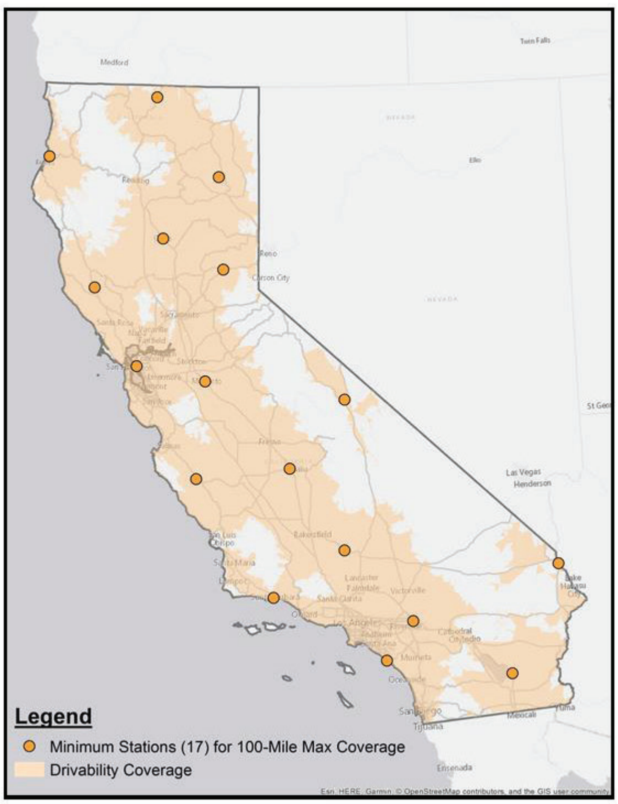
% of Households Covered		Drive Distance		
		25	50	100
# of Stations	50	89.3%	98.3%	99.8%
	100	96.0%	99.0%	99.9%
	200	98.4%	99.4%	

% of Mileage Contained		Drive Distance		
		25	50	100
# of Stations	50	43%	73%	93%
	100	57%	78%	96%
	200	64%	83%	

Figure 55: Geographically Optimized Station Networks to Minimize the Number of Stations Necessary to Provide Coverage to City Centers Subject to an X-Mile Limit of Coverage

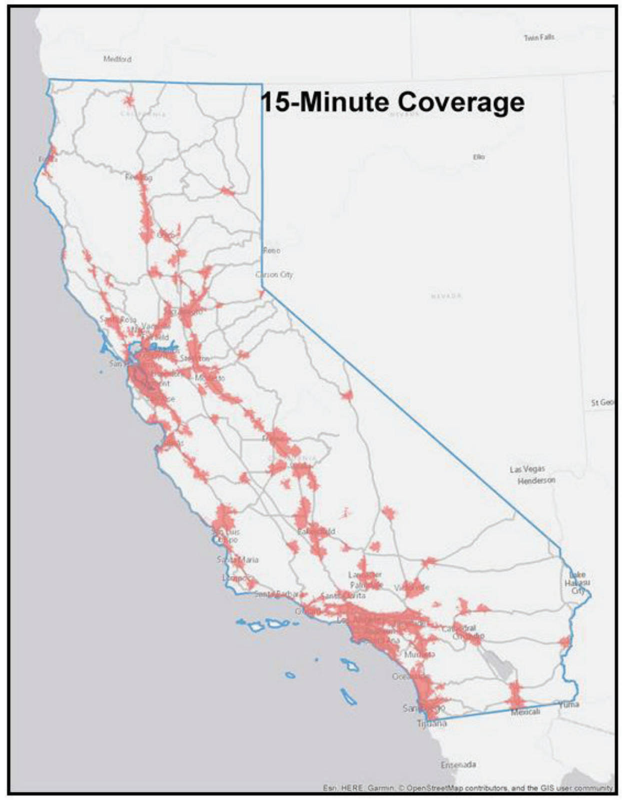


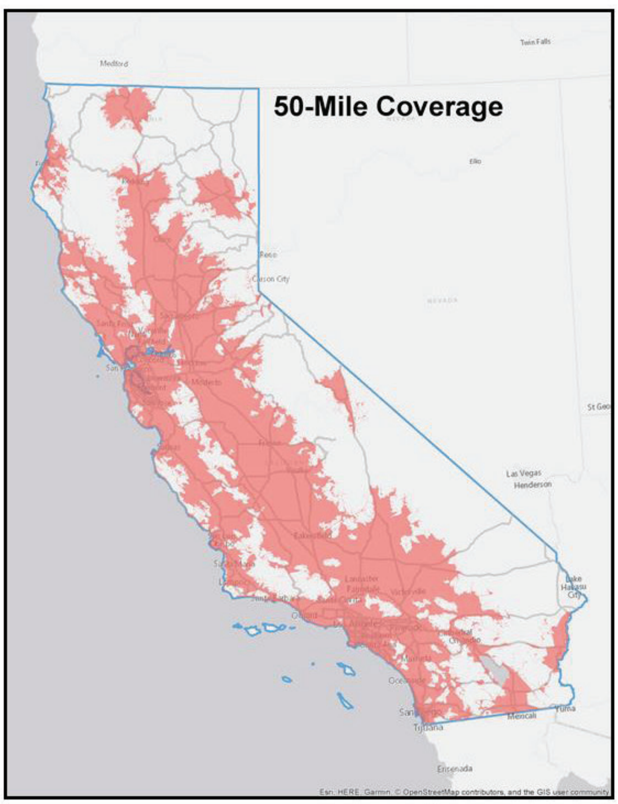




Optima (for Covering Demand Points)	Drive Distance		
	25	50	100
Minimum # of Stations	90	40	17
% of ZIP Codes Crossed	85.2%	90.5%	96.3%
% of Census Blockgroups Contained	89.8%	94.0%	96.3%
% of Population Covered	95.6%	98.1%	99.4%
% of Households Covered	95.5%	97.9%	99.3%
% of Mileage Contained	55.6%	69.1%	86.9%

Figure 56: Coverage Metrics for 1,000 Stations in 2030 as Determined by CHIT Evaluation





Roadmap 2030 Coverage Metrics	6-Minute Drive	15-Minute Drive	50-Mile Drive
% of ZIP Codes Crossed	62.6%	73.9%	93.1%
% of Census Blockgroups Contained	49.6%	86.3%	94.5%
% of Population Covered	62.8%	94.1%	99.1%
% of Households Covered	64.2%	93.9%	99.0%
% of Mileage Contained	19.4%	41.4%	77.6%

Figure 55 provides the solutions to the Minimize Stations problem, revealing the minimum necessary network to provide the most effective coverage possible to the set of city centers. All residents within the orange shaded areas of Figure 55 can reach a station within the driving distance indicated within each map's legend. It is immediately apparent that the minimum necessary networks are far smaller than 1,000 (as in the 2030 Vision); in particular, for 100-mile drivability between stations and city centers, only 17 stations are needed. Even for the network solutions in Figure 54, there is a degree of redundancy compared to the minimal networks in Figure 55. However, it is important to realize that the solutions with the smallest networks are defined in terms of efficient use of the indicated stations; addition of more station(s) negatively affects the tradeoff between number of stations and distance between stations and demand points. This is readily apparent when comparing the metrics across the scenarios, as the minimal station network solutions typically provide coverage to fewer residents and over fewer roadway miles than the scenarios explored in Figure 54.

Evaluation of the coverage provided by the 2030 Vision station network is shown in Figure 56. For the 50-mile coverage metric, there is significant similarity to the optimized scenarios with nearly 80% of roadway miles within a 50-mile reach of a station; in addition, nearly all residents in the state could have reasonable access to a station within a 15-minute drive and nearly two-thirds of residents would be within the preferred distance (a six-minute drive from home) for convenient fueling access. These metrics demonstrate that the 1,000 station network development as determined by market needs provides ample opportunity to ensure multiple goals can be met:

- Sufficiently redundant, high-capacity fueling opportunities established at convenient locations within high-adoption market areas commensurate to projected FCEV adoption rates
- Equitable baseline fueling opportunities to all potential FCEV drivers regardless of their home locations or their trip destinations
- Enabling FCEV drivers to take full advantage of the long range provided by their vehicles with ample refueling opportunity as needed along their journey

Overview of Evaluation Parameter Variations Considered in Development of 2030 Vision to 1,000 Stations

The hydrogen station network development scenario displayed in Figure 46 through Figure 51 represents the culmination of an iterative process of testing the inclusion and tuning of several input data and parameters. For example, the need for the gasoline station density tuning template was not immediately apparent at the commencement of the vision effort, but was developed in response to evaluation of several prior network development projections that focused first on tuning other key parameters. In all, nearly twenty different variations of parameter settings were investigated in order to determine the most appropriate methods for developing a consensus-gaining station network vision. Table 13 shows the majority of the evaluations that were performed and highlights the parameter definitions that made each unique (evaluations not shown were non-substantive variations on this set). As shown in the table, this process explored implementation of parameters beyond the finalized set (Evaluations K through N); these extra parameters either diminished or did not materially improve the reach and usability of the 2030 hydrogen station network compared to the finalized case and so were not included.

Table 13: Evaluation Parameters Explored through Process of Defining Vision to 1,000 Stations by 2030[23]

Evaluation	Method	Ratio Coverage: Capacity	Capacity Basis	Lock Out	Priority Areas: Recalculation Frequency	Priority Areas: Minimum Threshold
A	1 (Highest Point Basis)	2:1	2030	Station Cell	N/A	N/A
B	1 (Highest Point Basis)	4:1	2030	Station and Adjacent Cells	N/A	N/A
C	1 (Highest Point Basis)	4:1	Annually Variable	Station and Adjacent Cells	N/A	N/A
D	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	Annual	Constant
E	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	Every 30 stations	Constant
F	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 3 stations in each	Constant
G	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time
H	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time
I	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time and starts broader
J	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time and starts broader
K	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time and starts broader
L	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time and starts broader
M	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time
N	2 (Highest Points within Priority Areas)	2:1	Annually Variable	Station and Adjacent Cells	After 1 station in each	Decreases over time

23 Highlighted boxes in each row indicate changes in parameters from the row above. The row outlined in blue, marked Evaluation J, represents the finalized set of parameters used in the CHIT-based determination of a 1,000 station network development by 2030.

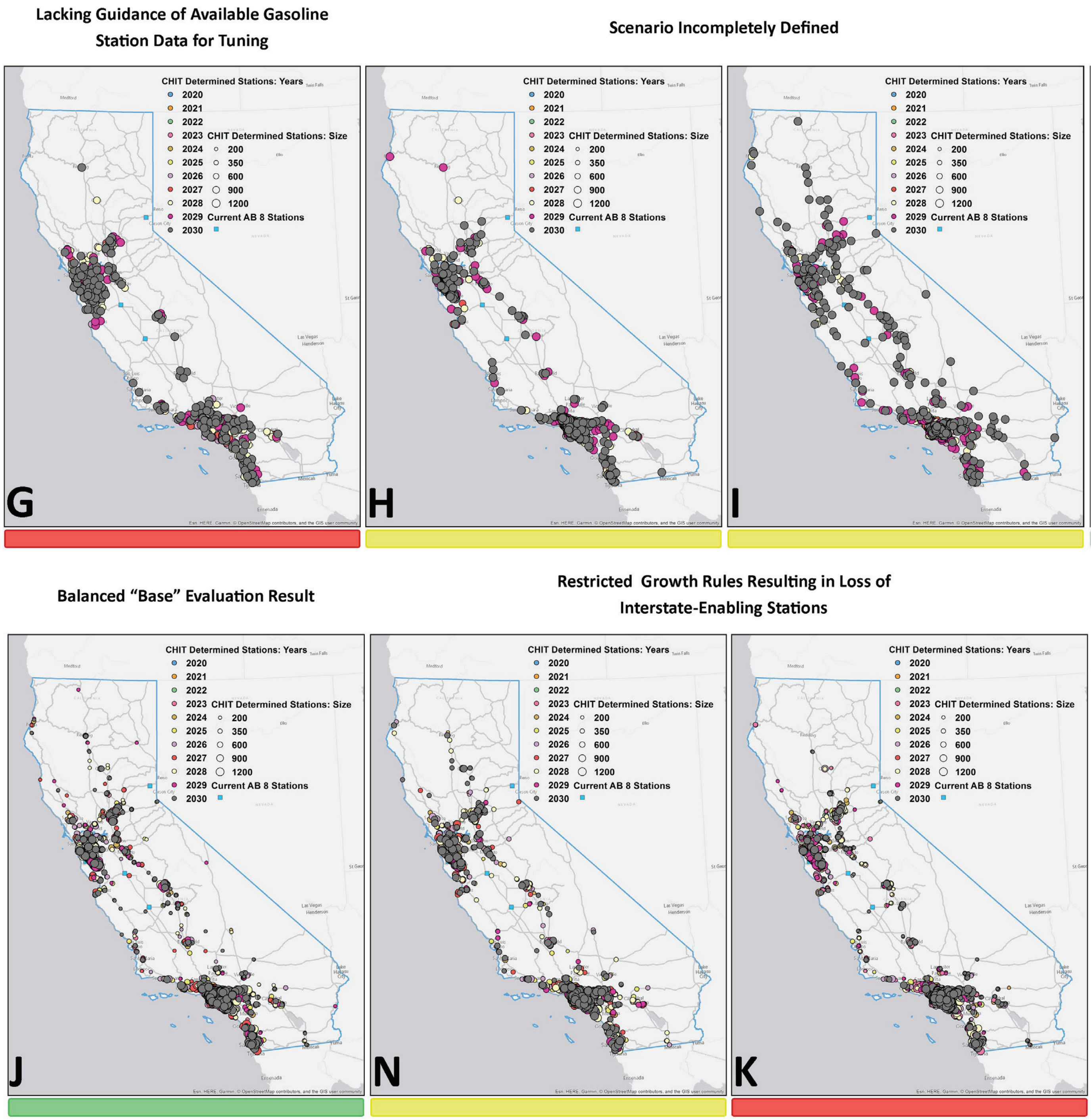
Available Station Locations	Gas Station Density Following	Evolving Station Size Distribution	Low Through-put Lockout	Early Adopter % Defined	Simulation Guiding Principle
Full State	No	No	No	No	"Where would we put hydrogen stations if we could put them anywhere in the state such that we optimize local capacity and coverage needs? What can we also learn about the order of these stations?"
Full State	No	No	No	No	
Full State	No	No	No	No	
Full State	No	No	No	No	
Full State	No	No	No	No	
Full State	No	No	No	No	
Full State	No	No	No	No	
Restricted Around Gas Stations	Yes	No	No	No	"We have candidates for the optimal locations, but can only choose a subset. Which ones do we choose to optimize coverage and capacity, and in what order ?"
Restricted Around Gas Stations	Yes	No	No	No	
Restricted Around Gas Stations	Yes	Yes	No	No	
Restricted Around Gas Stations	Yes	Yes	Yes	No	
Restricted Around Gas Stations	Yes	Yes	Yes	Yes	
Restricted Around Gas Stations	Yes	Yes	No	Yes	
Restricted Around Gas Stations	Yes	Yes	Reduced	Yes	

The parameters and settings implemented in the finalized scenario evaluation provided the most balanced hydrogen station network distribution among all the variations investigated. Evaluations with fewer input data and less restrictive parameters tended to have insufficient definition of the desired distribution of hydrogen fueling stations and therefore tended to concentrate station placement too heavily in highly urbanized markets, especially the San Francisco Bay area. These types of results are demonstrated by the first few panels of Figure 57 (the panels in the top row) and the results for evaluations A through I in Figure 58. On the other hand, some evaluations that utilized even greater amounts of input data resulted in networks with much the same issue; the numbers of stations projected outside of core urban areas remained small and too much emphasis was placed on the Los Angeles and Orange County regions. These evaluations are shown to the right of the green underscored panel in Figure 57 and the results for evaluations K through N in Figure 58.

Ultimately, the results provided by evaluation J (the green underscored panel in Figure 57 and the results shown directly adjacent to gasoline station data in Figure 58) were found to be the most desirable among all evaluations explored. As shown in Figure 58, this scenario provided the most balanced match across all regions as compared to the distribution of gasoline fueling station density. The regions shown represent areas where the match between projected hydrogen and recorded gasoline station density could be evaluated for a variety of geographical regions and market sizes.

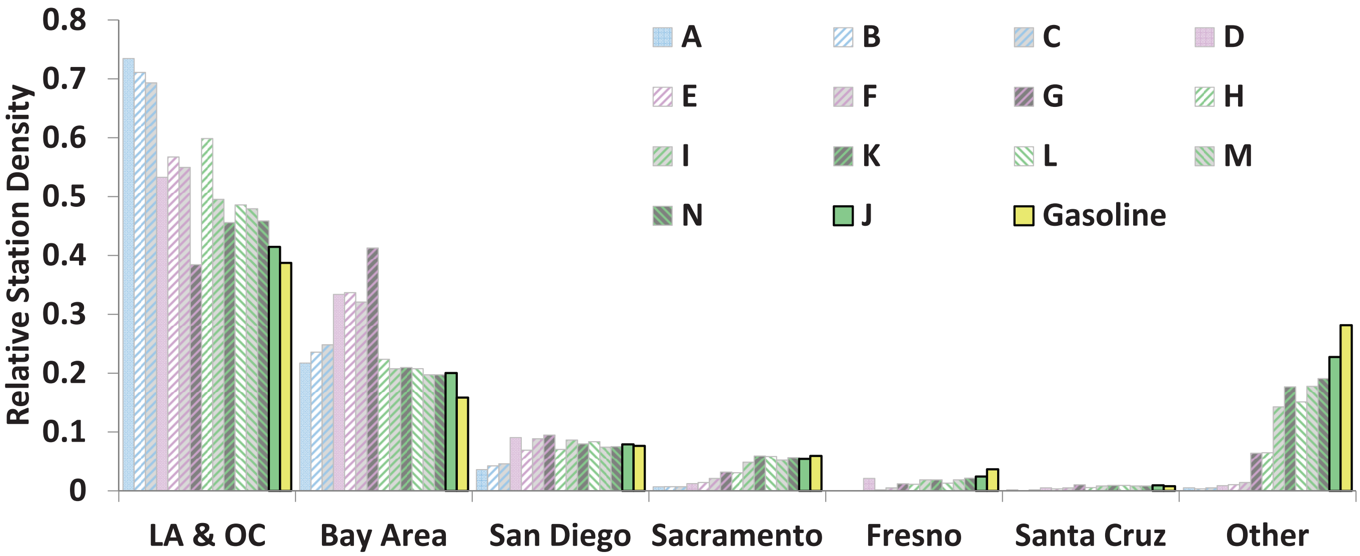
Los Angeles and Orange County, Bay Area, and San Diego represent three major markets with differing degrees of likely market strength and market size at different geographic locations across the state. Hydrogen station network scenarios that properly capture the relative need between these three demonstrate an ability to not only provide the appropriate amount of focus on highly urbanized areas with a strong market pull but also the nuance necessary to discern between their respective degrees of market strength. Sacramento and Fresno represent smaller first-wave and larger second-wave markets; properly capturing their respective needs demonstrates the ability to balance strong market pull in the primary areas against limited resources in terms of numbers and sizes of stations. Areas like Santa Cruz likely represent limited need for everyday fueling but are still critical for overall market health; scenarios that properly capture these features demonstrate a network that is not solely focused on near-home fueling. Finally, the "Other" category, which represents approximately 27% of gasoline stations, tests a projected station network's ability to address needs in the smallest local markets and at other connector and destination locations. By all these measures, the finalized station network based on evaluation J performs the best, with the most balanced agreement with gasoline station network distribution. It also achieves this without adding overly constrictive parameters and limitations. As expected, there is still room for improvement, especially with regard to the "Other" category of stations; however, with 1/8 the number of stations as compared to gasoline, the finalized scenario provides a reasonable approximation.

Figure 57: Comparison of 2030 Networks from Several Scenarios Evaluated[24]



24 Although Evaluations G, H, and I appear to show only 900 kg/day and 1,200 kg/day stations included in the result, these evaluations did include station capacities in the range of 300 kg/day to 1,200 kg/day. However, in these evaluations a single station size was assumed to be placed in a given year, with the size increasing in later years of the evaluation. Because of this, all smaller stations are hidden behind the larger stations that are visible in these maps.

Figure 58: Comparisons of Hydrogen Fueling Station Distribution in Various Regional Markets Among Scenarios Evaluated and as Compared to Gasoline[25]



Detailed Description of Individual Parameters

Further technical details on the implementation of each of the scenario parameters investigated are presented below.

Station Location Selection Method

For all evaluations shown in Table 13, the location of each of the 1,000 stations guided by CHIT was the center point of the highest-need evaluation grid cell (hexagons with a characteristic length of one-quarter mile), subject to the method of selection. In the very first scenario evaluations, this selection process was led by simply identifying the evaluation cell across the entire state that exhibited the greatest need for a new station. For the remaining evaluations, station location selection was a two-step process. First, priority areas (defined as contiguous regions of high-need areas) were first identified. Once priority areas were defined, a station(s) were placed in each according to the remaining parameter settings for the evaluation. The overall effect was to broaden the extent of the network. This is achieved because all cells in a priority area are considered to be equivalently desirable for a new station, even if there are gradations of that desirability within the priority area. Thus, rather than considering only a single quarter-mile evaluation cell for a station location, a much larger region could form the basis for a station location, with consideration for the next station directed towards a wholly separate region. By contrast, considering only individual evaluation cells separately had high probability for identifying locations within close proximity, both with high need, as distinct and separate market needs and thereby concentrated station location density.

Coverage and Capacity Score Ratio

Regardless of the station selection method, the calculation for determining the local degree of need for a new station was informed both by coverage and capacity needs. Consideration of both these aspects is crucial because even though there is often a correlation between the two, they are not universally identical (e.g., depending on the characteristics of pre-existing station network development in a region, there may be sufficient stations to satisfy coverage needs for the geographic distribution of likely adopters but the sum of their capacities may be insufficient to satisfy the projected local population of vehicles). In a select set of scenarios, the relative influence of coverage and capacity considerations was explored, with 2:1 and 4:1 (coverage:capacity) ratios considered (some evaluations not shown also explored the inverse of these ratios). Early on, a ratio of 2:1 was identified as most appropriate, especially as the scenario evaluations reach

25 Regions named in the figure are defined by a self-consistent set of rectangular areas containing the indicated regions and in some cases nearby cities or clusters of cities. These descriptive names are therefore used as general reference points and should not be interpreted to align with any formal boundaries for the indicated regions.

a network size at which it is expected that most urban areas' need for stations will be primarily guided by capacity-based pressures rather than coverage.

Capacity Evaluation Basis

Within the context of CHIT evaluations, coverage gap is a "relative" consideration; that is, addition of a station in one area can affect the assessment of need for a station in a separate, distant location. This is because coverage gap is constantly normalized to the greatest measure of gap between local market potential and coverage provided by the station network. Since every station is located in high-need areas and coverage was always more heavily weighted than capacity considerations, nearly every iteration of placing a station likely altered the distribution of coverage gap across the entire state. By contrast, capacity need is an "absolute" consideration; that is, addition of a station in one area only affects the assessment of need for a station in the area surrounding that station (effectively within the extent of coverage, which is a 15-minute drive in CHIT). Total demand is not normalized to the greatest need in the state; thus, localized capacity gap remains a function only of local market demand and nearby station network development.

In early evaluations, the full capacity need projected in 2030 was utilized as the basis for demand in these calculations. However, it became apparent that this was potentially another factor in disproportionately focusing station placement in dense urban areas with high FCEV market potential. In these scenarios, the 2030 demand far outweighed the potential capacity build-up for most of the simulation years in the evaluation because the station daily capacities utilized were so much smaller than the total 2030 demand. Later evaluations transitioned to a capacity need basis that was re-calculated each year, following the demand that would be apparent according to the "FCEV Vision" curve of Figure 52. Under this method, high-market areas' capacity needs could temporarily be met earlier in the simulation and increase the frequency of station selection outside of these core market areas.

Station Placement Lockout

In order to further enhance station dispersion, lockouts on potential sites were instituted. Options were investigated to only lock out the evaluation grid cell that contained the new station and to additionally lockout all adjacent evaluation grid cells. It was determined early on that lockout including adjacent cells was necessary to ensure sufficient geographical dispersion on the local level (i.e. dispersion within a local market, rather than dispersion among the several potential markets across the state).

Priority Area Recalculation Frequency

For the scenario evaluations that relied on determining priority areas to guide individual station placement, the minimum frequency of determining these areas and the number of stations per area were investigated. For all cases, the metric of priority area calculation frequency is a *minimum*; because of the methods of identifying priority areas (which enforce requirements of minimum square mileage and inclusion of evaluation grid cells above a minimum threshold), it is not always guaranteed that the number of priority areas identified will be sufficient for the number of stations within the selected period. Thus, for all options discussed here, priority areas could (and often were) calculated more frequently than the minimum indicated.

The first method investigated recalculated priority areas at the start of each simulation year, similar to the current AB 8 process. Another alternative was to enforce recalculation of priority areas after every set of thirty stations, as an approximation of an average solicitation cycle. In another evaluation, sets of priority areas were identified and then three stations were iteratively placed in each area successively. Finally, evaluations settled on identifying sets of priority areas and placing one station in each. Similar to other parameter definitions, this method was found to provide the greatest enhancement to proportional regional and statewide distribution of hydrogen fueling stations.

In addition to this minimum calculation frequency, any evaluations that considered a distribution of potential station capacities available in any given year also required recalculation of priority areas whenever the chosen station capacity changed. This was necessary because these evaluations relied on capacity value evaluations, as defined for GFO 15-605, rather than capacity need.

Priority Area Minimum Thresholds

In standard CHIT evaluations, priority areas are determined by the identification of two considerations related to coverage gap: 1) Contiguous areas that exhibit high coverage gap (also referred to as hot spots) and 2) Contiguous areas that are considered significantly higher than their surrounding areas according to geospatial statistical evaluation. Thus, priority areas in standard CHIT assessments are guaranteed to be high-scoring areas of similar need for new coverage that are distinctly identifiable from their surroundings. Unfortunately, the native process available in ArcGIS for the statistical evaluation requires significant execution time that renders it impractical for iterative placement of 1,000 stations. Therefore, for all evaluations considered, priority areas were determined only by the first factor.

This does not imply that priority areas identified in this work are any less valid than standard CHIT evaluations; rather, it simply means that there is less certainty about the distinction between evaluation grid cells included in priority areas and neighboring cells outside the priority areas. In practice, inclusion of the statistical consideration usually tended to broaden priority areas. However, in this work priority areas were determined not only by coverage considerations but also capacity considerations. The effect of including capacity in the determination had a similar effect of broadening identified priority areas, in spite of the different approach and rationale.

Regardless of whether the metric for need is coverage-based or coverage and capacity together, the determination of areas that are considered "high need" remains the same. Using built-in capabilities of ArcGIS, all evaluation grid indicator values were categorized into one of ten ranks, using the Natural Breaks method of data classification[26]. Priority areas are then those areas where all connected and adjacent evaluation grid cells have an indicator metric that falls above a defined rank group threshold. For example, in CHIT 2017 Release default parameters, priority areas consist of evaluation grid cells in rank group of seven through ten. In some of the scenario evaluations for this work, this same minimum rank group was maintained for definition of all 1,000 stations' priority areas. For others, the minimum rank group decreased over progressive simulation years, reflecting broadening of the market from first adopters towards the wider mass-market. In the finalized scenario evaluation, this was the case but also with the initial minimum was adjusted to rank group six to allow broader network development possibilities early on. Finally, whenever additional priority areas needed to be calculated and none could be found above the required minimum, the evaluation was allowed to reduce the minimum rank group by one to enable broader consideration and increase the likelihood of identifying viable priority areas.

Available Station Locations

For many of the scenarios evaluated, the entire state was considered available for a potential hydrogen fueling station; thus, the evaluation domain consisted of nearly 3.7 million evaluation grid cells, each of which could be determined to be an appropriate location for a hydrogen fueling station. As part of the effort to inform hydrogen fueling station location selection with observed gasoline demand and market development, the evaluation domain was significantly reduced to nearly 115,000 evaluation grid cells that are all within a short distance of gasoline fueling stations. By incorporating this parameter, the nature of the evaluation scenario shifted subtly away from attempting to optimize a blank canvas toward an optimized selection problem. In effect, implementation of this parameter generates a problem definition of knowing a set of candidate locations for hydrogen fueling stations and determining the best set and order of station development such that evolving coverage and capacity needs are optimally met by the network as a whole at any point in time.

Gas Station Density Following

Implementation of gas station density data leveraged the gasoline station distribution template of Figure 45 to inform localized limits on the number of hydrogen fueling stations that could be placed in an area. For these evaluations, prior to defining priority areas, the distribution of hydrogen stations that had previously been placed was cross-referenced against the boundaries of the polygons in the gasoline station distribution template. All gasoline density polygons that contained two or more hydrogen fueling stations were then identified and all evaluation grid cells that overlapped these polygons were then removed from consideration in defining priority areas for the remainder of the scenario evaluation.

This was accomplished by altering all indicator values for those selected evaluation grid cells to zero, such that their need for a new station was absolutely minimized. The limit of two was determined based on the ratio of 1,000 hydrogen stations to 8,000 gasoline stations across the state and the requirement that each gasoline density polygon contained at least 10 stations. Thus, an exact ratio would indicate 1.25 hydrogen stations per gasoline density polygon, which was rounded to two. Since this parameter was enforced at the

26 A discussion of the "Natural Breaks" method is provided in the November 2017 Webinar of CHIT 2017 Release Updates. *www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm* (see Webinar Presentation [Slide 93] & Webinar Recording links).

time of developing priority areas, rather than for each individual station placement, it acted more as a guide than a strict requirement and some areas would slightly exceed this limit.

Evolving Station Size Distribution

For many of the evaluation scenarios, every station placed in any given year of the scenario was assumed to be the same capacity, following the growth trend shown in Figure 59. By contrast, the finalized and later station evaluation scenarios assumed a distribution of hydrogen fueling station capacities would be available and deployed in each year, with the distribution among sizes evolving over time as shown in Figure 60. In general, the annually-varying distributions were designed to maintain average station capacity growth over time, include a brief delay before introducing additional small-sized stations (which would likely be preferential in areas outside the core high-market areas), gradually phase out the relatively small stations that are most common today, and to gradually introduce mid-range capacity stations over time followed by a reduction in their proportion to a minimum amount in order to maintain focus on increasingly larger station capacities.

Figure 59: Steady Station Capacity Growth

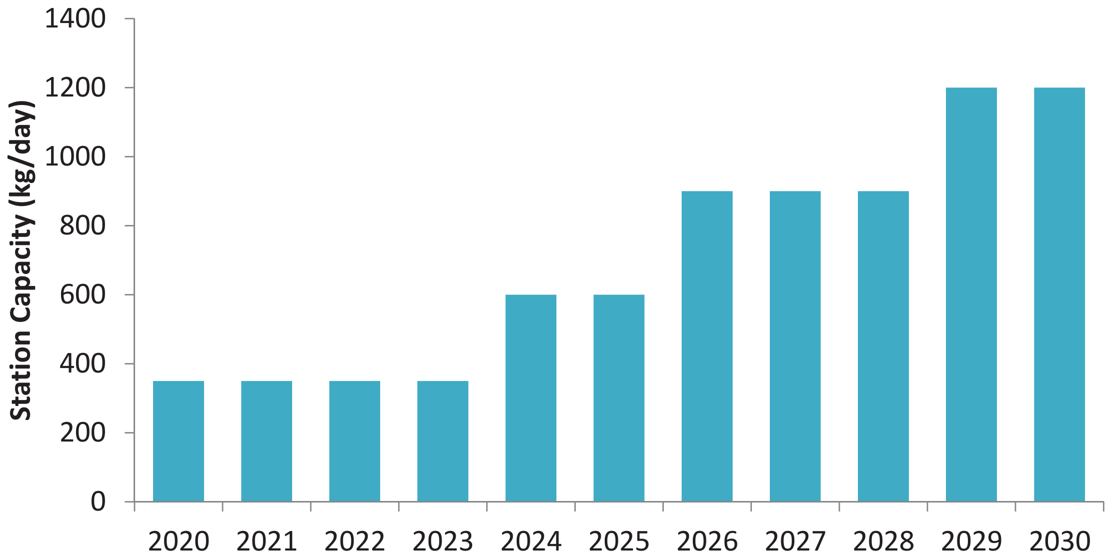
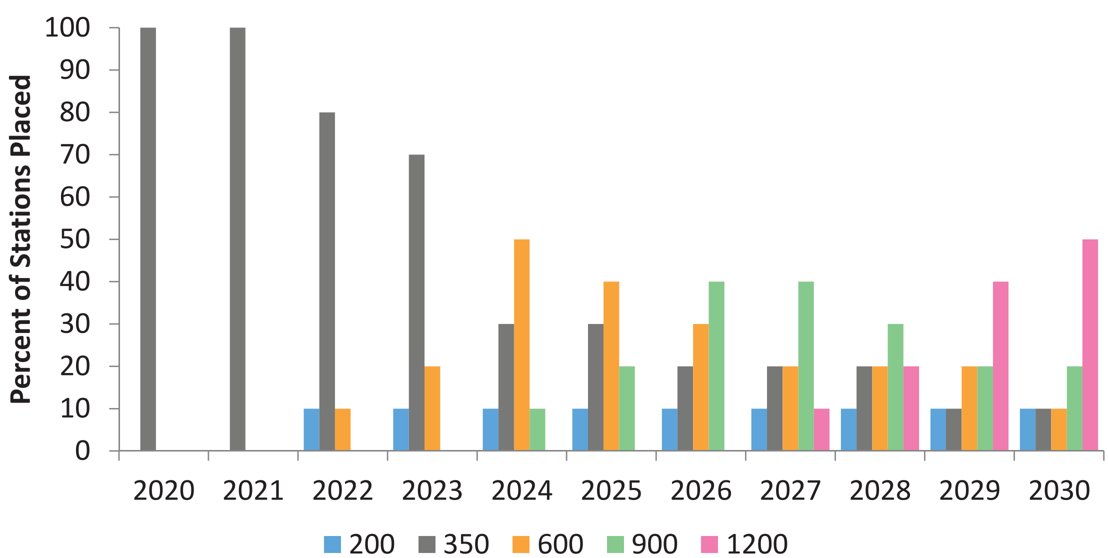
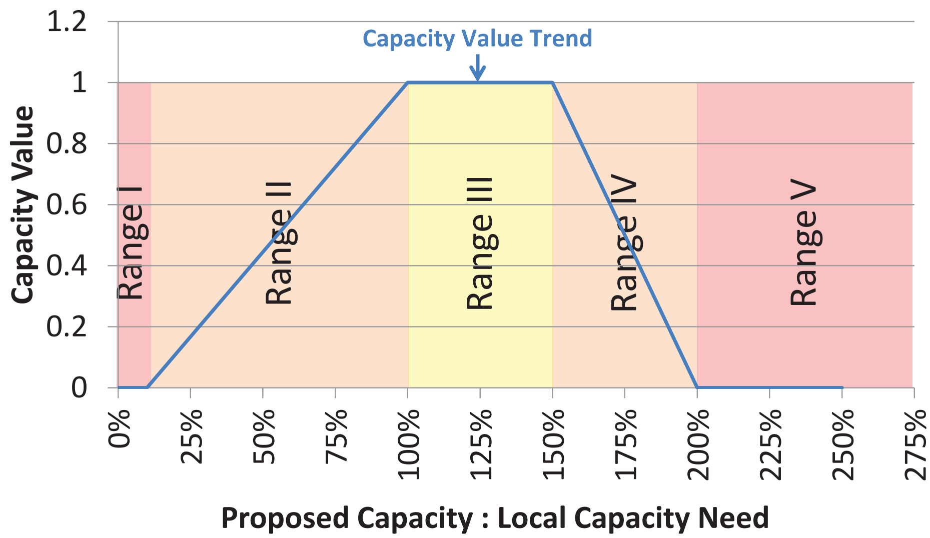


Figure 60: Annually-Varying Station Capacity Distribution



For all evaluations that followed the station growth of Figure 59, the capacity-based portion of the evaluation of new station need was determined only by the absolute local capacity gap (the difference between installed capacity and projected demand locally in any given year of the evaluation). However, for evaluations that included various station capacities available in every year according to Figure 60, an assessment of the appropriate station capacity for each area's local need was necessary. Therefore, these evaluations utilized the *capacity value* as was defined for GFO 15-605. The capacity value is a metric designed to favor stations with a capacity that most closely match the local need, with flexibility for a certain amount of over-build. Figure 61 provides an overview of the concept of capacity value for a given location; every location across the state has its own curve specifically tuned to the local capacity need. Finally, for these evaluations, stations in each year were always placed in order of increasing station capacity; that is, all 200 kg/day stations were placed before all 350 kg/day stations, and so on.

Figure 61: Concept of Capacity Value at a Given Location



Range I: Avoid severe under-building
Range II: Growth to maximum score at station capacity meeting exact need
Range III: Buffer to allow reasonable overbuild
Range IV: Decrease in score as overbuild approaches excess
Range V: Avoid severe overbuild

Low Gasoline Throughput Lockout

In addition to the iterative station placement lockout option, later evaluations explored the possibility of utilizing the gasoline throughput data to limit the hydrogen station potential in regions that currently exhibit extremely low gasoline station throughput. In order to accomplish this, the gasoline station data shown in Figure 45 were referenced to identify the regions that represent roughly the bottom 10% of gasoline sales (also equivalent to regions that have normalized gasoline sales less than 20% of the highest-sales region). With these areas identified, all evaluation grid cells overlapping these regions were modified in one of two ways. In some simulations, all overlapping evaluation grid cells were locked out of consideration for hydrogen station placement (by manually editing all their indicators for evaluation of new station need to zero). Thus, no station would be placed in these regions at any time through the scenario evaluation.

In an alternative method, all evaluation grid cells within these regions were tracked throughout scenario execution. In every iteration when priority areas were determined, the priority rank group was reduced by two levels for all these areas. Thus, these regions were not explicitly locked out, but they were significantly reduced in their priority in every iteration of station placement, typically delaying the placement of a station locally (in some cases, this delay was sufficient enough to determine that station placement in these areas would occur beyond the 1,000 stations investigated). Although this option was explored, it was ultimately determined that the stations that were delayed or removed due to implementation of this parameter were likely important to the overall usability of the network and would likely be identified as necessary stations upon stakeholder feedback. Thus, the finalized scenario chosen did not include consideration of this parameter.

Early Adopter Market Station Proportion Explicitly Defined

The final parameter that was explored was the explicit enforcement of relative numbers of stations to be placed in dense, high-potential core market areas versus the extended network outside these areas. In order to achieve this, the definition of priority areas was bifurcated: in each year, a certain number of stations would be placed in priority areas defined by focus on stronger adopter metrics (by utilizing a higher minimum priority area rank), and a smaller number would be placed in priority areas defined by lower priority area ranks. As with other evaluations, the minimum rank within each market type also decreased with time to reflect broadening of the market base. The schedule for each of these market types' minimum priority area ranks is shown in Figure 62, with the schedule of cumulative placement in each market type (and the in-year ratio between the two) shown in Figure 63. In addition to the differences in numbers and priority area definitions, extended market station introduction was delayed by two years in order to maintain focus on core market areas early in the evaluation scenario. Although this parameter provided an interesting option for further defining the station development scenario, it proved too restrictive and was not implemented in the finalized vision.

Figure 62: Minimum Priority Area Ranks in Core and Extended Markets

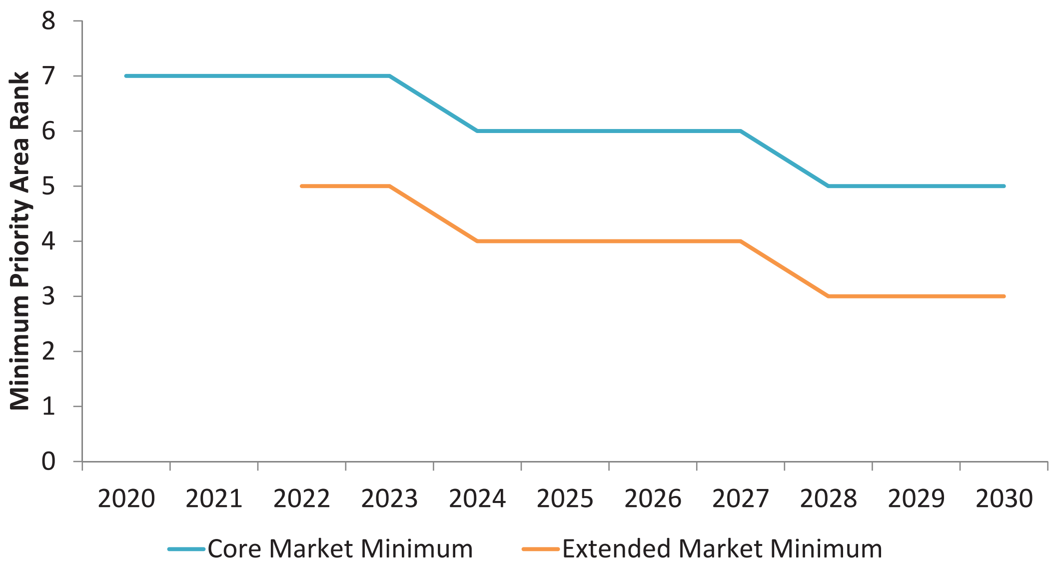
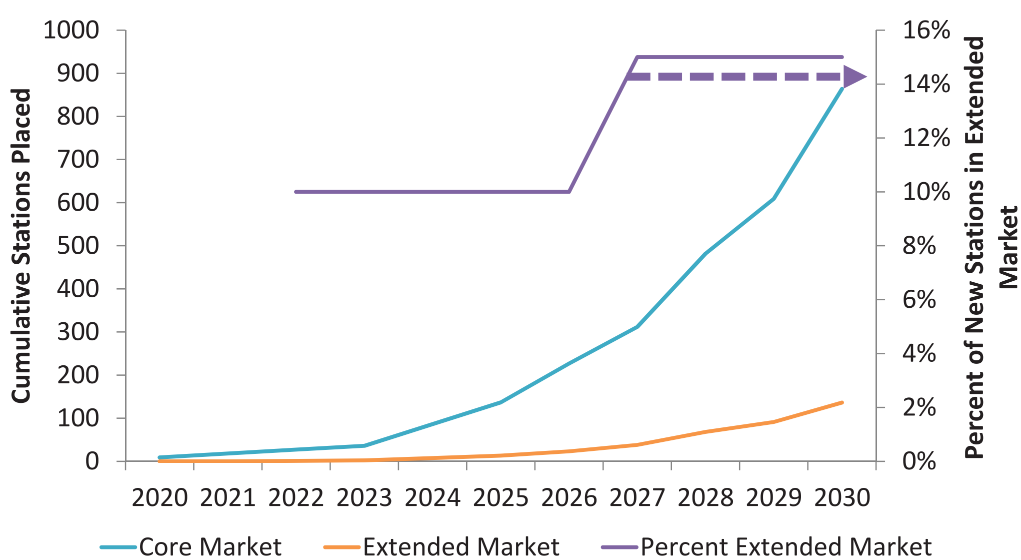


Figure 63: Core and Extended Market Enforced Proportions and Station Counts



Appendix E: CVRP Geospatial Response Analysis

Figure 64: Station Usage of CVRP Respondents in Western San Francisco Bay Area

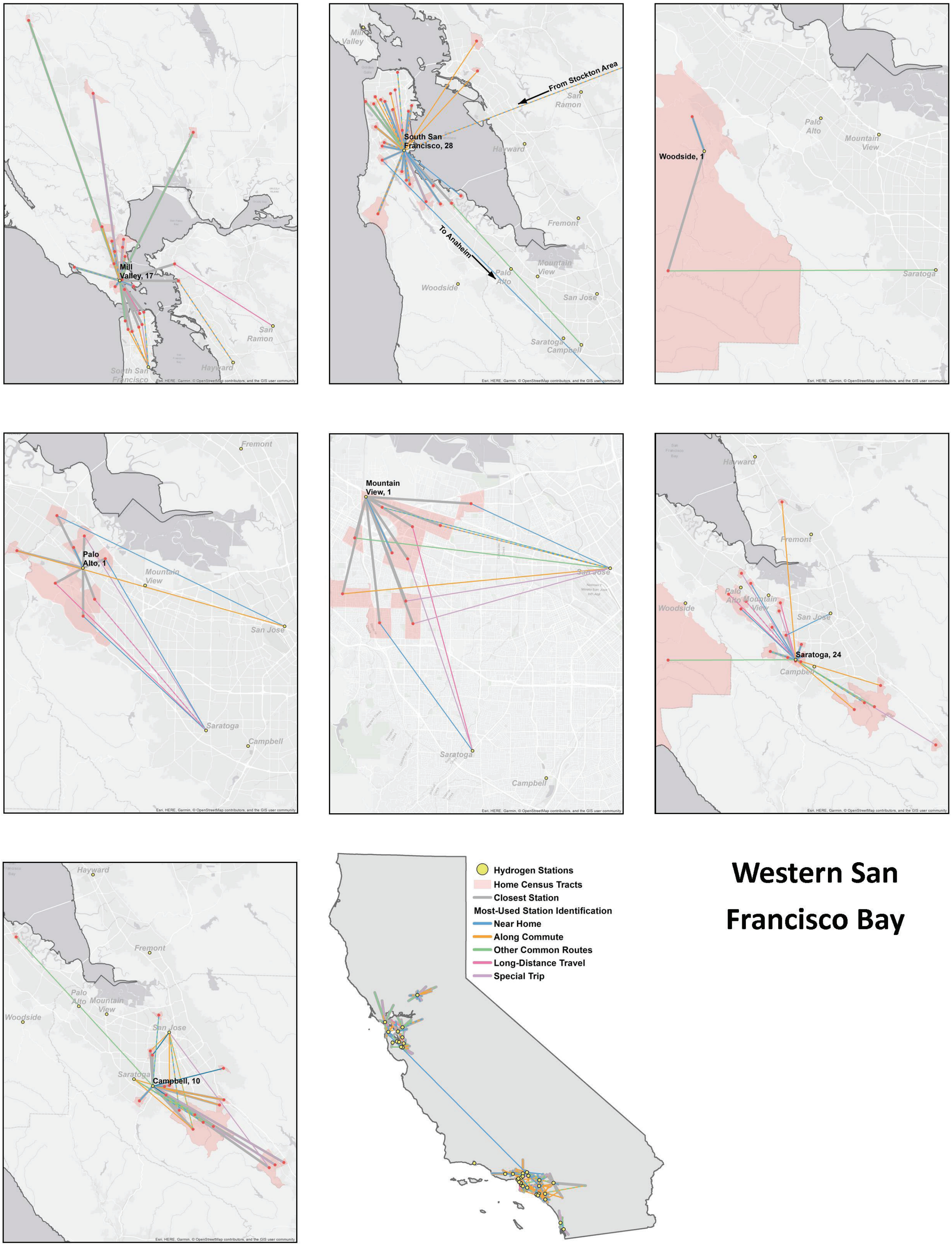


Figure 65: Station Usage of CVRP Respondents in Eastern San Francisco Bay Area

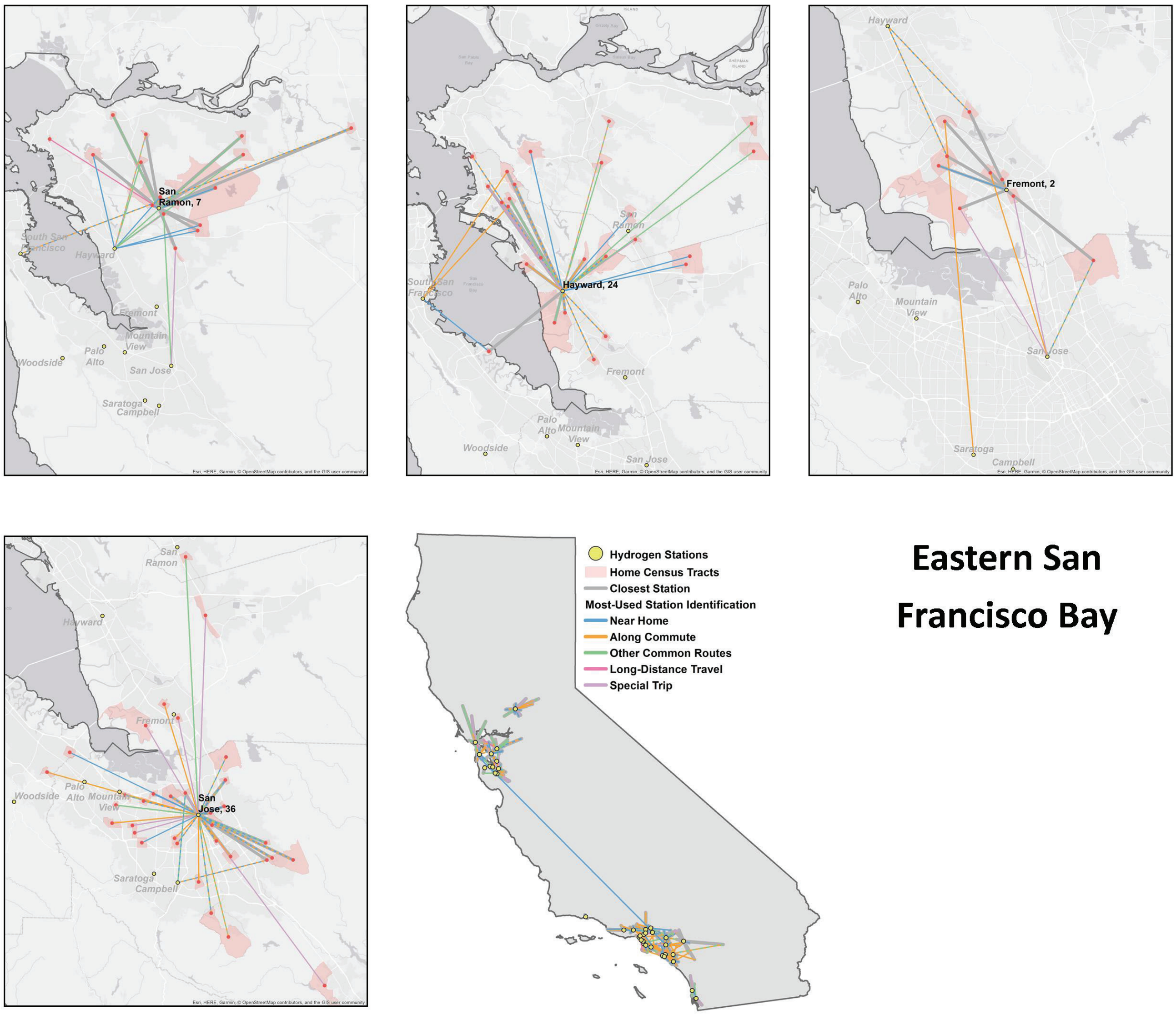


Figure 66: Station Usage of CVRP Respondents in Western Los Angeles Area

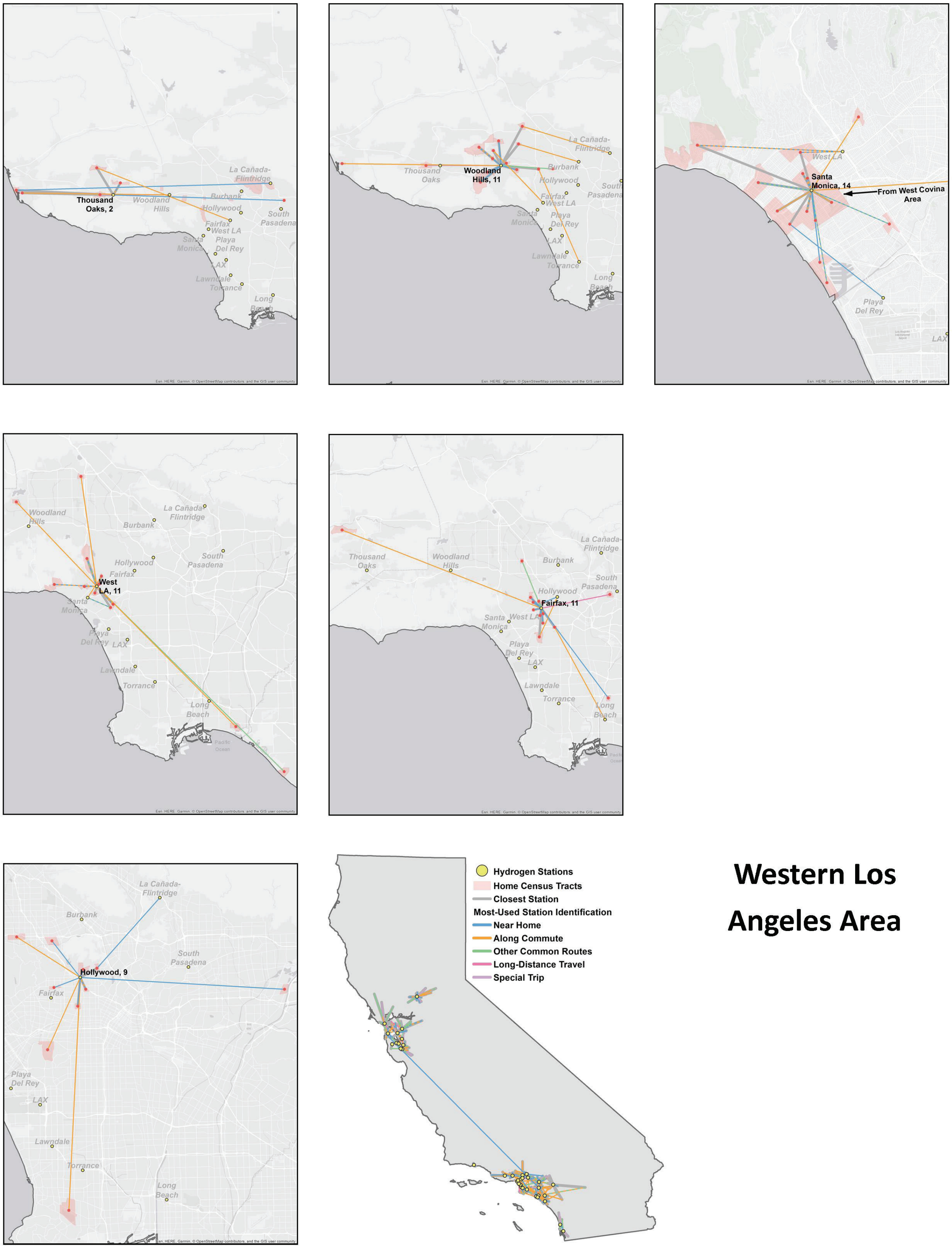


Figure 67: Station Usage of CVRP Respondents in Eastern Los Angeles Area

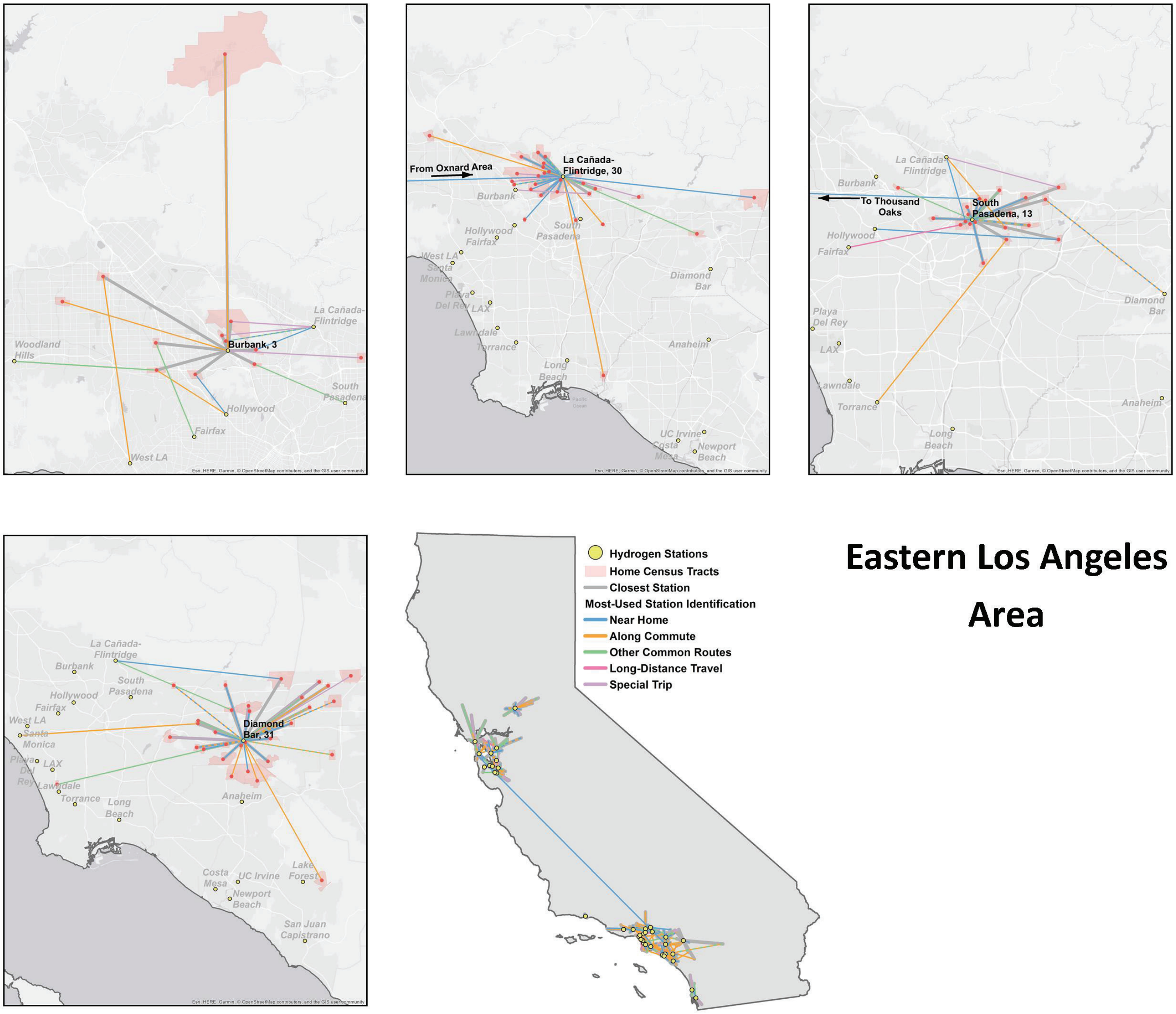
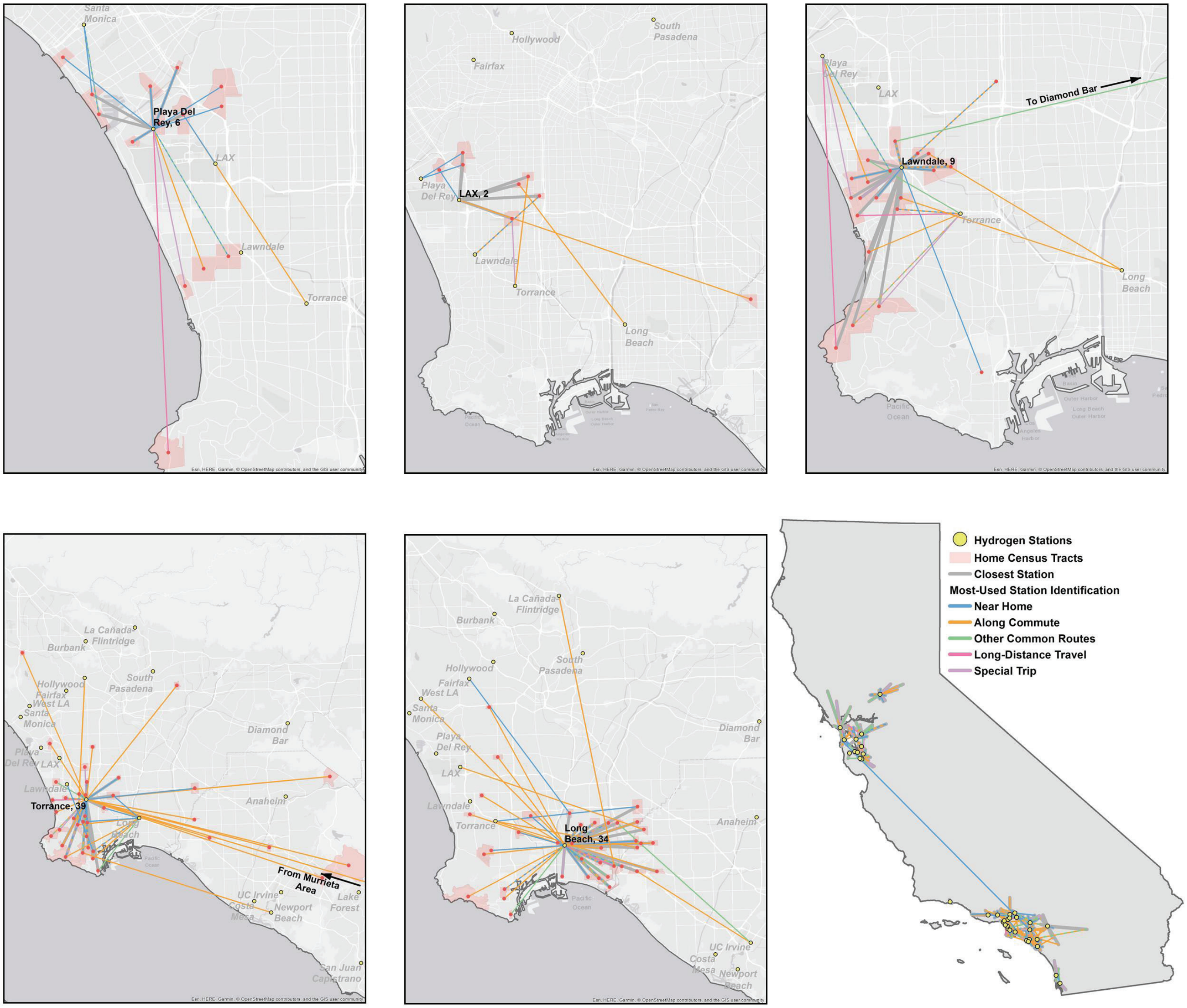


Figure 68: Station Usage of CVRP Respondents in Torrance South Bay Area



Torrance South Bay Area

Figure 69: Station Usage of CVRP Respondents in Orange County and Nearby Locations

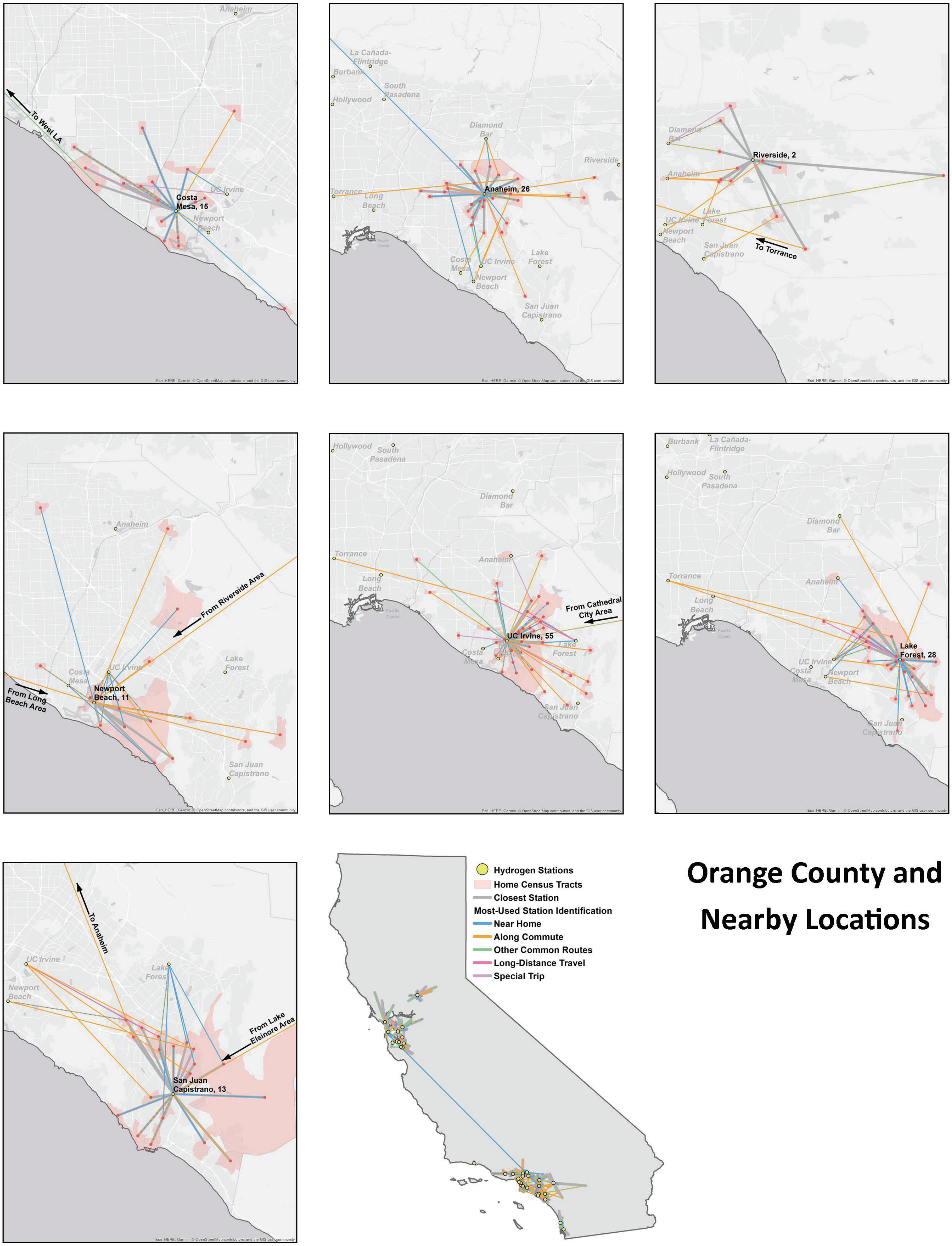
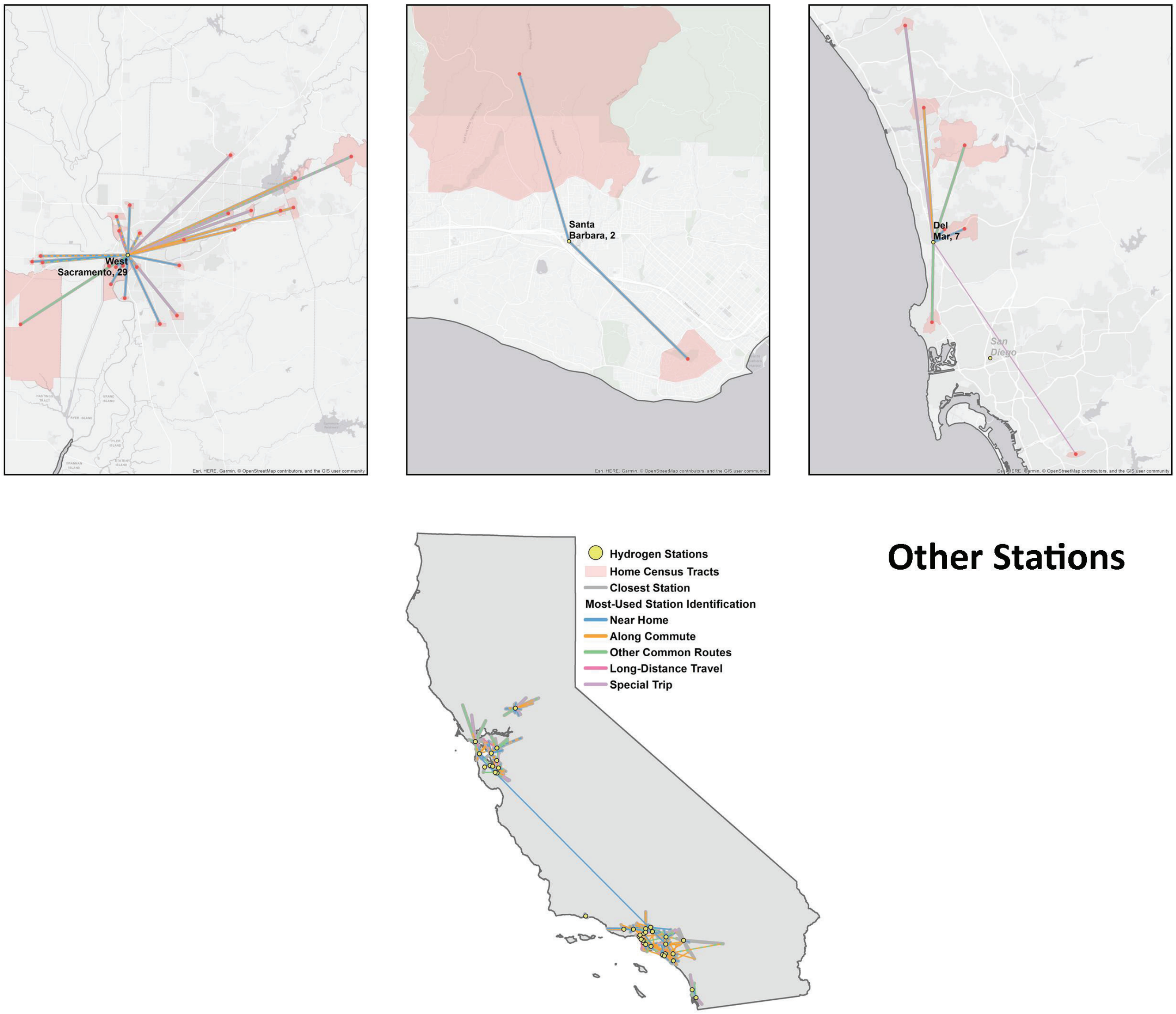


Figure 70: Station Usage of CVRP Respondents in Other Locations



Appendix F: Station Status Definition Details

The definition of an **Operational** station as adopted from Energy Commission GFO 15-605 (note that the definition included in previous and future Energy Commission grant programs like PON 13-607 may have different provisions) includes the following:

1. Has a hydrogen 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 Energy Commission agreement to make the station functional.
4. Has passed a test for hydrogen quality that meets standards and definitions specified in the California Code of Regulations, Title 4 Business Regulations, Division 9 Measurement Standards, Chapter 6 Automotive Products Specifications, Article 8 Specifications for Hydrogen Used in Internal Combustion Engines and Fuel Cells, Sections 4180 and 4180 (i.e., 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.
8. Has all of the required state, local, county, and city permits to build and to operate.
9. Meets all of the Minimum Technical Requirements (Section VI) of GFO 15-605.

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

The definition of an **Open- Retail** and all in-progress station statuses are adopted from the GO-Biz effort to define a set of station status definitions with stakeholder consensus across the State agencies and FCEV and hydrogen fueling industries.

Open-Retail stations are defined by:

1. The station has passed local inspections and has operational permit
2. The station is publicly accessible
3. The station operator has fully commissioned the station, and has declared it fit to service retail FCEV drivers. This includes the station operator's declaration that the station meets the appropriate SAE fueling protocol, and three auto manufacturers have confirmed that the station meets protocol expectations and their customers can fuel at the station, and it has passed relevant hydrogen quality tests.
4. Weights and Measures has verified dispenser performance, enabling the station to sell hydrogen by the kilogram (pursuant to CCR Title 4, Division 9, Chapter 1).
5. The station has a functioning point of sale system.
6. The station is connected to the Station Operational Status System (SOSS), maintained by CaFCP.

The remainder of the status definitions are as follows:

Fully Constructed: Construction is complete and Station Developer has notified the appropriate Authority Having Jurisdiction (AHJ).

Under Construction: Construction at the site has started and is currently active.

Approved to Build: The station developer has approval from the AHJ to begin construction. Depending on the station developer or individual project, construction may begin immediately or a pre-mobilization effort to select construction crews and deliver equipment may first be necessary.

Planning Approval: The site plan for the station has been approved, which indicates that a hydrogen station can exist on the site, subject to meeting all building, fire, and electrical codes and standards.

In Permitting: The permit application is currently under review by the AHJ planning agency.

Finishing Permit Apps: The station developer is preparing site layout, engineering, and other documents for submittal to the AHJ. This process is often iterative and may actually occur several times throughout the permitting process. In this Annual Evaluation, a station is reported as Finishing Permit Apps if it has not yet submitted this material for the first time (after first submittal, the station is moved to In Permitting, even if new documents are submitted later).

Establishing Site Control: The station developer is actively seeking a new site and/or negotiating a new site lease agreement.

California Air Resources Board

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