Californias
Advanced Clean Cars
Midterm Review

Appendix D:
Zero Emission Vehicle Infrastructure Status in California and Section 177 ZEV states

January 18, 2017

California Environmental Protection Agency
Air Resources Board

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I. Overview

This appendix will examine the status of zero emission vehicle (ZEV) infrastructure needed to support the ZEV regulatory "Mid-Range Case" compliance scenario (see Appendix A for details of this scenario development). This appendix reports on the current status of ZEV infrastructure in California and the Section 177 ZEV states,[1] reviews published assessments of existing infrastructure, and provides updated synthesis of these prior works that incorporates the latest data available. In addition, this appendix addresses the question of whether trends in infrastructure development indicate sufficient charging and fueling deployment rates in order to meet the demands of the expected ZEV fleet. Finally, this appendix details one potential 2025 electric charging infrastructure network, and analyzes how this potential network address the needs of a ZEV fleet envisioned by the current ZEV regulation and how those needs may change with an evolving vehicle and infrastructure landscape.

Since the Air Resources Board (ARB or the Board) adopted the Advanced Clean Cars (ACC) regulation in 2012, several important State initiatives have been adopted to drive ZEV deployment through associated infrastructure development. Assembly Bill 8[2] (AB 8; Perea, Statutes of 2013, Chapter 401), extended the funding programs of Assembly Bill 118[3] (AB 118; Nunez, Statutes of 2007, Chapter 750). AB 8 provides an assured annual funding source of up to $20 million for hydrogen fueling stations administered by the California Energy Commission (Energy Commission) and establishes an annual cycle of assessment of infrastructure and vehicle deployment progress and needs. AB 8 additionally continues funding programs for plug-in electric vehicles (PEV), meaning battery electric vehicles or BEVs and plug-in hybrid electric vehicles or PHEVs, first established under AB 118, though the amounts are allowed to vary annually. In addition, Senate Bill 350[4] (SB 350, De León, Statutes of 2015, Chapter 547) enabled investor owned utilities (IOU) to participate in transportation electrification through the funding of infrastructure using rate payer proceeds. SB 350 is significant for many reasons including the recognition of rate payer benefits from transportation electrification, including to non-PEV driving ratepayers. Overall, it is expected that this will significantly accelerate expansion of PEV infrastructure. These State actions have major direct impact on the deployment rate of the State's ZEV infrastructure deployment, though additional complementary policies have also been instrumental, as further discussed in Appendix E.

II. Summary of PEV Infrastructure Status

California and Section 177 ZEV states have seen substantial investments in PEV infrastructure in the past several years, and accelerated investments are expected as new infrastructure efforts emerge. PEVs and related infrastructure are no longer nascent technology but are fully commercialized, viable alternative transportation modes. Modern PEVs have been around for over a decade. Although next generation vehicle and battery technology is improving, current

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[1] Section 177 of the Clean Air Act allows states in non-attainment of the Federal ozone standards to adopt California's regulation. Nine states have adopted California's ZEV regulation: Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.
[2] Assembly Bill No. 8 (Perea, Statutes of 2013, Chapter 401).
[3] Assembly Bill No. 118 (Nunez, Statues of 2007, Chapter 750).
[4] Senate Bill No. 350 (De Le León, Statutes of 2015, Chapter 547).

technology is firmly established and all signs reinforce the PEV's place in the long term transportation future. Initial infrastructure challenges such as technical specifications, operability standards, communication protocols, signage, Americans with Disabilities Act (ADA) compliance specifications, and procuring funding for an initial infrastructure network have been addressed. Over $250 million of private capital has entered the national PEV infrastructure market, supported by emerging business cases for charging networks. However, challenges, including infrastructure serving multi-unit dwellings (MuD) and underrepresented communities, open access standards, and utility rate structures that employ prohibitive demand charges do remain. Some of the major success and findings within today's PEV infrastructure landscape include the following:

- 14,048 Level 1, Level 2, and direct current fast charger (DCFC) public and private (non-residential) connectors are operational in California.
- 7,035 Level 1, Level 2, and DCFC public and private (non-residential) connectors are operational in Section 177 ZEV states.
- Declining PEV infrastructure costs and growth in the global PEV market may enable increased deployment of charging equipment overall, though local conditions (such as the age of wiring in existing housing stock of a local market) may cause geographic variation of adoption rates.
- Recent state investments in DCFC corridors, both north/south and east/west, will facilitate a PEV with no more than 85 miles of range to traverse the entire State of California.
- Passage of SB 350 will accelerate widespread transportation electrification by directing investor owned electric utilities to make investments that accelerate the use of PEVs, either through infrastructure capital investments, electricity rates, etc. SB 350 identifies the need for transportation electrification on sufficient scale to achieve 2030 transportation emission targets for greenhouse gas (GHG) and criteria emission reductions. Utility investments will complement efforts by the private sector and other government entities (e.g., California's regional government infrastructure programs).
- The California Building Standards Commission (BSC) has revised the Green Building Standards (CALGreen) Code to mandate PEV infrastructure (electrical capacity) in new commercial, single family, and some multifamily dwelling units. This will lower the cost of future electric vehicle supply equipment (EVSE) installations at these sites.
- Employing scenario planning methods, National Renewable Energy Laboratory (NREL) has quantified the number of connectors needed to serve specific PEV deployments targets. Using these sufficiency forecasts ARB created ratios of required connectors per PEV in California and Section 177 ZEV states. Based upon a comparison of these ratios, it appears there may be sufficient infrastructure in many Section 177 ZEV states to support greater PEV deployments.

III. Electric Vehicle infrastructure Background and Basics

PEV infrastructure is the collection of hardware and systems that supply electrical power to a PEV. Broadly speaking, PEV infrastructure includes electricity generating facilities, transmission lines, and transformers. However, equipment and facilities upstream of a consumer's electrical meter is the responsibility of the electric utility and is overseen by the California Energy Commission (Energy Commission) and the California Public Utilities Commission (CPUC). Therefore, the focus of this section will be on equipment "behind the meter," specifically EVSEs, connectors, and charging stations.

EVSEs are devices that supply electrical power to a vehicle and are typically classified by their output power and referred to as Level 1 (120V), Level 2 (240V), or DCFC (400V), Level 1 being at the lowest level of power and direct DCFC being the highest.

Connectors are the hardware that physically attach to the vehicle. Nearly all connectors associated with Level 1 and Level 2 charging are designed to a common architecture standard specified by Society of Automotive Engineers (SAE) and is often referred to as SAE J1772. Connectors associated with DCFC generally fall into one of three types: CHAdeMO, SAE Combo Connector, or Tesla Connector. The maximum power levels associated with each of these unique standards is different and evolving. These three connector "standards" for DCFC are not interchangeable but Tesla does offer an adapter for their customers. BEVs are typically equipped to handle Level 1 and level 2 charging with optional DCFC capabilities. Most PHEVs are only equipped to handle Level 1 and Level 2 charging, and DCFC is not available for these vehicles, as it is not necessary.

Charging stations are locations with one or more EVSEs and associated equipment available for public or private use. The equipment that supplies power to a vehicle is not considered a "charging station," but the EVSE along with special signage, dedicated parking spaces, pay terminals, etc. all comprise a "charging station." Put another way, a gasoline pump is not considered a "gas station", but gasoline pumps in combination with storage tanks, a canopy, price boards, signage, and other amenities comprise a "gas station."

IV. PEV Infrastructure Costs

Since 2010, sales of EVSEs have grown substantially. Although EVSE costs have sharply declined over the same period, the purchase of a Level 2 home EVSE remains a financial investment for most consumers. Home charging costs in ARB's 2012 rulemaking used cost figures contained in the draft 2010 Joint Agency Technical Assessment Report (2010 TAR), released by the United States Environmental Protection Agency (U.S. EPA), National Highway Traffic Safety Administration (NHTSA), and ARB. Those figures calculated a per vehicle cost of up to $1,616 for home EVSE charging infrastructure. Those costs have significantly declined over the past 5 years.

In November 2015, the U.S. Department of Energy (U.S. DOE) released a report titled, *Costs Associated With Non-Residential Electric Vehicle Supply Equipment.*[5] This report provides the most recent compilations of EVSE costs and factors influencing cost trends. This report was a synthesis of various studies on the subject in addition to data collected from EVSE owners, electric utilities, manufacturers, and installers. This section summarizes costs associated with installation of non-residential electric vehicle (EV) infrastructure. These costs include: trenching to install conduit, electrical panel upgrades, meeting ADA requirements, and geographic labor rates.

Installation rates for home EVSEs (Level 2) can vary significantly by region. This could be due to variation in material costs across regions, geographic labor rates, and the age of existing housing stock. For example, a report by the Electric Power Research Institute (EPRI) found that between 10 and 20 percent of the installations studied required electrical upgrades.[6] These upgrades are less necessary in geographic areas with newer housing stock where higher power electrical panels are more prevalent.

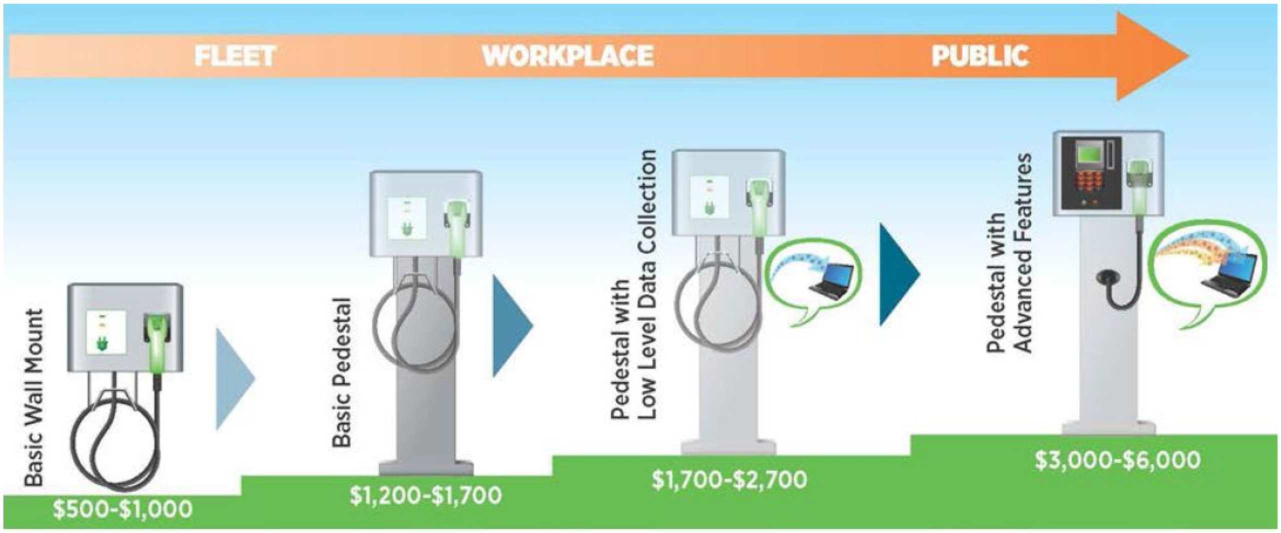
Table 1 and Figure 1, from the U.S. DOE's *Costs Associated With Non-Residential Electric Vehicle Supply Equipment* report, illustrate the costs and price variation in EV infrastructure equipment and installation costs.

Table 1 - Non-Residential EVSE Equipment and Installation Costs[7]

EVSE Type	EVSE Unit* Cost Range (Single Port)	Average Installation Cost (per unit)	Installation Cost Range (per unit)
Level 1	$300 - $1,500	Not available	$0 - $3,000 **
Level 2	$400 - $6,000	≈ $3,000 EV Project	$600 - $12,700
DCFC	$10,000 - $40,000	≈ $21,000 EV Project	$4,000 - $51,000
* EVSE unit costs are based on units commercially available in 2015 ** The $0 installation cost assumes the site host is offering an outlet for PEV users to plug in their Level 1 EVSE cord sets and that the outlet already has a dedicated circuit.			

[5] U.S. DOE 2015, U.S. Department of Energy, Costs Associated With Non-Residential Electric Vehicle Supply Equipment, November 2015, http://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf
[6] EPRI 2013, Electric Power Research Institute, Electric Vehicle Supply Equipment Installed Cost Analysis, December 6, 2013 http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000577
[7] U.S. DOE 2015.

Figure 1 - Costs by Equipment Type[8]



Part of the reason EVSE costs are declining is the global market for PEVs, which has grown from approximately 30,000 vehicles in 2010 to nearly 500,000 by 2015.[9] This strong growth in PEV sales has led to solid growth in the EVSE market, which has led to technological and production efficiencies resulting in lower costs.

Navigant Research, a leading consulting firm that specializes in global clean technology markets, expects the global market for EVSE to grow from around 425,000 units in 2016 to 2.5 million in 2025, a compound annual growth rate (CAGR) of 22%.[10] These sales figures include all EVSE units—residential and commercial, Level 1, Level 2, DCFC, and wireless charging. This affects costs; a Level 2 residential EVSE, formerly priced between $900 and $1,000 in 2013, is currently priced in the $500-$600 range for basic units and is expected to fall below $500 in the near term.

V. Where Drivers Charge

Charging of a PEV occurs in one of three places: at home, at the workplace, or at a public facility. Determining where PEV drivers charge and how they use non-home based infrastructure is an important topic for infrastructure planning. As a result, many studies and analyses have been published on charging patterns and behaviors of PEV drivers. ARB analyzed in-use data provided by automakers from eleven different PEV models, including charging data from a small subset of those vehicles. As displayed in Figure 2 and explained in

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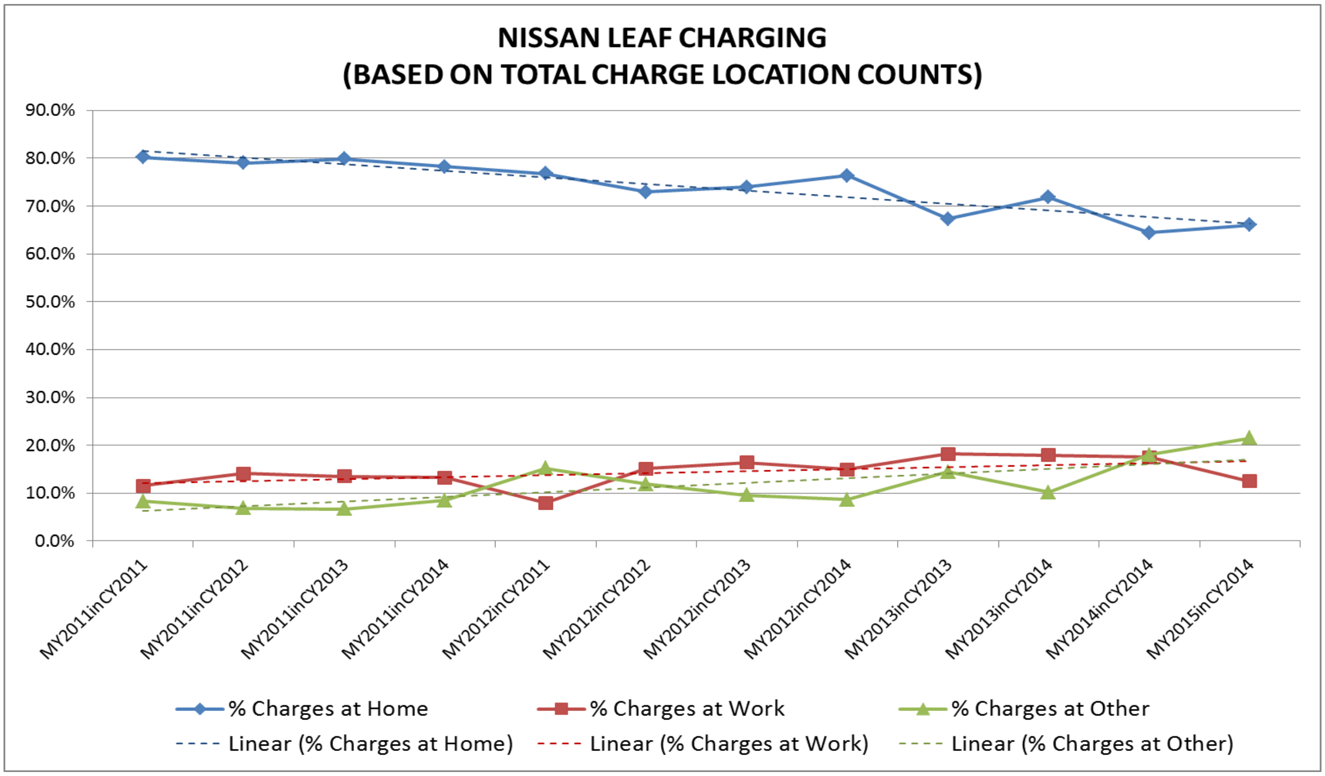
[8] U.S. DOE 2015

[9] Navigant 2015, Navigant Research. "Electric Vehicle Market Forecasts Global Forecasts for Light-Duty Hybrid, Plug-In Hybrid, and Battery Electric Vehicle Sales and Vehicles in Use: 2015-2024", Quarter 4, 2015, https://www.navigantresearch.com/research/electric-vehicle-market-forecasts

[10] Navigant 2016. Navigant Research, "Level 1, Level 2, DC Fast Charging, and Wireless Charging for Residential and Commercial Applications: Global Market Analysis and Forecasts", Q2 2016, https://www.navigantresearch.com/research/electric-vehicle-charging-services

greater detail in Appendix G, looking at the Nissan Leaf data shows most drivers are charging their vehicles at home, although this has declined from 81% of charge events in 2011 to 67% in 2014 in part as more workplace and public infrastructure has become available. Trends found in Figure 2 are similar to results from various other studies such as white papers from INL's EV Project.[11]

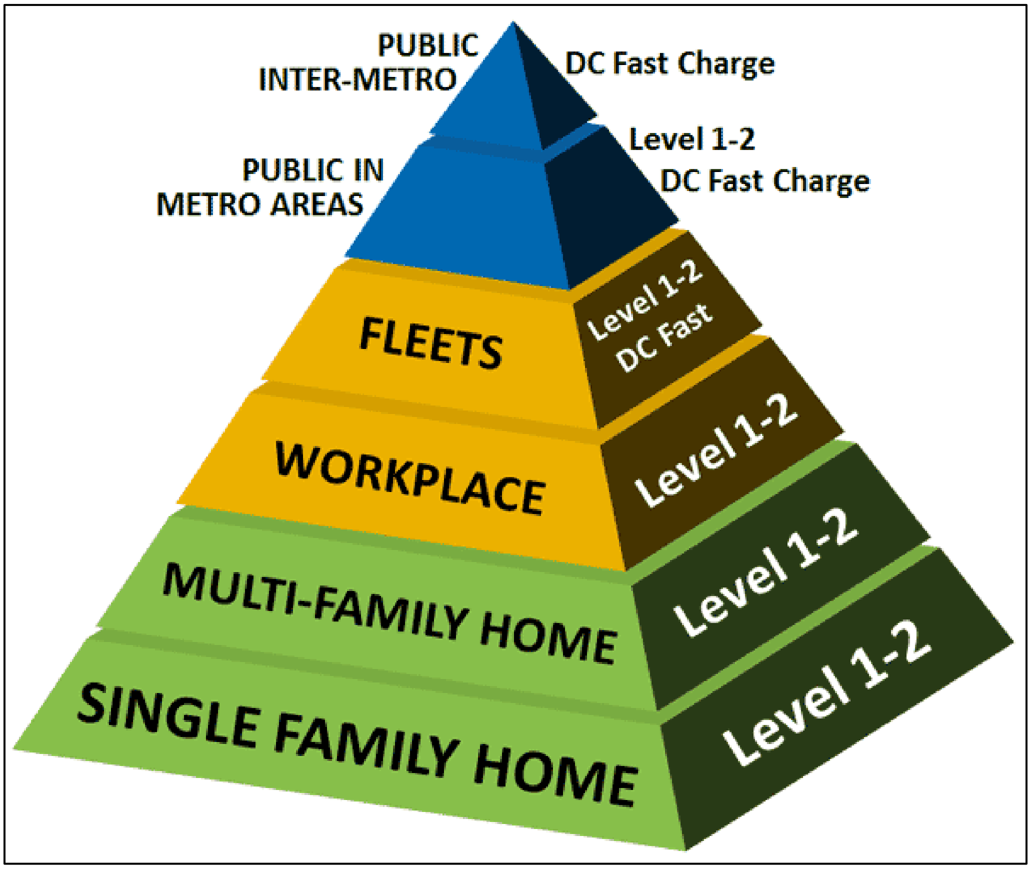
Figure 2 – Charging Location Trends: Nissan Leaf



The trends from these various studies can be summarized using a construct called the "charging pyramid." New York State Energy Research and Development Authority (NYSERDA) developed one such "charging pyramid" (Figure 3) which graphically depicts the interconnected relationships between charger type, location, costs, and frequency of charge events. The majority of charging events occur at home, at lower costs, and over longer periods of time. Additionally, as power increases, charging time decreases, but costs increase - - leading to fewer charging events at that higher power level. As the charging pyramid depicts, the majority of charge events occur at low cost Level 1, followed by more expensive Level 2. The fewest charging events occur at DCFCs.

[11] INL 2014, Idaho National Laboratory, "What Kind of Charging Infrastructure Did Nissan Leaf Drivers in The EV Project Use and When Did They Use It?" The EV Project, INL, 2014 https://avt.inl.gov/sites/default/files/pdf/EVProj/LeafHomeAwayL1L2DCDayNightCharging.pdf

Figure 3 – Charging Pyramid[12]



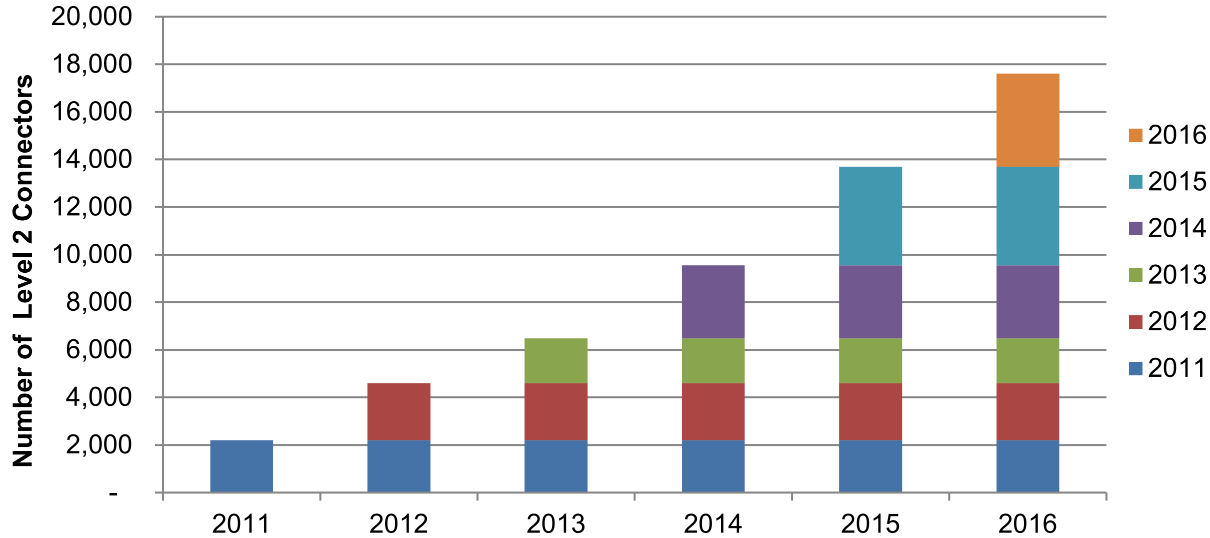
VI. PEV Infrastructure Trends

VI.A. Trends in Station/Connectors

The number of charging stations and connectors in the U.S. are increasing at varied but continual annual rates. The U.S. DOE's Alternative Fuel Data Center (AFDC) maintains a database of public and private charging stations and connectors dating back to the 1990s.

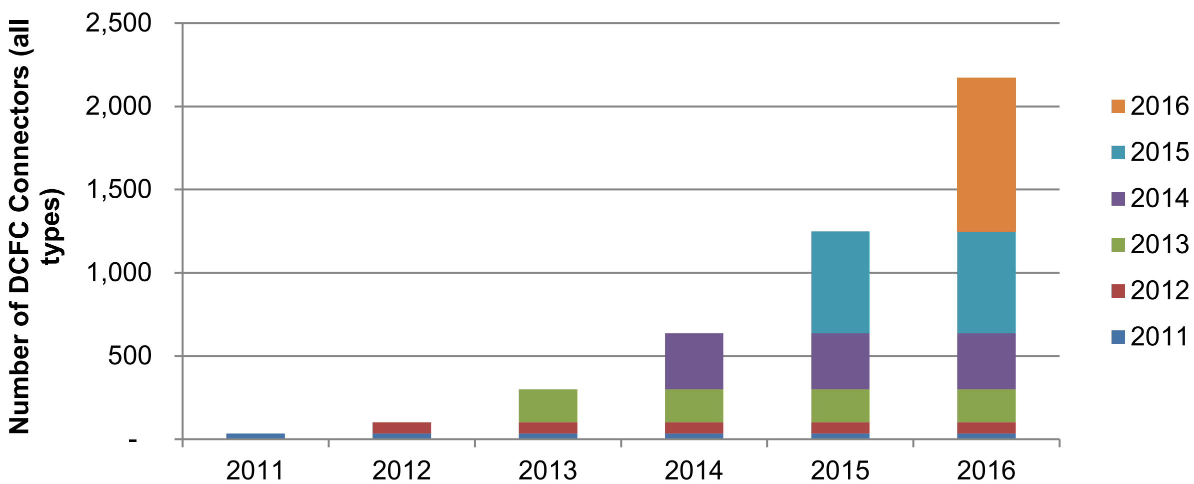
[12] NYSERDA 2016. New York State Energy Research and Development Authority, web-site, accessed October 19, 2016, https://www.nyserda.ny.gov/Researchers-and-Policymakers/Electric-Vehicles/Info/Charging-Station-Hosts

Figure 4 – California and Section 177 ZEV State Level 2 Connectors



Source: U.S. AFDC Database accessed 1/09/2017

Figure 5 - California and Section 177 ZEV State DCFC Connectors



Source: U.S. AFDC Database accessed 1/09/2017

Figure 4 and Figure 5, created using the AFDC database, clearly depict that PEV infrastructure in the U.S. has increased substantially over the past 5 years. In 2010, there were approximately 206 public and private (non-residential) Level 2 charging stations and 347 Level 2 connectors. Nationwide, there are over 16,000 public and private (non-residential) Level 2 charging *stations* and over 36,000 Level 2 *connectors*, as of January 1, 2017. The national totals represent nearly a 70-fold increase in the number of connectors and stations in the past 5 years. California's share of the national total equals over 3,700 Level 2 charging *stations* and over 11,000 Level 2 *connectors*. Additionally, California and Section 177 ZEV states' share of the National Level 2 connectors is 45%.

VI.B. Trends in DCFC EVSE power

The trend in charging, in particular DCFC, is towards higher power which ultimately will enable significantly faster charging and facilitate shorter "refueling events" similar to hydrogen or gasoline. As detailed in Appendix C, batteries in BEVs are becoming larger, increasing the vehicle's range and potentially increasing the need for DCFC.

As battery technology is evolving − increasing energy density, decreasing costs − so is the technology designed to recharge those batteries. In general, DCFC (specifically CHAdeMO and SAE Combo) standards currently support charging rates of up to 50 kilowatts (kW) for most installations. However, CHAdeMO announced on June 1, 2016 that its standard has been amended to support 150kW charging.[13] Installations with the new 150kW standard (beginning in 2017) will be able to support current and previous vehicles that are capable of utilizing CHAdeMO DCFC equipment.

The SAE Combo standard is also being revised to support higher charging rates. The combined charging standard (CCS) effort is being led by an industry formed and supported group called The Charging Interface Initiative e.V. (CharIN e.V.). The CCS covers single-phase AC and three-phase AC and DC high-speed charging (in both Europe and the U.S.) all in a single, easy to use system.[14] CharIN e.V. is working to get CCS supported charging standards to 150kW as quickly as possible, with the ultimate goal of supporting up to 350kW charging rates[15] (over 7 times the current DCFC levels). This very high charge rate is intended to refuel a 200 mile BEV in a matter of minutes.

VI.C. Trends in EV infrastructure related to Building Codes

The clear trend with building codes and standards is toward developing sufficient requirements to support PEV charging. For example, as a result of ARB's involvement, the Green Building Standards (CALGreen) Code has been revised to include more robust requirements for PEV charging infrastructure in new buildings. ARB staff have worked closely with the Building Standards Commission (BSC) and Housing and Community Development (HCD) to develop and incorporate provisions into the CALGreen Code that require installation of PEV charging infrastructure, such as increased panel capacity and conduit to support a dedicated 240 volt circuit, in new commercial buildings. Note, this infrastructure requirement does not include the EVSE unit. New single-family homes, duplexes, and townhouses with attached private garages must install similar PEV charging infrastructure. Multifamily dwellings with 17 or more units on the building site must install PEV charging infrastructure in 3 percent of total parking spaces. Currently, nonresidential buildings with parking lots that have a minimum of 51 spaces must install EV charging infrastructure in 3 percent of parking spaces. However, effective January 1,

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[13] CHAdeMO 2016. CHAdeMO Association Europe, Press Release, June 1, 2016 http://www.chademo.com/wp/wp-content/uploads/2016/06/2016-06-01_High_power_CHAdeMO.pdf

[14] Charin 2016. Charin.org, website accessed September 29, 2016, http://www.charinev.org/ccs-at-a-glance/ccs-specification/

[15] InsideEv 2016, InsideEV.com, website accessed September 29, 2016, http://insideevs.com/abb-joins-charin-150-kw-charging-coming-soon-350-kw-targeted-future/

2017, the requirements are increasing such that parking lots with 10 or more parking spaces must install PEV charging infrastructure in about 6 percent of parking spaces.[16]

Staff is planning to measure the rate of installation of EVSE chargers in new buildings to track progress towards the statewide goal of infrastructure to support 1 million ZEVs by 2020 as articulated in Governor Brown's Executive Order B-16-2012. Specifically because the CALGreen code does not require the actual EVSE unit, staff intends to study how many sites add this final piece of hardware. Staff will also continue to provide suggested code changes based on future updates to projections for PEV charging infrastructure needs.

VII. Status of the Infrastructure Networks in CA and Section 177 ZEV states

The status of the national PEV infrastructure network is robust and growing. The PEV infrastructure network in California and Section 177 ZEV states is equally strong, if not more so than the national average. As detailed in Table 2, and displayed in Figure 4 and Figure 5 above, the total number of public and private connectors in California and the Section 177 ZEV states is over 21,000, which represents nearly 47% of the national total.

[16] ICC 2016, International Codes Council, 2016 Green Building Standards Code 2016, http://codes.iccsafe.org/app/book/toc/2016/California/Green/index.html

Table 2 - Number of Public and Private Connectors (non-residential)[17]

	Level 1	Level 2	DCFC	Total
Publically Accessible Connectors				
	Level 1	**Level 2**	**DCFC**	**Total**
California	619	9,803	1289	11,711
Section 177 ZEV states	488	5,352	841	6,681
Sub-Total	*1,107*	*15,155*	*2,130*	*18,392*
Privately Accessible Connectors (non-residential)				
	Level 1	**Level 2**	**DCFC**	**Total**
California[1]	408	1,902	27	2,337
Section 177 ZEV states[1]	64	545	15	624
Sub-Total	*472*	*2,447*	*42*	*2,961*
Public and Private Connectors Combined				
	Level 1	**Level 2**	**DCFC**	**Total**
California Connectors[2]	1,027	11,705	1,316	14,048
Section 177 ZEV states Connectors	552	5,897	856	7,305
Total (CA & Section 177)	**1,579**	**17,602**	**2,172**	**21,353**
NATIONAL TOTALS	***3,626***	***36,312***	***5,257***	***45,195***

[1] Does not include home charging
[2] Infrastructure funded by Energy Commission represents approximately 17% of California's total
Source: U.S. AFDC Database accessed 01/06/2017

VII.A. Status of California Network – Installed and Currently Funded

Although California's PEV infrastructure landscape could is robust, this singular synopsis ignores both the significant investment, and strategic planning efforts that have resulted in the State's growing PEV infrastructure network. The Energy Commission, the State's investor owned and municipal utilities, local government, private capital markets, and ARB have all contributed toward the health of the PEV infrastructure landscape. The following paragraphs will explore the contributions and investments by some of these key stakeholders.

[17] AFDC 2016, United States Department of Energy, Alternative Fuels Data Center, Accessed 09/29/2016, http://www.afdc.energy.gov/fuels/electricity.html

VII.B. Electric Utility Investment

Perhaps the greatest catalyst in the current PEV infrastructure landscape is with the introduction of private and public electric utilities in the PEV infrastructure market. In 2015 California enacted SB 350 which directs the CPUC to guide IOUs investments in the widespread transportation electrification including the deployment of charging infrastructure. This law is very significant for several reasons: it will allow IOUs to ultimately commence "phase 2" electrification programs if they are determined to meet specific requirements thereby potentially greatly expanding infrastructure for PEVs and other mobile sources in California. In addition, SB 350 defines how ratepayers benefit from transportation electrification (reduced emissions, reduced impacts to public health and the environment, increased use of alternative fuels, renewable energy integration, and economic benefits), and therefore can participate, through utility rates, in the funding of electrification programs.

Currently, three of the State's largest investor-owned electric utilities have proposed, or are in the process of, investing over $200 million in PEV infrastructure. These initial, pilot investments will result in over 12,500 connectors or "make readies" at over 1,000 sites, many in low income areas (10%). In addition, three IOUs have announced that if these pilot programs are successful, they plan to invest millions more in PEV infrastructure.

VII.C. Governmental Investment

The Energy Commission has invested nearly $50 million in PEV infrastructure and an additional $7.6 million in planning-related activities. Their coordinated planning, modeling, and investment activities have yielded the results shown in Table 3.

As detailed in Table 3 and displayed in Figure 6, the Energy Commission's current and proposed investment in DCFC infrastructure will result in over 320 DCFCs and more significantly, the ability to traverse the entire State north/south as well as east/west in a BEV with a 85 mile range. Although not quantified here, a number of regional and local governments have funded the installations of EVSEs (for example air districts).

Table 3 - Energy Commission Funded EV Charging Stations as of November 15, 2015

	Residential	Multiunit Dwelling	Commercial	Workplace*	Fleet	DC Fast Chargers	Total
Installed	3,937	247	1,903	233	97	65	6,482
Planned	-	48	924	133	34	256	1,395
Total	3,937	295	2,827	366	131	321	7,877

Source: California Energy Commission. Does not include projects that have yet to be approved at a Commission business meeting. *An unspecified number of additional workplace charging stations are included in the commercial column, which were funded before workplace chargers were tracked separately.

VII.D. Private Investment

In addition to government and electric utility funding, significant private capital has flowed into the PEV infrastructure market. Nationally, Charge Point, EVgo, and Tesla are three of the largest private companies operating in the infrastructure space. These firms have invested hundreds of millions of dollars in EV infrastructure, networks, and related systems. These *private* investments have yielded over 7,700 charging stations and 21,000 connectors nationally, including nearly 3,000 DCFC connectors. As such, it is a testament to the strength of the infrastructure market and an affirmation of market confidence.

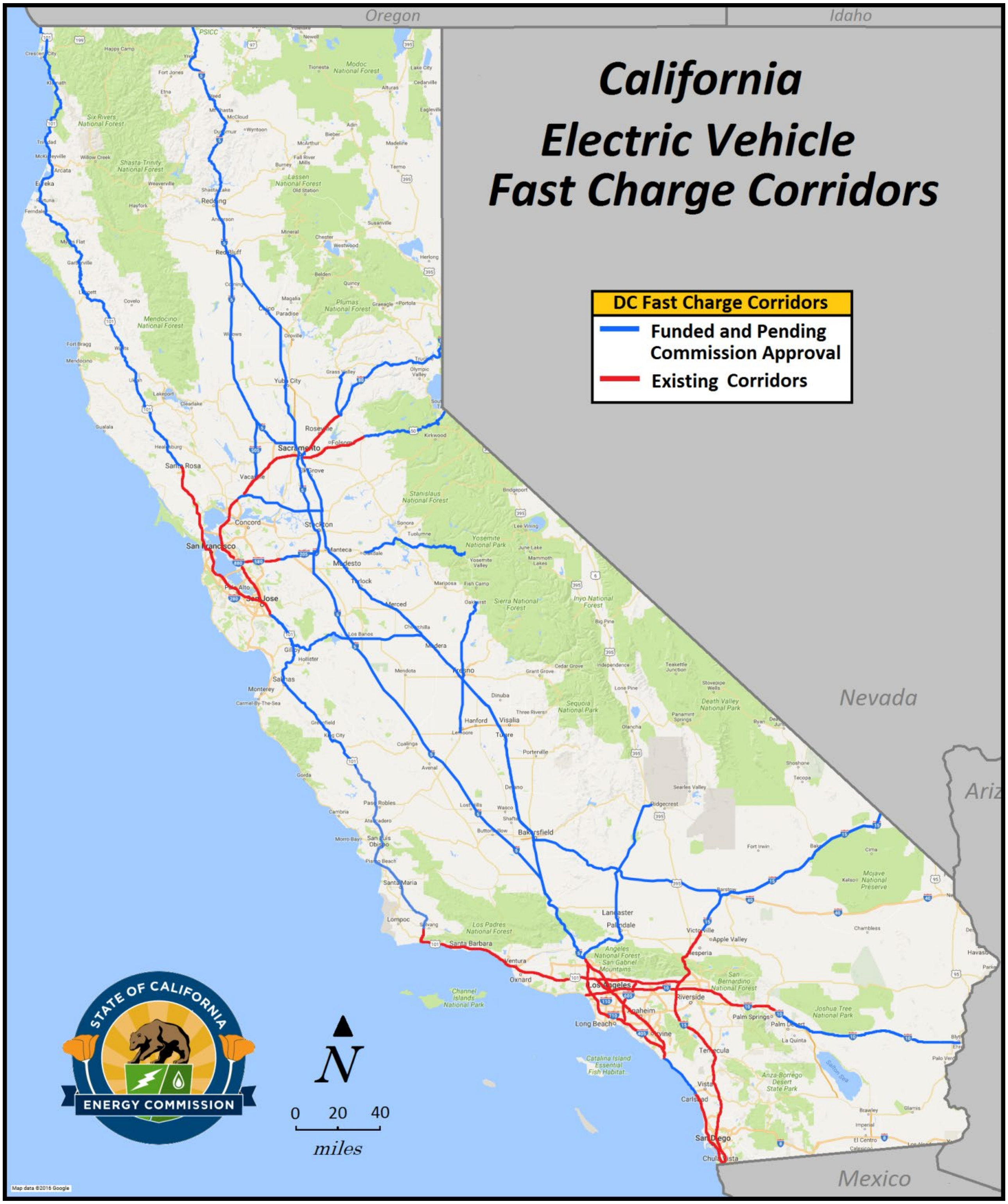
VII.E. Innovative Funding Opportunities

Recognizing the broad environmental benefits related to zero-emission vehicles and the need for additional resources to support the infrastructure for these vehicles, California is continually looking for innovative opportunities to direct new investments in PEV infrastructure.

One such opportunity arose in 2012 when the CPUC was negotiating a settlement with NRG Energy (NRG) over their involvement in the 2001 California electric power crisis. As a result of these negotiations, NRG agreed to install at least 200 DCFC stations across California including 20% in low income areas. In addition, NRG agreed to install infrastructure for "plug-in" Level 1 and Level 2 EVSEs. These "make readies" as they are commonly referred to, are being installed at MuDs, workplaces, and public interest sites.[18]

[18] CPUC 2012, California Public Utilities Commission, Press Release, April 27, 2012, http://docs.cpuc.ca.gov/word_pdf/NEWS_RELEASE/165145.pdf

Figure 6 - Existing and Planned Statewide DCFC Network Corridors (Funded by Energy Commission)

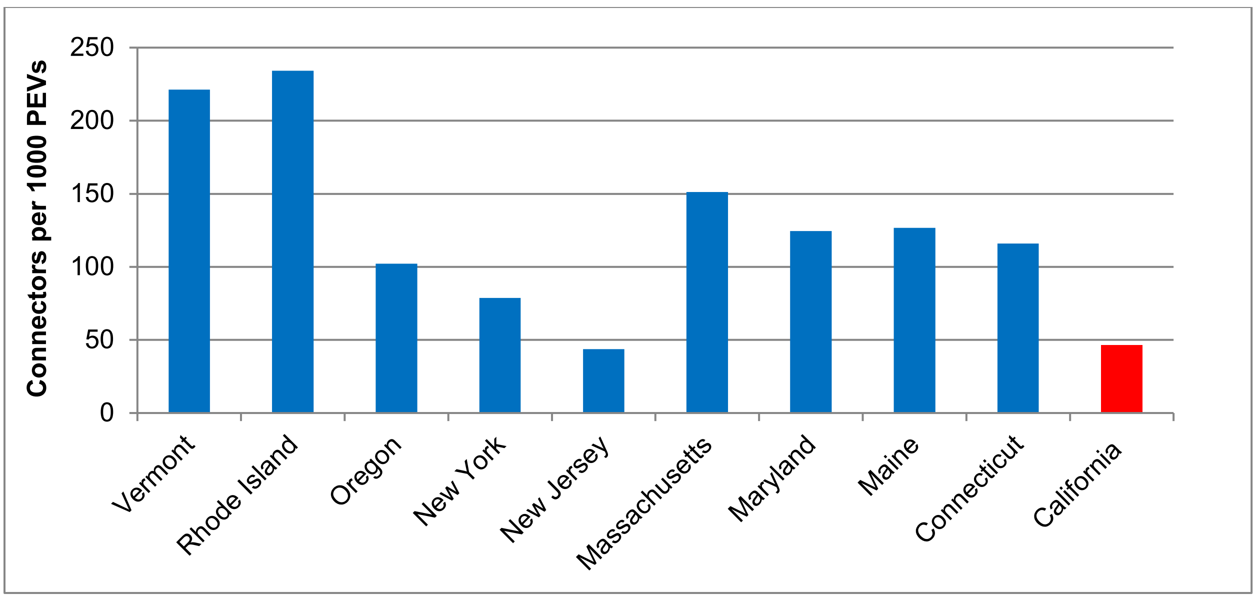


In addition, Volkswagen in the proposed consent decree for actions related to the use of a "defeat device" on many of their light-duty diesel vehicles in the U.S., has agreed to invest $800 million over 10 years in California, and $1.2 billion in the other 49 states, in PEV infrastructure, consumer education, green cities, and in increasing ZEV access for the advancement of zero-emission vehicles technology. It is likely this investment will greatly increase infrastructure and access to infrastructure across California.

VII.F. Status of the Network in the Section ZEV 177 States

Although California is the leader in PEV infrastructure, public infrastructure in Section 177 ZEV States is healthy. In the context of their respective PEV fleets, Section 177 ZEV States' infrastructure is more robust than California's. One metric of infrastructure access is the ratio of public and workplace connectors to the number of PEVs on the road. In California the ratio of connectors to 1,000 PEVs is approximately 46. In Rhode Island, there are 234 connectors per 1,000 PEVs. In eight out of the nine Section 177 ZEV states, the ratio is higher than California's. Only New Jersey, at 44 connectors per 1,000 PEVs, has a slightly lower ratio. Although this data does not determine if current infrastructure is "sufficient", it does imply there are other reasons why PEV sales are lower in Section 177 ZEV states compared to California.

Figure 7 - Ratio of Public and Workplace Connectors per 1,000 PEVs



VIII. PEV Infrastructure Needs for Forecasted Demand in CA

The topic of infrastructure sufficiency is important in answering questions related to infrastructure's role in supporting or impeding the projected expansion of the PEV market as envisioned in the ZEV regulation. Specifically, does ample charging infrastructure facilitate PEV adoption or does insufficient infrastructure hinder adoption?

A statistical link between charging infrastructures and sales may exist but studies in this area are limited. However one such study to address this topic was released in October 2016 by the

International Council on Clean Transportation (ICCT). They issued a white paper titled *Sustaining Electric Vehicle Market Growth in U.S. Cities*. In this paper ICCT finds a statistical correlation between charging infrastructure and PEV market growth and that expansive charging networks in northern California and elsewhere are linked with higher PEV sales.[19]

However, the larger question of what constitutes sufficient infrastructure remains. The issue of sufficiency is a particularly challenging question due to the evolving PEV/infrastructure landscape. Larger vehicle batteries with greater energy density, greater vehicle range, higher power charging, and an evolving PEV driver profile may make today's charging behavior, which formed the foundation for research on sufficiency, profoundly different by 2020 and 2025.

However, despite the evolving nature of PEV charging and associated uncertainty, the importance of the "sufficiency" question motivated the Energy Commission to contract with the National Renewable Energy Laboratory (NREL) to investigate this issue. In May 2014, the Energy Commission released the *California Statewide Plug-in Electric Vehicle Assessment*[20] which explored the issue of infrastructure sufficiency using scenario planning methods. A new analysis is forthcoming by NREL for the Energy Commission and is expected to be complete in 2017.

The 2014 NREL report estimated the number and type of EVSEs needed to meet the Governor's goals in Executive Order B-16-2012 (infrastructure to support 1 million ZEVs by 2020) by estimating the total annual power demand for 902,000 PEVs.[21] Using a set of equations solved simultaneously (Figure 8).

This report looked at two scenarios for charging; a "Home Dominant" scenario where the majority of charging occurs at home, and a "High Public Access" scenario where workplace and other public charging provide a greater percentage of the overall fleet charging requirements. It should be noted that even under the "High Public Access" scenario, the majority of charging events occur at home[22].

Scenario planning analysis is often used in emerging markets where there exists a high degree of uncertainty in the data and trends, as was the case with PEV infrastructure between 2010 and 2014. As scenario planning analysis continues to evolve, ARB is using the results of NREL's assessment to bracket a high and low range for sufficient PEV infrastructure. To calculate this range, ARB examined the number of "charge points" required under these two scenarios and divided by the number of PEVs they are intended to serve. A ratio of "charge points" to PEV was calculated, and this ratio can be used as a metric in evaluating our progress in meeting PEV infrastructure goals. The Table 5 details these ratios:

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[19] ICCT 2016. International Council on Clean Transportation, "Sustaining Electric Vehicle Market Growth in U.S. Cities", October 2016 http://www.theicct.org/leading-us-city-electric-vehicle-2016
[20] NREL 2014. National Renewable Energy Laboratory, "California Statewide Plug-In Electric Vehicle Infrastructure Assessment", May 2014 http://www.energy.ca.gov/2014publications/CEC-600-2014-003/CEC-600-2014-003.pdf
[21] PEV share of Governor Brown's ZEV infrastructure goal for 1 million ZEVS + PHEVs by 2020
[22] NREL 2014

Figure 8 - Equations to Calculate the Quantity of EVSEs Needed to Meet EO B-16-2012

The analytic approach involves calculating the number of EVSE stations through two equations, one being function of installed EVSE capacity and peak hourly demand (kW) and the other a function of electricity used by PEVs (kWh). These two equations are solved simultaneously to determine the total number of EVSE units.

$$N_{i,j} = \frac{Q_{total} \cdot f_{i,j}}{m_{event,i,j} \cdot \eta_j \cdot N_{Chgpts/Stn} \cdot N_{Chgs/Chgpt}}$$

where,

N_{ij} = Number of EVSE stations of type and location i providing electricity to PEV type j
Q_{total} = Total kWh of electricity required for all PEVs (kWh/day)
f_{ij} = Percent of total electricity provided by EVSE type i to PEV type j (percent)
$m_{event\,ij}$ = Average daily e-miles provided per charging event by EVSE type i to PEV type j
η_j = Electricity consumption rate by PEV type j (Wh per mile)
$N_{Chgpts/Stn}$ = Average number of charge points per EVSE station
$N_{Chgs/Chgpt}$ = Average number of charging events per charge point per day

$$N_{i,j} = \frac{Qtotal \cdot f_{i,j} \cdot d_{hr.peak,i} \cdot (1 + \beta_{i,j})}{C_i}$$

where,

N_{ij} = Number of EVSE stations of type and location type i providing electricity to PEV type j
Q_{total} = Total electricity provided to all PEVs (kWh/day)
f_{ij} = Percent of total electricity provided by EVSE type i to PEV type j (percent)
$d_{hr.peak\,i}$ = Percent of electricity provided during the peak hour of a typical day (% per hour)
β_{ij} = Capacity buffer for EVSE of type i providing electricity to PEV type j (percent)
C_i = Nominal installed capacity of EVSE type and location i (kW)

Table 4 - Connectors Modeled by Scenario to Reach EO Targets (from NREL's Statewide Assessment)[23]

	Number and Type of EVSE needed						
	HOME		WORKPLACE		PUBLIC		
Scenario/Charge Level	**Level 1**	**Level 2**	**Level 1**	**Level 2**	**Level 1**	**Level 2**	**DCFC**
Home Dominant Scenario	511,000	365,000	20,100	82,000	1,620	20,100	551
High Public Access Scenario	517,000	289,000	22,900	144,000	2,100	46,500	1,550

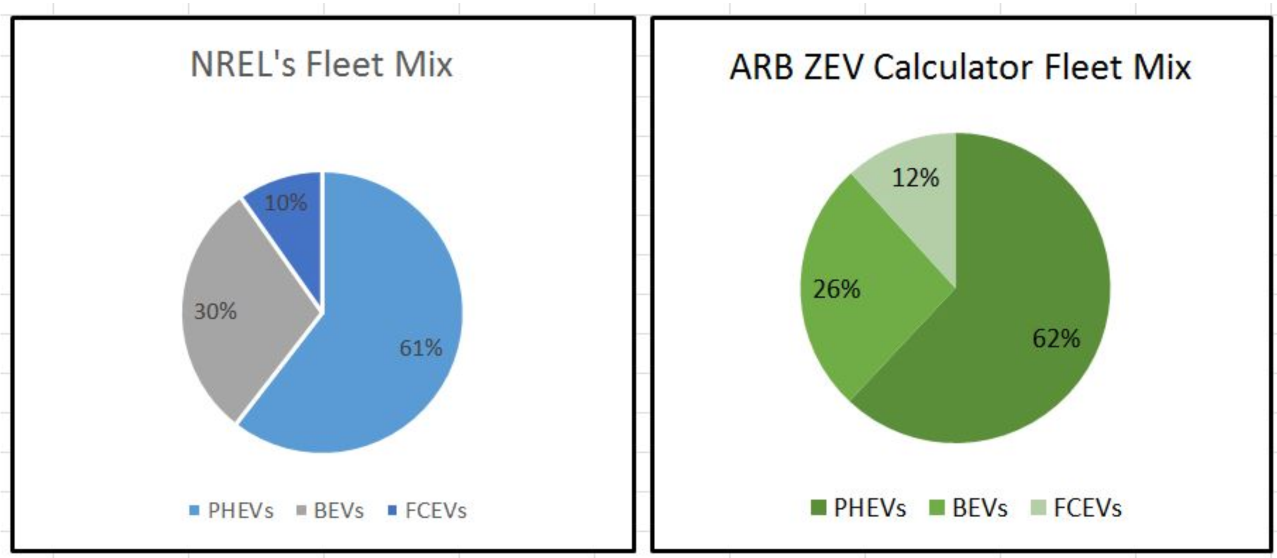
[23] NREL 2014

Table 5 - Ratio of Connectors per PEV by Scenario Type (combining all charging levels)

	HOME	WORKPLACE & PUBLIC
Home Dominant Scenario	0.971	0.1379
High Public Access Scenario	0.894	0.2406

The above ratios were derived from the total power demand calculated from equations in Figure 8. The total power demand is partially a function of the vehicle fleet mix (i.e., the more FCEVs in the fleet the less electric power demand and fewer EVSEs are needed). Therefore, a comparison of the NREL fleet mix to the ARB fleet mix is useful.

Figure 9 - NREL's Fleet Mix vs ARB's Mid-Range Input Scenario[24] (2020)



Using NREL's ratio of PEVs to connectors and the projected number of PEVs in ARB's "mid-range" compliance scenario, ARB calculated the annual and cumulative number of PEVs, along with the annual and cumulative number of connectors to support the projected PEV deployment. These calculations are plotted in Figure 10 and Figure 11.

[24] See Appendix A

Figure 10 - Cumulative Number of Workplace and Public Connectors Projected for the mid-range ZEV compliance scenario (through 2025)

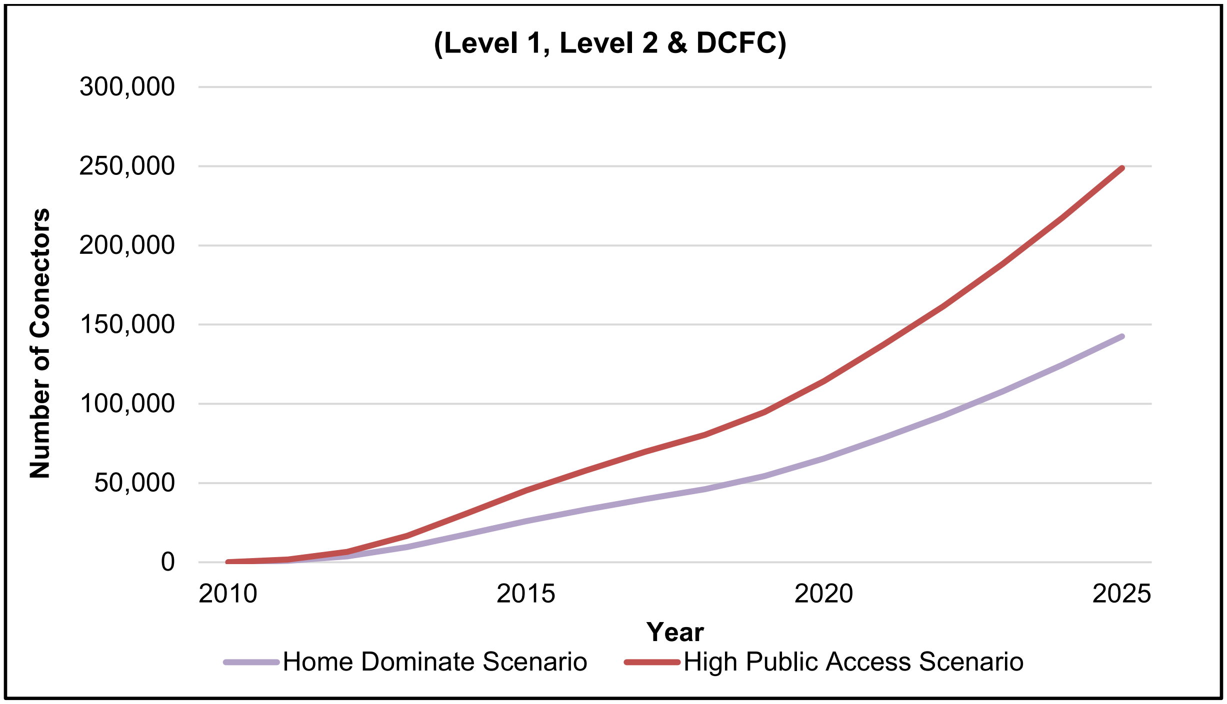
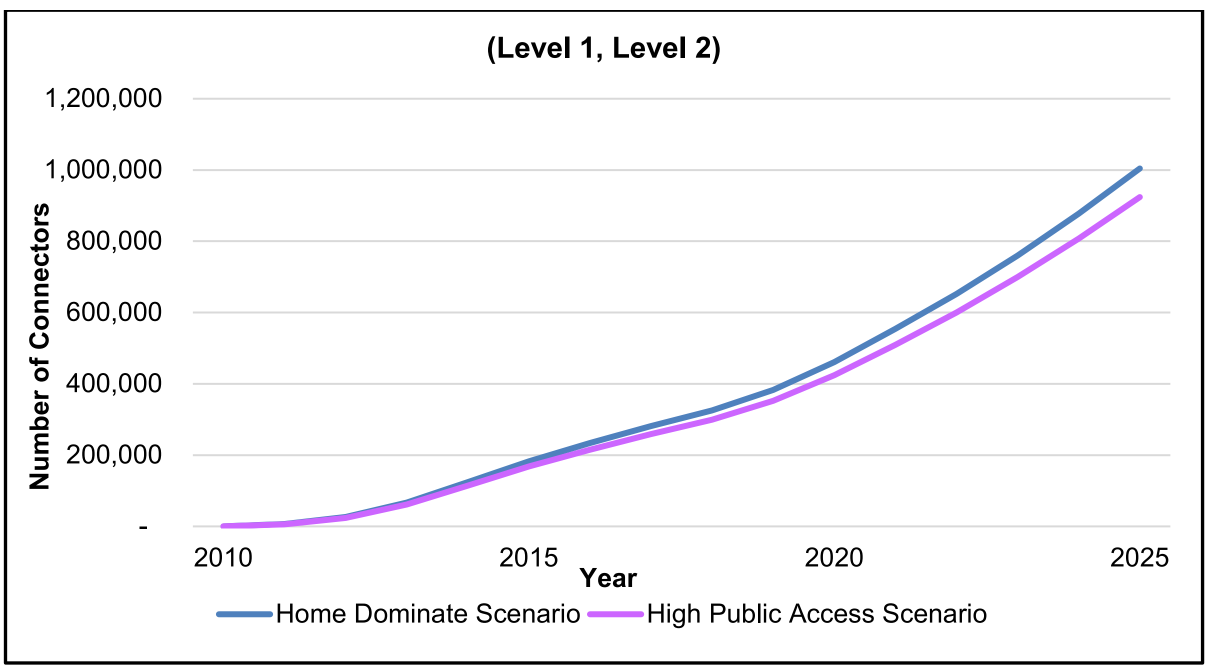


Figure 11 - Cumulative Number of Home Connectors Projected for the mid-range ZEV Compliance Scenario (through 2025)



IX. Public Infrastructure Needs - Where We Need to Be (2025)

Building upon the forecasted charger needs from Figure 10 and Figure 11 the following questions arise:

1) What scale of infrastructure deployment is needed to meet projected demand? And

2) How will current actions in infrastructure development address this demand?

The first question of needed infrastructure was answered in the above analysis and figures. This second question is explored below. To show a reference of PEV infrastructure by 2025 from current programs, staff examined historical infrastructure data growth rates and used this to extrapolate a forecast to 2025, the results of which are show in Table 6. As with any extrapolation, the conditions that influenced past trends need to be present moving forward or cease to be relevant. Table 7 expands upon this issue.

Table 6 - Projected Public and Private Connectors through 2025 vs NREL's Forecasted Requirements (Level 1, Level 2, and DCFC)

	2010	**2012**	**2014**	**2016**	**2018**	**2020**	**2022**	**2024**	**2025**
Current Connector Trends (extrapolated)	809	3,624	7,653	12,989	15,001	20,628	26,759	33,344	36,795
Projected new connectors from state programs	0	0	0	1,750	7,000	14,143	21,286	28,429	32,000
Projected Connector Total	**809**	**3,624**	**7,653**	**14,739**	**22,001**	**34,771**	**48,045**	**61,773**	**68,795**
Estimated Connectors Needed under 2014 NREL Home Dominant Scenario	29	3,705	17,619	33,196	46,146	65,494	92,574	124,606	142,582

As Table 6 details, California may not be track to meet the suggested sufficiency thresholds as detailed in NREL's Statewide Infrastructure Assessment.25 However, is should be noted that the NREL 2014 work in this area was an initial analysis and is being updated. Instead of using scenario planning methods, the updated analysis will develop a model that will use inputs such as actual travel data, expanded PEV driving range, and electricity rates that influence where drivers charge. This new approach should help answer the question of infrastructure sufficiency more fully. It is possible that this model will decrease the suggested number of connectors required to meet the charging needs of California's 2025 fleet. In addition, the introduction of

[25] NREL 2014

BEVs with ranges of 200 to 250 miles priced comparable to their gasoline counter parts are starting to arrive. These "long range" BEVs could significantly lessen the dependence upon public and private Level 1 and Level 2 chargers, thereby making the projected connector numbers more closely aligned with the NREL's projections.

Table 6 details a mathematical extrapolation of historic connector installation trends. As mentioned, for the extrapolation to hold, the factors that influenced the data being extrapolated needs to continue moving forward or cease to be relevant. The following Table 7 lists some of the conditions and complementary measures that influenced previous PEV infrastructure development and conditions that will be present in the future:

Table 7 - California's Infrastructure Programs and Complementary Policies - Past vs Future

	Past	**Mid/Long Term**
Government Investment in PEV Infrastructure	YES	YES
Utility Investment in PEV Infrastructure	EXISTING	INCREASING/ SB 350
Private Capital in PEV Infrastructure Market	EXISTING	INCREASING
Consumer Awareness of infrastructure Options	LOW	INCREASING
PEV Infrastructure Requirements in Building Codes and Standards	EXISTING	INCREASING
Open Access – SB 454	NO	YES
EVSE Costs	Declining	Continued Decline
DCFC Charging Power	50kW	150 kW or higher

X. Home Charging Infrastructure Needs - Where We Need to Be (2025)

With regards to home charging infrastructure, Figure 11 depicts a significant number of connectors needed to accommodate a large scale PEV expansion. Due to a lack of reliable data on home charging infrastructure it is difficult to use NREL's ratios and extrapolate current home charging trends to quantify potential gaps, if any, in projected home charging infrastructure. However, as noted earlier, between 80% – 85% of all charging occurs at home; in fact NREL's infrastructure assessment used high access to home charging as a basis in both their scenarios. Therefore, it is reasonable to conclude that the majority of current PEV drivers have access to, or the ability to install, home charging infrastructure.

However, because the goal is to expand the number of potential PEV drivers, then targeted efforts to increase home charging infrastructure in non-traditional, single family housing will be needed. Approximately 50% of the State's population lives in rental housing and a large percentage of the population lives in MuDs. Charging infrastructure in rental housing and MuDs presents unique challenges and may result in the need for more public charging infrastructure or dedicated resources to resolve these challenges.

XI. Challenges and Opportunities with PEV Infrastructure

The PEV infrastructure environment, in its current state, has been in development and refinement for nearly a decade, and many of the initial challenges have been met: technical standards, communication protocols, signage and design guidelines have all been adopted. As a result of meeting these initial challenges, consumer acceptance, private capital investments, and electric utility involvement have followed. However, challenges and opportunities surrounding PEV infrastructure exist and the following paragraphs detail some of the more prominent issues.

XI.A. Challenge - Multi-unit Dwelling (MuD)

Electric utilities estimate that over 80 percent of all current PEV charging occurs at home, usually in a garage with access to electrical power. However, nationwide, approximately 36 percent of households reside in rental housing with 60 percent of those households living in MuDs. Most MuDs do not provide EVSE or access to electrical power in proximity to parking and access to charging in MuDs is important. Specific challenges include:

- Physical Facilities: Age, existing electrical infrastructure, and physical layout of parking within a MuD all present unique challenges in installing and operating PEV infrastructure.
- Diversity: MuDs are comprised of a variety of structures from modern, urban high-rise buildings to sprawling, midrise suburban apartment complexes to low-density townhome condominiums. Given this physical diversity, there is no universal solution or standardized cost for providing EVSE access in MuDs.
- Economics: Costs associated with installing, maintaining, and operating EVSE needs to be accounted for; however, equitable distribution of these costs among building occupants, PEV drivers, and the building owner remains a challenge.

XI.B. Challenge - Increasing Battery Capacity Impact on Infrastructure Needs

As explained in greater detail in Appendix C, vehicle battery costs are declining while energy density is increasing. Currently, most BEVs sold today have a range under 100 miles; the most common BEV on the road today, the Nissan Leaf, has a range of 84-107 miles depending upon the model year. Tesla vehicles are the primary exception, offering a range in excess of 200 miles but at a much higher price. However, General Motors has recently introduced the Bolt

EV, a BEV with a 238 mile EPA estimated range and a MSRP of $37,495 before incentives.[26] The Bolt EV is currently available at GM dealers in California. Tesla has commenced orders on the Model 3, a BEV with an estimated 215 miles of range and a starting price of $35,000 before incentives.[27] These developments hold the potential to alter the need for, and use of, public charging infrastructure in ways unknown. For example, larger battery packs will take longer to charge which may increase the demand for DC fast charging and decrease the demand for Level 1 and Level 2 public charging. However, it is also likely that longer range PEVs will charge less often which may also impact public charging infrastructure. These uncertainties require on-going analysis of the PEV market and charging behavior.

XI.C. Challenge and Opportunity – Inductive Charging

As detailed more fully in Appendix C, current PEV charging standards and protocols involve connected, conductive charging. PEV batteries are charged by physically attaching the vehicle to a power source via the EVSE. Currently, this physical connection is essential to almost all PEV charging.

However, some automakers, third party vendors, and charging providers have begun to develop wireless, inductive charging. Inductive charging uses an electromagnetic field to transfer energy between the vehicle and the power source where no physical connection is required. Although challenges with safety and efficiently still remain, INL is studying inductive charging and it appears that these challenges will be addressed and inductive charging will enter the market place well before 2025.

XI.D. Opportunity – Electric Utility Involvement in PEV Infrastructure

In addition to the electric utility investment as detailed above under SB 350, other state power companies and authorities are entering the PEV infrastructure sector. The New York Power Authority (NYPA) and others are collaborating in an initiative called ChargeNY which aims to reach 3,000 PEV charging stations to support an expected 30,000-40,000 PEVs on the road in New York by 2018.

The State of Oregon has introduced SB 1547 (Beyer), which allows their PUC to direct electric companies to file applications for programs to accelerate transportation electrification, including customer rebates for PEV charging and related infrastructure.

XI.E. Opportunity – Vehicle Grid Integration

PEVs store a large amount of energy in their on-board batteries. Current EVSE and charging specifications and protocols are intended to facilitate the one-way power transfer from the electrical grid to the vehicle. However, new protocols and standards are being developed and tested to facilitate the two-way transfer of energy from the vehicle back to the grid; this is referred to as vehicle grid Integration (VGI). VGI holds the potential to assist electric utilities in meeting their peak power demands by tapping a new source of power storage − a large PEV

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[26] GM 2016, General Motors, 2017 Bolt EV, http://www.chevrolet.com/bolt-ev-electric-vehicle.html accessed September 22, 2016
[27] Tesla 2016. Tesla Motors, Tesla Model 3, https://www.tesla.com/model3, accessed September 22, 2016

fleet. Many programs across the nation are in place to study VGI including programs in California, Delaware, and at the U.S. Department of Defense. The Energy Commission, in coordination with the CalISO developed a Vehicle Grid Integration Roadmap[28] in 2014 to outline a way to develop solutions that enable PEVs to provide grid services while still meeting consumer driving needs. CalISO and PUC have on-going policy actions to put this in place and tests are occurring, but implementation will take a number of years.

Pilot projects exist to experiment with the operational concepts. On the east coast, Delaware has been a long-standing leader in VGI research and grid service pilot experimentation. The U.S. Department of Defense (DOD) has become a leader in VGI pilot studies with a prominent project at the LA Air Force Base.[29,30] This project, in partnership with CalISO, Energy Commission and the Southern California Energy (SCE) utility, is experimenting with a fleet of light-duty and medium-duty BEVs providing grid services while not being used. Grid pricing and long-term cost effectiveness are being evaluated. This typically involves studying the benefit to the grid (with payments to the vehicle owner) while also studying the impact on the vehicle battery's life.

XI.F. Opportunity – Utility Demand Response and Time of Use Rates (TOU)

In broad terms, electrical power on the grid comes from central electric generation facilities. This electricity is owned or purchased by an electric utility and resold to its customers. Although most utility bills make the cost of electricity appear relatively uniform, the actual cost to procure electricity from a generator can vary greatly. Prices can spike (or fall) quickly and with little notice. Factors that affect the price of electrical power include temperature, weather, time of day, demand for power, availability of operational power plants, and many others.

Currently PEVs charge when they are parked, and most vehicles, including PEVs, are parked 96 percent of the time. Therefore, a PEV doesn't need to be charging at all times when it is parked. This fact, coupled with emerging technologies that allows an electric utility to communicate with advanced EVSEs and control the power transfer, provides utilities a unique opportunity. Utilities could effectively manage PEV power demands in the broader context of regional grid operation, power generation and supply, local transformer capacity, and price fluctuations. The next generation of networked EVSEs provides a valuable opportunity for utilities to operate more efficiently and effectively.

In addition to hardware and emerging technology to control when PEVs charge, thereby striving to optimally balance load and supply, electric utilities (including eight utilities in California and three in Section 177 ZEV states) have introduced TOU electric rates. Simply put, TOU rates set higher and lower electric tariffs based upon predetermined times of the day. Historically speaking, electricity demand is cyclical and relatively predictable. Therefore, an electric utility can predetermine when demand will be high and set rates to discourage use during those

[28] CAISO, 2014. California Independent System Operator. "Vehicle Grid Integration Roadmap" February 2014. http://www.caiso.com/documents/vehicle-gridintegrationroadmap.pdf
[29] DOD 2013. Department of Defense. "DoD Plug-In Electric Vehicle Program" March 2013. http://electricvehicle.ieee.org/files/2013/03/DoD-Plug-In-Electric-Vehicle-Program.pdf
[30] LBNL 2013. Ernest Orlando Lawrence Berkeley National Laboratory "Los Angeles Air Force Base Vehicle to Grid Pilot Project" June 3-8, 2013. https://drrc.lbl.gov/sites/all/files/lbnl-6154e.pdf

periods. As mentioned, PEVs are typically parked longer than they need to fully charge, therefore customers can choose to charge their vehicles when TOU rates are low, thereby saving money and helping to smooth out peak electrical demand.

Using simple market mechanisms that TOU rates provide, electric utilities can more effectively balance load and supply. Although TOU rates may not be for all consumers, they do provide an option for PEV drivers that can use the rate structure effectively. INL has studied the effect of TOU pricing has on power demand and has concluded that electric utilities, without TOU rates, can expect a median peak demand of 0.8 kW per day from each PEV in the service territory and this peak occurred at approximately 10 p.m. In contrast, electric utilities that offered TOU rates, can expect a median peak demand of 1.7 kW per day from each PEVs in the service territory. In the INL study this peak occurred within an hour of the start of the greatest incentive period.[31]

XI.G. Opportunity FAST Act - Nationwide Alternative Fuel Corridors

In December 2015, President Obama signed The Fixing America's Surface Transportation (FAST) Act. This bill not only authorized funding for traditional surface transportation projects, but section 1413 of the bill requires the U.S. Department of Transportation (U.S DOT) to designate corridors to improve mobility of passenger and commercial vehicles that employ electric, hydrogen fuel cell, propane, and natural gas fueling technologies across the U.S. by December 2016. Although the bill does not provide direct funding for alternative fuel infrastructure, the U.S. DOT can support these corridors through technical assistance, analytical support, peer review, marketing and branding. In addition, this bill amended the Congestion Mitigation and Air Quality Improvement (CMAQ) Program to give priority to designated EV and compressed natural gas corridors. This bill facilitates the planning activities required in the construction and implementation of nationwide PEV corridors.

XI.H. Challenge and Opportunity - PEV Charging Impact on the Grid and Related Emissions

As transportation becomes electrified, the energy supply will partially move from refineries to the electric grid. This means electricity demand will grow and electric utilities will need to plan for the new loads, both in terms of production supply and local distribution of power. Although the transportation electricity demand will remain small for a number of years, utilities, regulators and research entities are already managing this. Most prominently in the U.S., EPRI has led many programs to evaluate the growing impact.[32] In California, the CPUC, ISO, and Energy Commission also are very active in this space.

In general, peak load demand will not be a problem for a few years as vehicle loads are still small, but will become more prominent post 2020. In California's utility territories, with the growth of solar generation, daily grid generation profiles have peaks in the early afternoon when solar is high; but have problems in early evenings as homeowners return home turning everything on as solar production is declining. If PEVs are also plugged in at this time (early

[31] INL 2015, Idaho National Laboratory, "Characterize the Demand and Energy Characteristics of Residential Electric Vehicle Supply Equipment", June 2015 https://avt.inl.gov/sites/default/files/pdf/EVProj/CharacterizeEnergyDemandResidentialEVSE.pdf

[32] EPRI, 2015. Electric Power Research Institute. Environment. http://et.epri.com/ResearchAreas_Environment.html

evening), it will amplify the grid management problem. Time-of-day grid pricing will help mitigate this and encourage charging late at night (or in the late morning at work). The CPUC and CalISO are actively exploring these pricing mechanisms.

DCFC is a more near-term issue with high power spikes on the grid currently at 50kW. The higher power levels being explored, 150kW and 350kW noted earlier, may create a strain on local grid distribution equipment, and may necessitate a dedicated power supply to the properties for the charging stations. On-site battery storage can also help mitigate the voltage spikes on the grid distribution equipment, but adds equipment costs. Storage costs may be worth the investment depending on electric load demand charges from grid providers.

With regards to the national grid emission impacts from transportation electrification, in September 2015 EPR) and National Resources Defense Council (NRDC) published the *Environmental Assessment of a full Electric Transportation Portfolio* to examine these impacts. The study authors examined two scenarios of the 2050 electric sector, a *Base GHG scenario* and a *Lower GHG scenario*. Both scenarios demonstrated lower grid emission by 2050, however the *Lower GHG scenario* showed greater reductions due to an increasing carbon price resulting in faster deployment of lower carbon electrical power generation technology.[33] The study examined both GHG and criteria emission impacts.

XII. Summary of Hydrogen Infrastructure Status and Projections in California

California has been the focal point of fuel cell electric vehicle (FCEV) deployment in the U.S. and the related development of hydrogen fueling infrastructure. While early efforts grappled with the difficulties of establishing two nascent industries that are mutually dependent on one another (success of the FCEV market fundamentally depends on success of the hydrogen fueling network, and vice-versa), California's current programs (most prominently Assembly Bill 8) are enabling growth of the first major FCEV and hydrogen fueling markets in the U.S. Major policy and technical hurdles have been overcome in recent decades thanks to the coordinated efforts of the State and industry partners.

The substantial progress made to date is helping address the issues of launching new technology markets, but stakeholders are also keenly aware of new challenges that will need to be addressed in order to move the industries into mainstream mass-market appeal. Managing and accelerating hydrogen fueling network growth, addressing economic hurdles of the hydrogen fueling business, and ensuring continual advancements in the retail customer experience are all at the forefront of today's efforts. Major success and challenges within today's industry are as follows:

- 30 stations (retail and non-retail) are now open in California's hydrogen fueling network, which is more than double the amount available at the end of 2015.

[33] EPRI/NRDC 2015, Electric Power Research Institute and National Resources Defense Council, Environmental Assessment of a full Electric Transportation Portfolio, Sept 2015, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=3002006881

Stations with full retail capability and amenities are now the standard in California and expected to comprise fueling networks in new markets across the United States.

- Station development timelines are improving, and benefitting from lessons learned during the process of contracting, permitting, constructing, and commissioning the earliest retail stations. Bets practices based on these experiences are incorporated into the latest Energy Commission grant solicitation and may offer a blueprint for future development in Section 177 ZEV states.

- Use of the HyStEP device to validate new stations' adherence to standardized fuel protocols has begun. Implementation of the device is alleviating burden previously placed on auto manufacturers to test and validate new stations.

- Fueling demand at hydrogen stations is rapidly growing. Developer FirstElement Fuel, who operates 16 stations currently, has shared that they fueled 1 million miles of FCEV travel in their first 9 months of operation. They anticipate reaching the second million only 60 days later and a total of 3.5-4 million by the end of 2016.

- Auto manufacturer projections of FCEV deployments indicate 43,600 FCEVs may be on California's roads by 2022.

- Projected demand for hydrogen fuel is expected to exceed the capacity of the State-funded network of hydrogen fueling stations around 2020. As a result, stakeholders are devoting significant efforts to engage more private funds in the build-out of California's hydrogen fueling network.

- Expansion of the hydrogen fueling network beyond the 100 station benchmark set in AB 8 is expected to particularly require increased participation of private funds, greater nameplate fueling capacity, and development of more cost-effective stations, with greater capacity for fuel dispensing per dollar invested.

- Hydrogen prices at the pump are forecast to decline over the next decade to approximately $11/kilogram (kg). At this price, hydrogen may be cost-competitive with gasoline.

- Station equipment technology and stakeholder diversity (including fuel providers, equipment providers, and station owners/operators) are growing.

- Renewable hydrogen content in the funded fueling network is expected to exceed Senate Bill 1505 requirements, at approximately 45%.

Further discussion of these major findings and other aspects of the developing hydrogen fueling network are discussed through the body of this Appendix.

XIII. Current Status of Hydrogen Infrastructure and Current and Projected Needs of California's FCEV Market

XIII.A. Current development status of California's hydrogen fueling network

California's hydrogen fueling network currently contains 50 stations that are either operating or received a grant award for development and are currently in some phase of development (one station at Fountain Valley decommissioned at the end of 2016).

Figure 12 provides an overview of the status of development across the fueling network[34]. The following list provides an overview of the station status terminology utilized in the figure. The definitions are common terminology used by the State (led by the consensus-building efforts of the Governor's Office of Business and Economic Development [GO-Biz]) and stakeholders in the FCEV and hydrogen fueling infrastructure industries to assure consistent communication of individual station development progress.

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.

Open-Retail stations are defined by:

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

The remainder of the status definitions are as follows:

[34] Energy Commission 2016a. California Energy Commission. Draft Joint Agency Staff Report on Assembly Bill 8: 2016 Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California. January 2017.

Fully Constructed: Construction is complete and station developer has notified the appropriate 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.

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

Figure 12 - Station Status as of December 5, 2016 (Source: Energy Commission and GO-Biz)

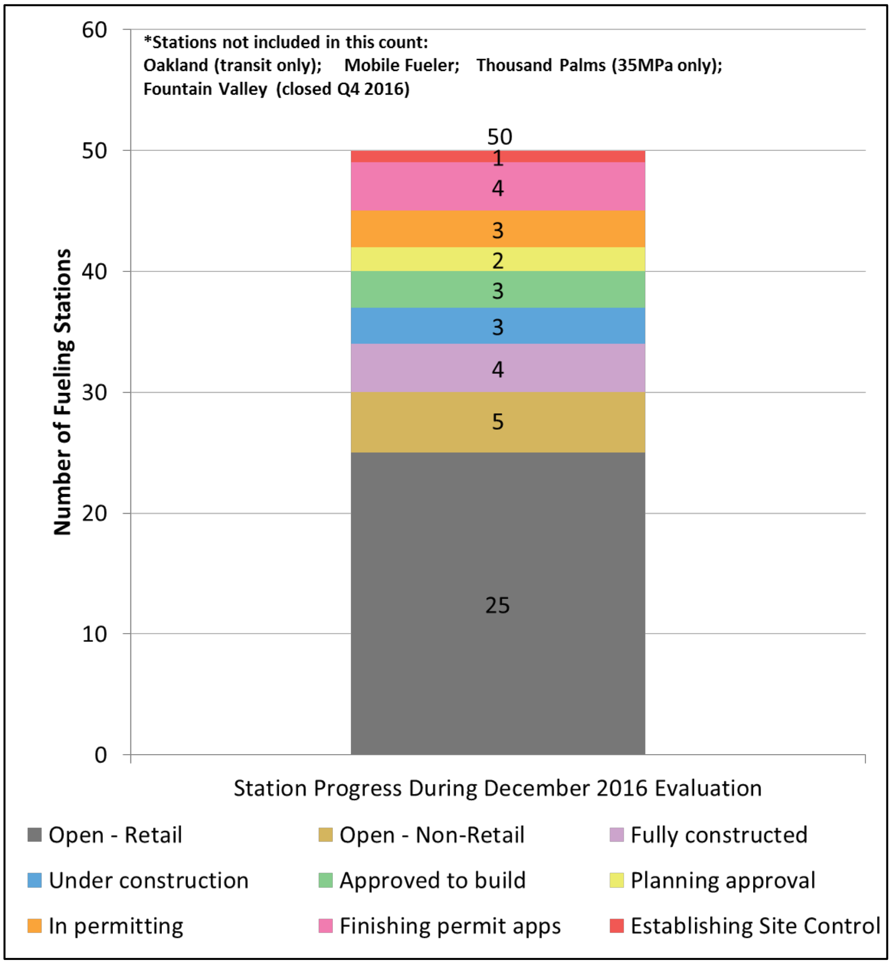
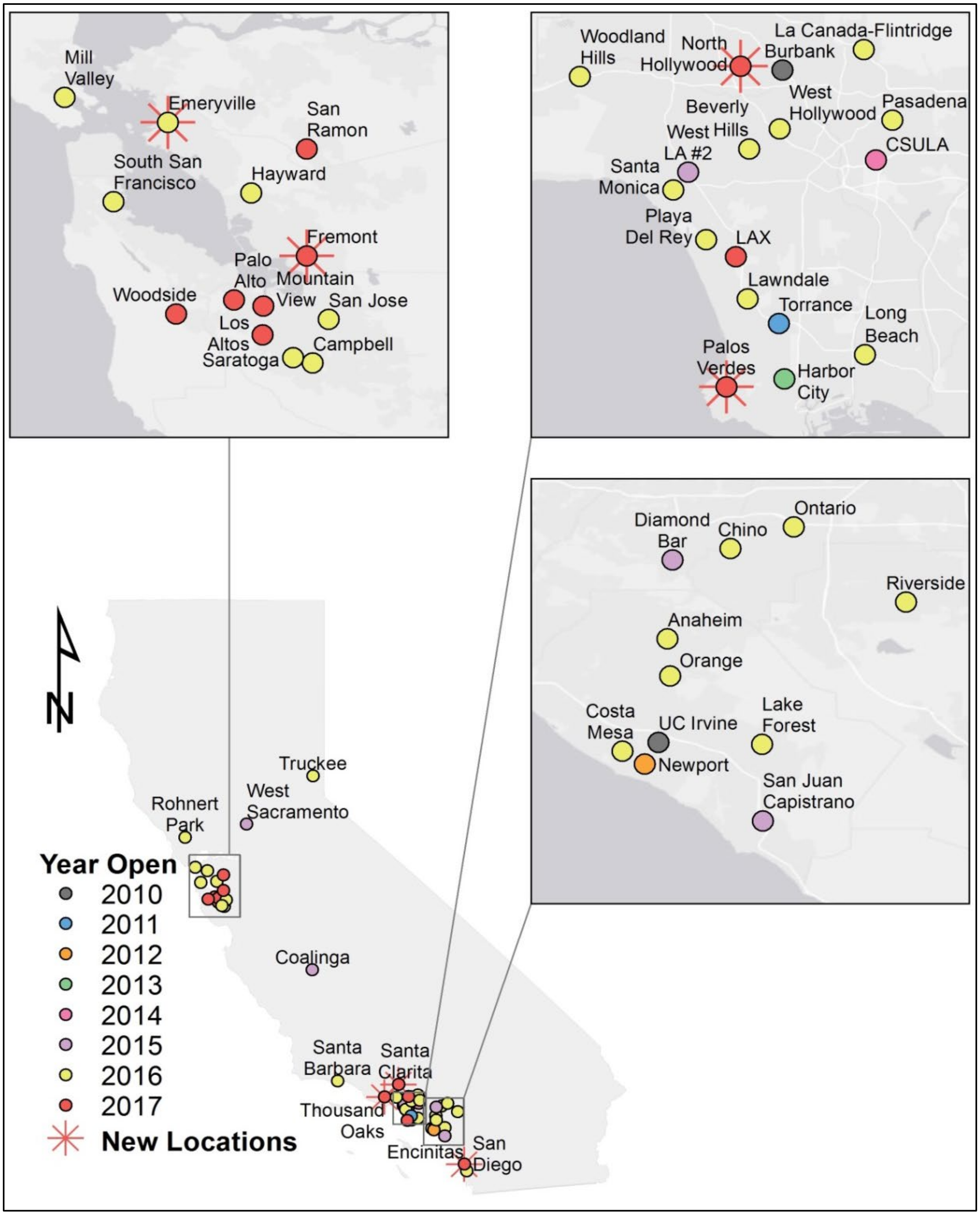


Figure 13 – Historical and Projected Schedule of Hydrogen Fueling Station Openings[35]



As Figure 12 shows, as of December 5th, there were 30 hydrogen fueling stations open across the state, with 25 of those providing a fully retail experience to FCEV drivers.[36] Drivers that visit Open – Retail stations can expect to be able to simply drive up to the dispenser, pay with their preferred payment method, and receive a full fill within five minutes; all of this should be able to be accomplished regularly and reliably at an Open – Retail station. ARB's expected schedule for achieving Open – Retail status for the remaining stations, as of June 2016, is shown in Figure 13. As of the June 2016, all remaining stations were expected to be completed by 2017.[37] In addition, the Energy Commission's Grant Funding Opportunity (GFO-15-605) is expected to add at least 16 State co-funded stations to the network.[38] Contracts are expected to be signed in early 2017 and stations funded under that solicitation may begin opening as soon as 2018.[39]

XIII.B. Current and projected FCEV deployments

In the most recent Annual Evaluation and Joint Agency Staff Report, ARB updated its count of FCEVs currently on California's roads and projections for future FCEV deployments, shown in Figure 14. Based on California Department of Motor Vehicle records in October 2016, 925 FCEVs were registered in the state. This was lower than the end-of-year projection for 2016 previously made. Additionally, in June 2016 ARB projected 13,500 FCEVs on the road by 2019 and 43,600 by 2022.[40] Each year, ARB reports then-current FCEV registrations and deployment projections based on annually updated auto manufacturer surveys. In 2016, ARB also provided a comparison of the latest deployment schedule projections and those from prior Annual Evaluations. While short-term deployment plans were found to be delayed by one year, the projections for 2020 and beyond were actually greater than previously reported. ARB reported that this near-term delay is likely a reaction to hydrogen fueling station development that has also been delayed by one year from previous expectations.

Although the pace of deployment has been slower than previously projected, there has still been significant growth. Since the ARB's June 2016 report, media reports indicate that Toyota has released a further 371 vehicles in August alone, largely due to an employee incentive program initiated at the time.[41] On a similar note, at the 2016 Advanced Clean Car Symposium organized by ARB and hosted by the South Coast Air Quality Management District, CEO and Co-Founder of FirstElement Fuel Joel Ewanick noted accelerating throughput in his company's network of stations. Across their now 15 stations, Mr. Ewanick stated that 9 months elapsed before their network fueled 1 million miles of FCEV travel. The second million miles' worth of fuel will be dispensed only 60 days after the first million (sometime in late September or early October) and by the end of 2016, the company estimates 3.5-4 million miles will have been fueled by their network alone. Mr. Ewanick went on to note that two stations (which have opened in the past

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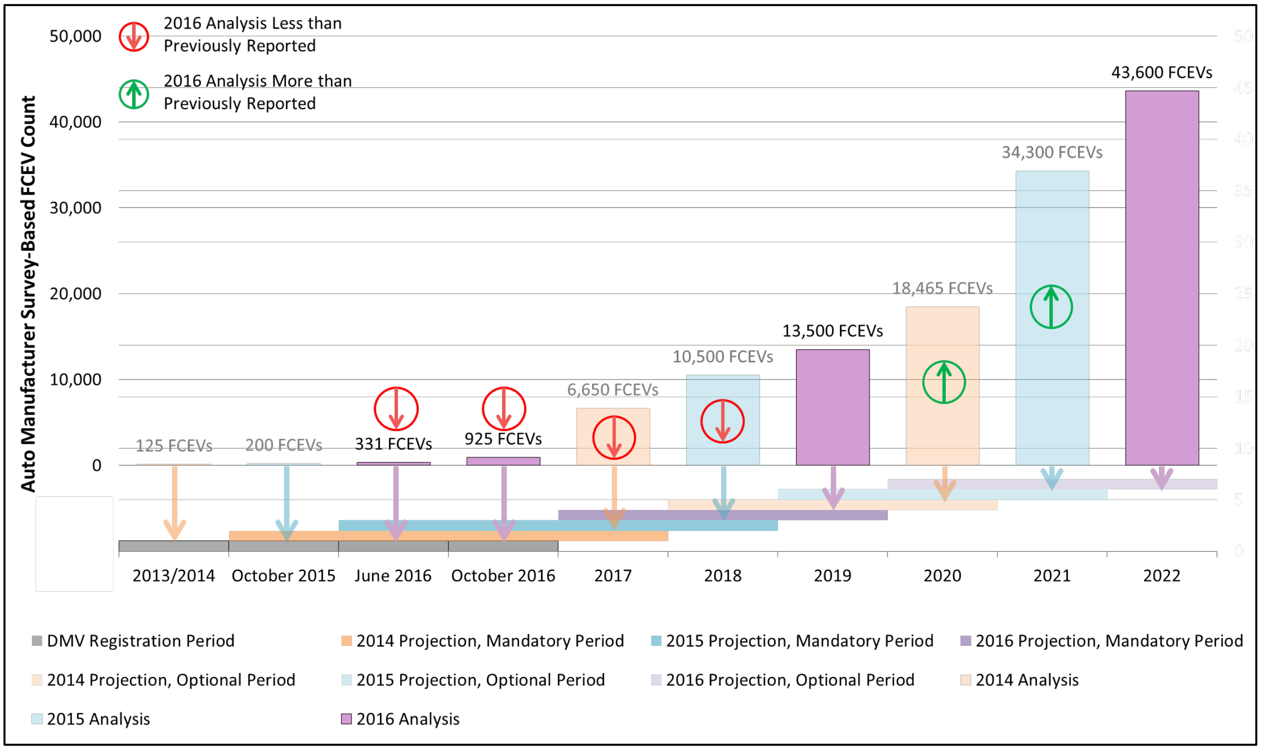
[35] ARB 2016a. California Air Resources Board. 2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. July 2016. https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf.
[36] Energy Commission 2016a
[37] ARB 2016a
[38] Energy Commission 2016b. California Energy Commission. Grant Funding Opportunity Alternative and Renewable Fuel and Vehicle Technology Program Light-Duty Hydrogen Refueling Infrastructure Application Manual. July 2016.
[39] ARB 2016a
[40] Ibid.
[41] Green Car 2016. Green Car Reports. Price cut and monthly sales spike for Toyota Mirai fuel-cell sedan. September 2016. http://www.greencarreports.com/news/1106296_price-cut-and-monthly-sales-spike-for-toyota-mirai-fuel-cell-sedan. Accessed September 26, 2016.

year) have completely run out of fuel. Their company previously expected the 180 kg/day dispensing capacity designed for their stations to be sufficient for years to come; they have now realized that much larger stations will need to be built into their network sooner in order to meet accelerating demand.[42]

Figure 14 - ARB's 2016 Reported FCEV Registrations and Projections for Future Deployment[43]

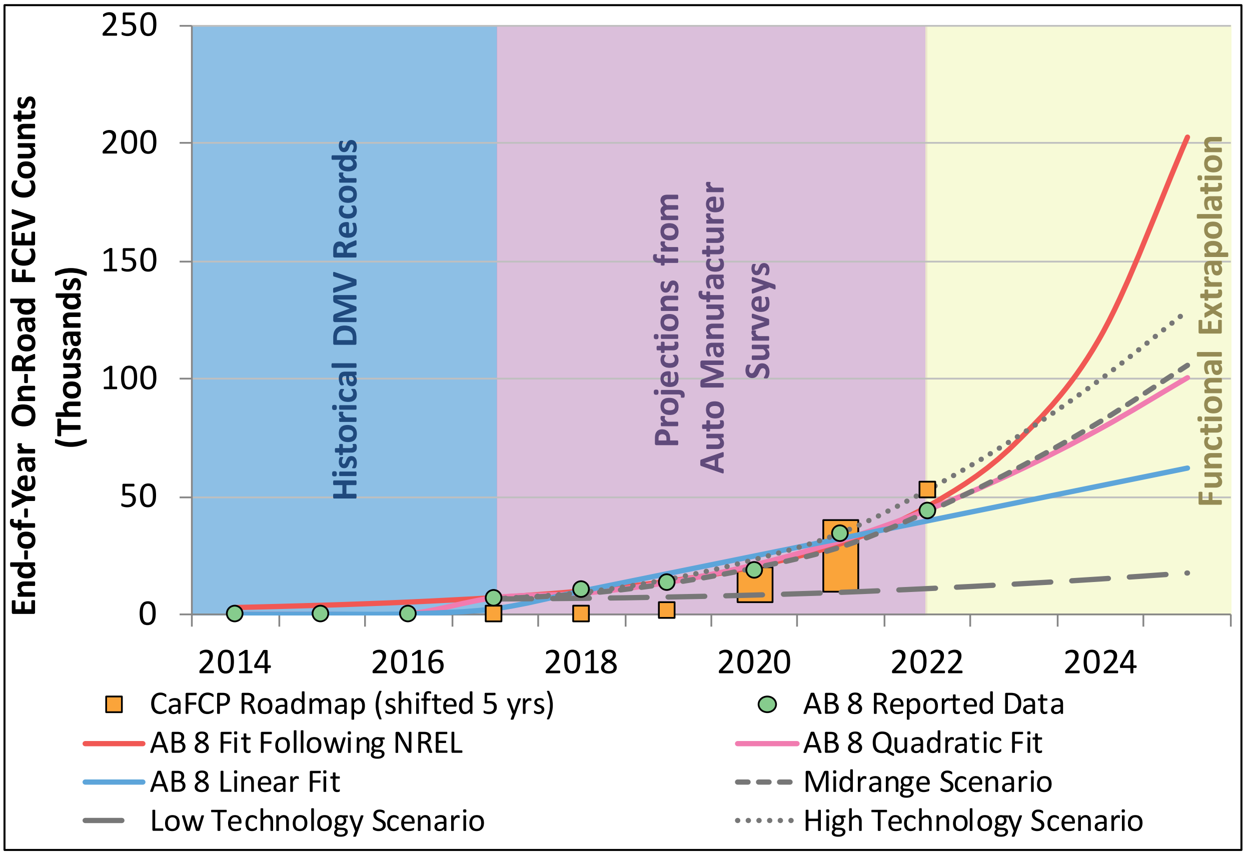


Although the June Annual Evaluations report auto manufacturer-based projections of FCEVs only to 2022, there are other sources available for projecting FCEV deployments further in the future. One resource is the 2015 December Joint Agency Staff Report, prepared by the Energy Commission and ARB.[44] For the Staff Report, NREL prepared an analysis of FCEV market growth and fueling needs that extended to 2025. The "Expected" market growth was modeled after an argument made in the 2015 Annual Evaluation,[45] which pointed out that early FCEV deployment plans seemed to follow a power-law growth curve. That is, the more FCEVs expected on the road, the greater the expected acceleration in further deployment rates. This

[42] Ewanick 2016. Ewanick, Joel, First Element. "Status of the World's First Retail Hydrogen Network and What's Ahead." Advanced Clean Cars Symposium: The Road Ahead. 27 September 2016. South Coast Air Quality Management District. Diamond Bar, CA. https://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/moving_toward_network_expansion_joel_ewanick.pdf
[43] Energy Commission 2016a
[44] Energy Commission 2015
[45] ARB 2015a

may be a reasonable deployment path, especially considering the interaction between FCEV and hydrogen fueling markets. As more FCEVs are released, further infrastructure development can be justified (due to improving throughput and business cases at individual stations), which in turn justifies increased FCEV deployment rates. However, acceleration after many years overestimates vehicle deployment expectations in this type of model; extrapolation is only reasonable for a handful of years.

Figure 15 - Potential Trajectories of FCEV Deployment in California Beyond 2022 Horizon of Latest Auto Manufacturer Survey[46,47,48,49]



46 ARB 2016a

47 Energy Commission 2015. California Energy Commission. Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California. December 2015. http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf

48 A complete explanation of staff's updated ZEV Calculator can be found in Appendix A of this report, and is posted at the following link: https://arb.ca.gov/msprog/zevprog/zevcalculator/zevcalculator.htm

49 CaFCP 2012. California Fuel Cell Partnership. A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles (Technical Version). June 2012. http://cafcp.org/sites/default/files/A%20California%20Road%20Map%20June%202012%20%28CaFCP%20technical%20version%29.pdf

In addition, as provided in the 2016 ZEV Scenario Compliance Calculator, ARB's analysis of ZEV regulation compliance scenarios provides Midrange, Low Technology, and High Technology estimates of FCEV deployment rates out to 2025.[50] All of these potential deployment trajectories are presented in Figure 15, along with the data provided in auto manufacturer surveys. Also included in the figure are linear and quadratic trajectories fit to the auto manufacturer survey data for 2017 to 2022. For all years 2017 to 2022, the data reported in the survey are consistently between the Midrange and High Technology scenarios. Additionally, extrapolating the survey data out to 2022 according to a quadratic nearly identically follows the ZEV Midrange compliance case. A quadratic fit does indicate a time-dependent acceleration in deployment, though the acceleration is not based on the on-the-road count at any moment in time.

At the high-volume extreme is the model utilized in the 2015 Joint Agency Staff Report, which assumes the deployment rate accelerates proportionally to cumulative vehicle deployment. Under this model, approximately 200,000 FCEVs would be expected on the road in 2025; this is roughly twice the Midrange scenario and a 60% increase over the High Technology scenario. Although the NREL model is higher than even the High Technology scenario, it is worth remembering that all ZEV compliance scenarios assess only the minimum requirements for compliance. Individual manufacturers and the industry as a whole may produce more vehicles than these compliance scenarios illustrate. Given substantial market success of FCEVs and appropriate levels of supporting infrastructure development, the projection according to the NREL model is a viable scenario for FCEV deployment in the 2025 timeframe.

At the opposite end is the Low Technology scenario, with less than 20,000 FCEVs on the road in 2025. Unless there is a complete failure of the FCEV and hydrogen markets, this scenario is unlikely. It assumes a long period of essentially stagnant market growth between 2018 and 2022, which does not match the auto manufacturer projections. Additionally, the cumulative deployment by 2025 is far below even the linear fit projection, which represents a case assuming no acceleration in market deployment out to 2025. FCEVs are a new technology that will be marketed to early adopters during this timeframe; acceleration in market deployment is a fundamental characteristic of new technologies in this time frame. Thus, the linear extrapolation is itself an extreme lower bound and the Low Technology scenario can be considered indicative only of the deployment that would occur in the case of market failure or extreme stagnation.

Both the 2015 and 2016 Annual Evaluations and Joint Agency Staff Reports have noted that business-as-usual rates of development in hydrogen fueling infrastructure are unlikely to keep pace with fueling demand beginning in 2020.[51,52,53,54] Currently, infrastructure development is almost completely funded through competitive grant solicitations administered by the Energy Commission under the directives of AB 8 (AB 8; Perea, Chapter 401, Statutes of 2013). These grants provide up to 85% of the capital expense funds and an additional $300,000 for

[50] See Appendix A for a complete explanation of the ZEV Calculator, and description of the mid-range case.
[51] ARB 2015a
[52] Energy Commission 2015
[53] ARB 2016a
[54] Energy Commission 2016a

operations and maintenance costs during the early years of station operation.[55] Thus, to meet the needs of the vehicles included in auto manufacturer deployment plans prior to 2022, new funding mechanisms and/or sources of funds will likely need to be pursued.

The FCEV deployment projections shown in Figure 15 (other than the Linear and Low Technology scenario) represent success of the FCEV and hydrogen fueling market. The current heavy participation of State funds is during a time of high risk, when the FCEV market is first beginning to develop and success has not yet been demonstrated. It is expected that as the deployment progresses and the market proves itself, the perceived risk for private investment in hydrogen infrastructure will correspondingly decrease. This will in turn incentivize greater participation of private capital in the deployment of hydrogen fueling infrastructure. The State already anticipates providing supporting funds through AB 8 until at least 2023. Increased participation of private funds can therefore be expected to help fill the gap between expected hydrogen demand and the capacity that could be deployed by State funds alone. It is too early to determine the likely magnitude of private investment in 2020 and beyond, but ARB and the Energy Commission are expecting to gain insight into the willingness for private firms to participate through responses to the current GFO-15-605.

XIII.C. Existing fueling market coverage

Considering the volumes of vehicles estimated for 2022 and projected out to 2025, the FCEV market will likely remain in the early adopter phase for the better part of the next decade. ARB's California Hydrogen Infrastructure Tool (CHIT) has been utilized in its Annual Evaluations to assess coverage needs to support growth in specifically this early market phase.[56,57] (For a discussion of the concept of coverage, see "Fueling network design and analysis concepts" section below). Figure 16 shows a comparison of the areas identified through CHIT as the highest potential for successful FCEV deployment during the early adopter phase (termed "High Market Areas" in the figure) and the coverage provided by the 50 open and funded stations. As shown in the figure, large portions of the likely first adopter markets have some degree of coverage already provided by California's planned 50 stations. The greatest concentration of coverage currently resides in the southern tip of the San Francisco Bay area, from Palo Alto down to Campbell and including parts of San Jose. Relatively high levels of coverage are also seen in West Los Angeles and Santa Monica, though the strength of the market in this region indicates that there is a need for additional stations. Other parts of Los Angeles and Orange counties have mid-range coverage with stations in some areas establishing the first signs of overlapping coverage to the local first adopter market. Additionally, several stations are open or funded that will provide coverage in important long-distance connector locations, travel destinations, and future secondary markets.

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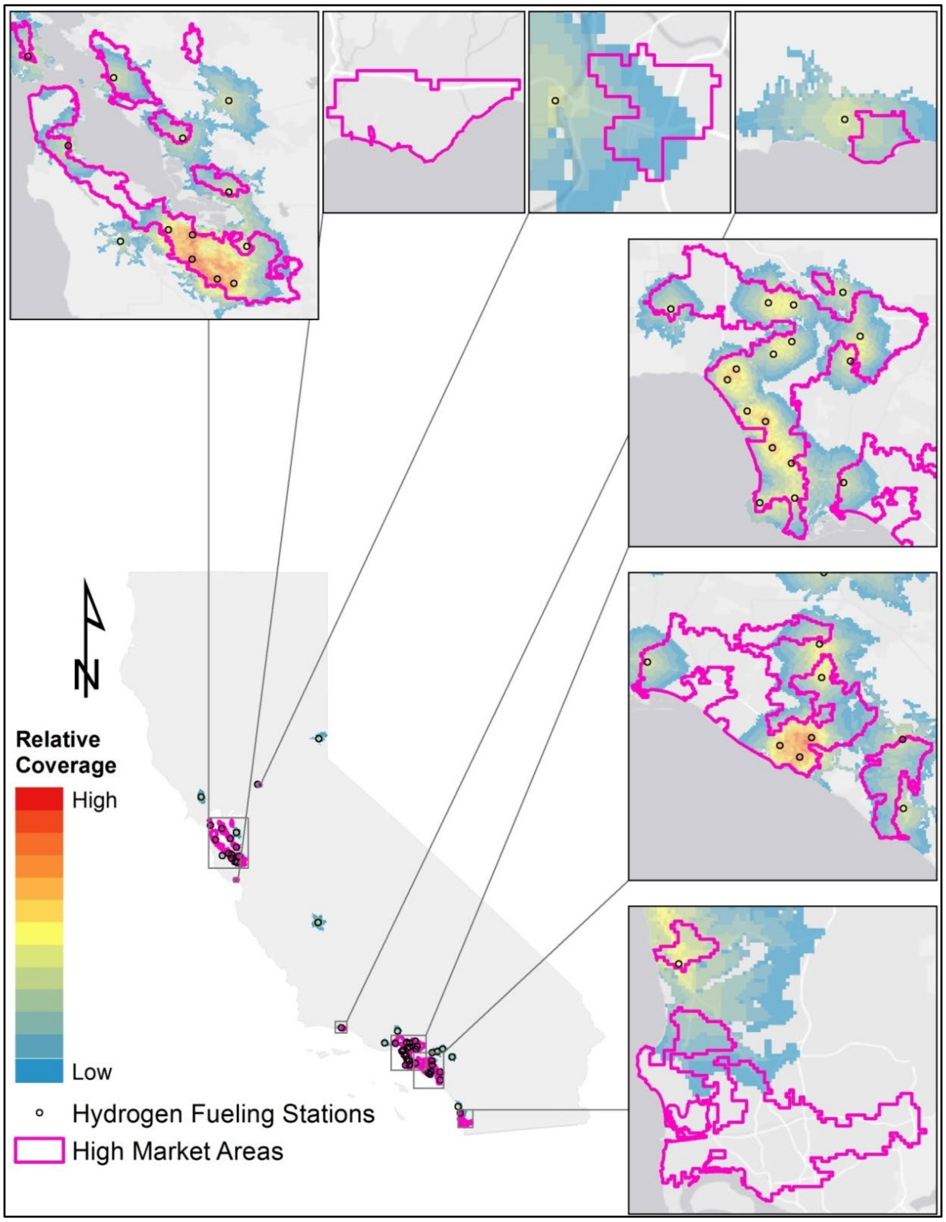
[55] Energy Commission 2016b
[56] ARB 2016a
[57] ARB 2015a

Figure 16 - Evaluation of Coverage Provided by 50 Open and Funded Stations and Comparison to Areas Identified with High Market Potential



While the currently open and funded network provides at least a base, though often non-redundant, level of coverage to so much of the early first adopter market, there are clear areas that have not yet begun to be addressed. San Francisco is a very high market potential area that does not yet have any stations providing a high degree of local coverage. Large portions of the San Diego market area likewise do not yet have coverage, nor does the stretch of coastal Orange County between Costa Mesa and Long Beach. Santa Cruz has also been identified as having a high potential market, though it does not yet have any fueling coverage. Though these gaps exist in the currently funded 50 station network, they have been identified through ARB's

Annual Evaluations and the Energy Commission has incorporated these suggestions into GFO-15-605. Though available funds in the grant solicitation may not be able to establish fueling coverage in all the identified gaps, it is anticipated that the structure of GFO-15-605 will result in many of the gaps being filled and for coverage to be strengthened in areas that have been identified as needing their existing coverage augmented. ARB envisions CHIT as a living tool; future grant solicitations through the Energy Commission may continue to be informed by revised assessments in CHIT as the hydrogen fueling network continues to grow.

XIII.D. Hydrogen fueling capacity needs for projected FCEV deployments

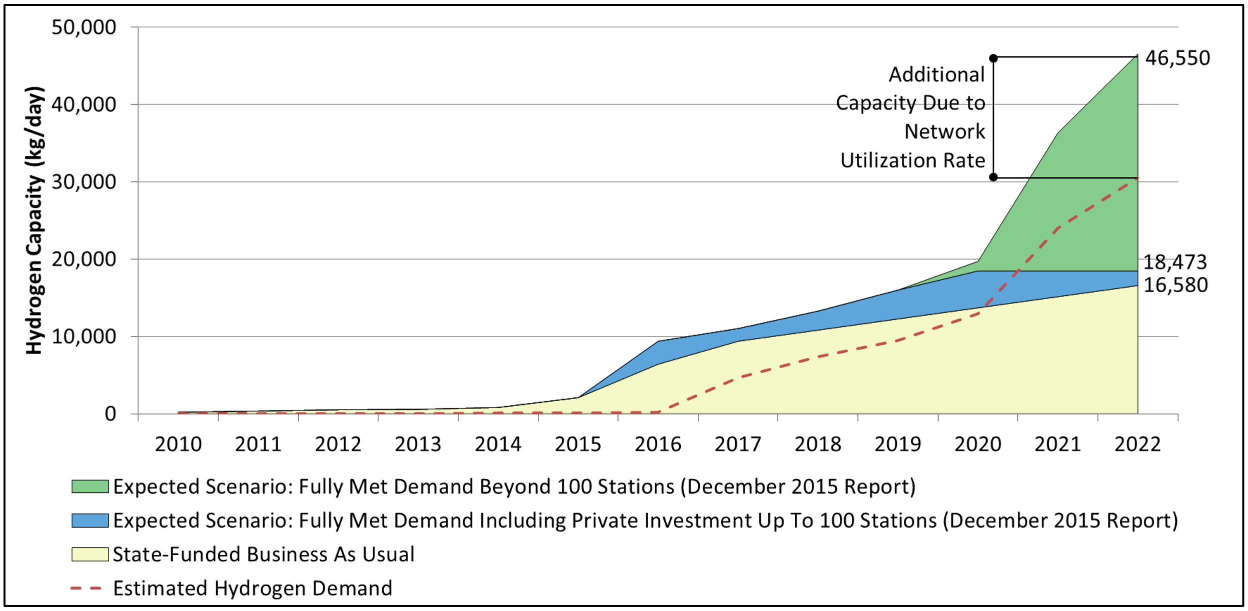
Based on the information provided by auto manufacturers in the 2015 and 2016 annual surveys, the Energy Commission and ARB have projected potential capacity scenarios for California's expected FCEV fleet out to 2022. In all scenarios, it has been shown that the annual allocation of $20 million available to the Energy Commission for hydrogen fueling stations through AB 8 will not be sufficient to meet the expected growth in hydrogen fueling demand.[58,59,60] Through separate analyses, the 2015 and 2016 Annual Evaluations and the 2015 Joint Agency Staff Report projected that investment beyond these State funds would be necessary sometime around 2020. As shown in Figure 17, the hydrogen fueling demand will surpass network capacity in 2020 under business-as-usual assumptions of $20 million per year and consistent average hydrogen station daily fueling capacity (currently 180 kg/day). Assuming station cost reductions over time, the 2015 Joint Agency Staff Report still found a potential shortfall, though the gap was smaller by about 2,000 kg/day capacity. By 2022, assuming an average network utilization rate of 75% (the ratio of daily hydrogen dispensed to a station's full capacity), more than 28,000 kg/day of capacity would need to be installed utilizing funds beyond the current AB 8 allocation.[61] Projections for capacity need beyond 2022 are less certain, given the range of potential vehicle deployment scenarios presented above and considering that AB 8 in its current form expires in 2023.

While the challenge of a fueling capacity shortfall is significant, the State and partner organizations (like H2USA and the California Fuel Cell Partnership [CaFCP]) have been actively working to identify strategies to address the coming issue. The 2015 Annual Evaluation outlined a number of potential paths to pursue, and industry stakeholders are consistently proposing and discussing other options in public and private meetings. The Energy Commission has also begun to enact some of the suggested changes. The new solicitation GFO-15-605 significantly increased the minimum daily capacity requirement for all applications from the previous 100 kg/day to 180 kg/day.[62] Potential and plans for capacity expansion without additional State funds has also been added as a required narrative item and scoring criterion in the new GFO. ARB and the Energy Commission anticipate that review of final applications to GFO-15-605 may reveal new trends and updated technology status of hydrogen fueling station equipment that could also improve the business-as-usual outlook. These agencies plan to continue to work with each other and stakeholders to monitor and assess the status quo of hydrogen fueling

[58] ARB 2015a
[59] ARB 2016a
[60] Energy Commission 2015
[61] Ibid.
[62] Energy Commission 2016b

station technology and determine if further action is needed, either within or outside of the Energy Commission's grant solicitation process.

Figure 17 - Comparison of Fueling Needs and Potential Fueling Network Capacity under Various Scenarios[63]



Finally, Figure 15 provides an example of a previous assessment of fueling infrastructure sufficiency under a sample FCEV deployment scenario. In the 2012 CaFCP Roadmap, a prospective scenario based on aggregating projection data from auto manufacturers at the time showed a market launch of FCEVs would require deploying 53,000 total vehicles over a five to six year period.[64] In the original Roadmap, this was assumed to occur between 2011 and 2017, with the assumption of correspondingly swift fueling infrastructure development. The actual history of the infrastructure deployment and thus vehicle deployment were slower; in the figure, the projected vehicle deployments have been shifted by 5 years, which aligns the Roadmap's expectation of roughly 300 vehicles in 2011 with the realized 331 vehicles reported in April of 2016.

The goal of the Roadmap was to develop, assess, and communicate a plan for infrastructure deployment that could adequately support this FCEV rollout schedule. Through the use of the University of California-Irvine's Spatially and Temporally Resolved Energy and Environment Tool (STREET; see "Fueling network design and analysis concepts" section below) model and iterative feedback with auto manufacturers, the Roadmap found that a total of 68 stations would be necessary to support the projected rollout of 53,000 FCEVs.[65,66] Importantly, these 68

[63] ARB 2016a
[64] CaFCP 2012
[65] Ibid.
[66] Stephens-Romero 2010. Stephens-Romero, Shane D., Brown, Tim M., Kang, Jae E., Recker, Wilfred W., and Samuelsen, G. Scott. 2010, "Systematic planning to optimize investments in hydrogen infrastructure deployment," International Journal of Hydrogen Energy , 35, 4652-4667.

stations represented the minimum required in order to support a market launch, not necessarily ongoing development of the hydrogen fueling industry. The goal of the 68 stations was to provide at least single-station fueling coverage to FCEV early adopters that would match their expectations from experience with gasoline fueling. Thus, the stations could provide the projected 53,000 early adopters with convenient access to at least a single station within a 6-minute drive. The assessment did not consider redundancy to each early adopter nor did it consider questions of total throughput capacity of the network or individual stations. Additionally, the 68 stations were a specific set of 68; many were concentrated in five primary clusters of early adopter markets while others were hand-selected destination and connector fueling locations.

The development of stations that has occurred since the Roadmap release has historically taken longer than originally expected. However, under business as usual assumptions, ARB reported in its 2016 Annual Evaluation that close to this number of stations (66) could be open by 2019, at a time when the expected number of FCEVs on the road is expected to be 18,465, much lower than the 53,000 reported in the Roadmap as relying on 68 stations.[67] Thus, the fueling network development is currently projected to be ahead of schedule of the Roadmap's requirements on the basis of vehicle counts, though the timeline for all development has shifted back a number of years. Still, some issues remain to be resolved in addition to the capacity issue mentioned above (which was not even forecast in the Roadmap). Some of the currently-funded 50 stations are not within the same set as the 68 outlined in the Roadmap; thus, more than 68 total stations will likely need to be built in order to cover the target markets in the same way as CaFCP envisioned in the Roadmap. Additionally, questions of redundancy were not completely addressed in the Roadmap, though the importance of this consideration is becoming increasingly apparent as more experience is gained with the first adopter markets' fueling behaviors. Finally, a development trajectory for the hydrogen fueling industry beyond early adopter coverage that addresses economic self-sufficiency of hydrogen fueling operations is not yet entirely clear.

These are all questions that ARB, CaFCP, the Energy Commission, GO-Biz, and others are continually striving to understand. Future plans for network development can be expected to be informed by and adjust according to lessons learned through driver and station operator experience and ongoing modeling and assessment of the hydrogen fueling network and its apparent gaps.

XIV. Hydrogen Fueling Station Technology Overview

XIV.A. History of California's hydrogen fueling network development

The State of California has recognized that the success of the FCEV market and the hydrogen fueling market are inextricably connected. In order for FCEVs to make the expected contribution to achieving California's ZEV market development goals, the hydrogen fueling station network must also be in place to provide reliable service. In 2007, the State passed

[67] ARB 2016a

Assembly Bill 118, which formally recognized the need for fueling stations to precede vehicle sales in order to provide the greatest opportunity for successfully building a FCEV consumer market.[68] In addition, the bill set into place the first formal funding program for hydrogen refueling stations. In parallel, then-governor Schwarzenegger's Hydrogen Highway program provided impetus for development of the first research and market demonstration stations to be installed and operated in the state.

These earliest stations provided fueling service to a small, hand-selected group of public FCEV drivers, who were driving demonstration or pre-commercial vehicles. These stations were often approved for use by individual auto manufacturers for drivers of their vehicles and were not completely open to the public. Many were behind fences requiring access authorization and use of the station would require release of liability agreements and fueling service contracts, as opposed to real-time purchase of fuel by the kilogram. Additionally, station hardware technology was still in its infancy; many standards and best practices for design and operation did not exist and the stations did not look like familiar fuel dispensers as they were not intended for retail service. The hydrogen dispenser at the left of Figure 18 is an example of one of these very early stations.

As station technology matured, hydrogen fueling station designs began to improve. Many would no longer be placed in areas with limited access, and the appearance and user interfaces would more closely approximate drivers' experiences at gasoline stations. Fueling service contracts were still predominant, as there was not yet a legally defined certification method to allow sale of hydrogen by the kilogram. The center image in Figure 18 is an example of one of these stations. More recently, under the funding program established by Assembly Bill 8 (which extended Assembly Bill 118 [AB 118; Nunez, Chapter 750, Statutes of 2007]), stations are required to provide a fueling experience essentially identical to retail gasoline sales.[69] Stations have familiar interfaces, can be placed anywhere on gasoline station property, are fully publically accessible, and can sell hydrogen by the kilogram without any need for access agreements or releases of liability. Additionally, all drivers of all FCEV models are equally able to fuel at any of these new stations. Examples are shown in the images on the far right of Figure 18.

The earliest retail stations encountered more development challenges than may have been anticipated. Examples include educating local jurisdictions about hydrogen, early difficulties with securing site control and lease agreements, and variations in permitting procedures across jurisdictions. The process of overcoming these challenges has provided valuable insight to station developers, the State, and local governments. This has in turn enabled the more recent stations to be built at a faster pace than previously observed. The Energy Commission has so far funded three sets of stations between 2009 and 2014, and the fastest average development times (from grant award to Open-Retail status) has fallen from 1,481 to 730 days (several stations are not yet complete, so these estimates are still currently developing and final values will be larger, though newer retail stations are still on track to develop faster than older

[68] Assembly Bill No. 118 (Nunez, Statues of 2007, Chapter 750).
[69] Assembly Bill No. 8 (Perea, Statutes of 2013, Chapter 401).

stations).[70] It is anticipated that as the retail station network continues to grow, development timelines will also continue to improve. Additionally, in its newest solicitation, the Energy Commission has incorporated some of these lessons and requires applicants to meet planning-based milestones (such as making contact with the local permit authorities) prior to distributing funds to any grantee.[71]

Figure 18 - Evolution of California's hydrogen fueling stations

Currently, almost all stations have a single dispenser able to dispense at both H70 (700 bar, 10,000 psi) and H35 (350 bar, 5,000 psi), though not typically at the same time. H70 is the current standard used by commercial FCEVs; some pre-commercial FCEVs utilized H35, and it can be utilized for a half-fill on H70 capable vehicles at times that the station's H70 compression system may be unavailable. Stations have also progressed in their capability to provide increasing numbers of fills in a single hour without the need to recharge high-pressure storage tanks. Early stations were not designed for high-volume throughput, while current designs are required to fill at least three cars in an hour and some have shown capability for as many as six in an hour. Each fill can be achieved in approximately five minutes from a near-empty tank to

[70] Energy Commission 2016a
[71] Energy Commission 2016b

greater than 97% state of charge. Daily fueling capacity has also grown, with today's station designs typically able to fuel 50-100 (for dual-dispenser, simultaneous-fill designs) vehicles over the 12-hour peak fueling cycle. Finally, all stations are required to receive certifications for the accuracy of their dispensing; all stations certified to date are capable of metering fuel to within 5% accuracy, though requirements are currently set to become increasingly stringent in the future.[72] Further discussion of potential designs for future stations is presented later in this Appendix.

Along with the more capable design features, retail hydrogen stations meet more stringent operational requirements. Particularly when the statewide or local network of fueling stations is still small, individual station availability becomes a critical factor for retail customer use. Stations can become unavailable for a number of reasons, including scheduled maintenance; compression, storage, and dispensing equipment malfunctions; point-of-sale malfunctions; utility and city servicing and project schedules; and unrelated construction projects at the host site. Station operators strive to minimize the service interruptions caused by these types of situations. The first retail stations to open have provided valuable lessons to station operators and other stakeholders, and there has been significant movement to anticipate and even avoid service interruptions that are now well-understood.

Additionally, reliable communication with the FCEV driver community must be available and provide accurate information about the operational status of stations, especially new stations. The CaFCP's SOSS has for years provided station status information to consumers, though it is now also being used to communicate progress towards expected levels of reliability at new stations. Particularly through the efforts of GO-Biz and the CaFCP, industry consensus has been garnered for a standardized process of first declaring new stations as "New Station" for a minimum of 60 days. This designation communicates to drivers that the station operator may still be using this period to "debug" the station (operators can voluntarily choose to extend the New Station period). This empowers customers to make an informed decision about visiting a station that may not yet be proven to be as reliable as more established stations on the network.

Today and for the foreseeable future, the retail hydrogen station is the standard in California and likely to be the standard in new markets across the United States as well. Air Liquide is currently developing a dozen stations in the Northeast and public comments indicate that their stations will meet many, if not all, of the same retail service expectations of California's hydrogen stations.[73] The Energy Commission's current GFO for new stations includes provisions that require greater performance metrics than previous grant solicitations and asks that applicants describe plans for future expansion and upgrades. This forward momentum for retail stations will be instrumental in supporting the growing FCEV market.

[72] DMS 2016. California Department of Food and Agriculture Division of Measurement Standard. CTEP Certificate of Conformance Database Search. https://www.cdfa.ca.gov/dms/ctep.html. Accessed September 26, 2016.
[73] Air Liquide 2016. Air Liquid Announces Locations of Several Hydrogen Fueling Stations in Northeast U.S.A. April 2016. https://www.airliquide.com/united-states-america/air-liquide-announces-locations-several-hydrogen-fueling-stations-northeast.

XIV.B. Fueling network design and analysis concepts

Planning the development of California's hydrogen fueling infrastructure network has historically relied on two key concepts: coverage and capacity. Coverage refers to the geographical locations of stations and the areas and communities each station and the network as a whole are likely to serve. In nearly all assessments of coverage, a limit to the extent of coverage provided by any individual station is assumed based on convenience afforded to FCEV drivers; typically this limit is expressed in terms of drive time. For example, a FCEV driver will likely feel that a station they can drive to within 3 minutes offers convenient fueling opportunity (assuming the station is also consistently available and offers amenities similar to typical gasoline stations). However, that same driver would not consider a station 20 minutes away to be convenient. The first station provides coverage to that driver, while the second does not.

Figure 19 - Sample Evaluation of Coverage at a 9-Minute Drive Time for Orange County Beach City Stations

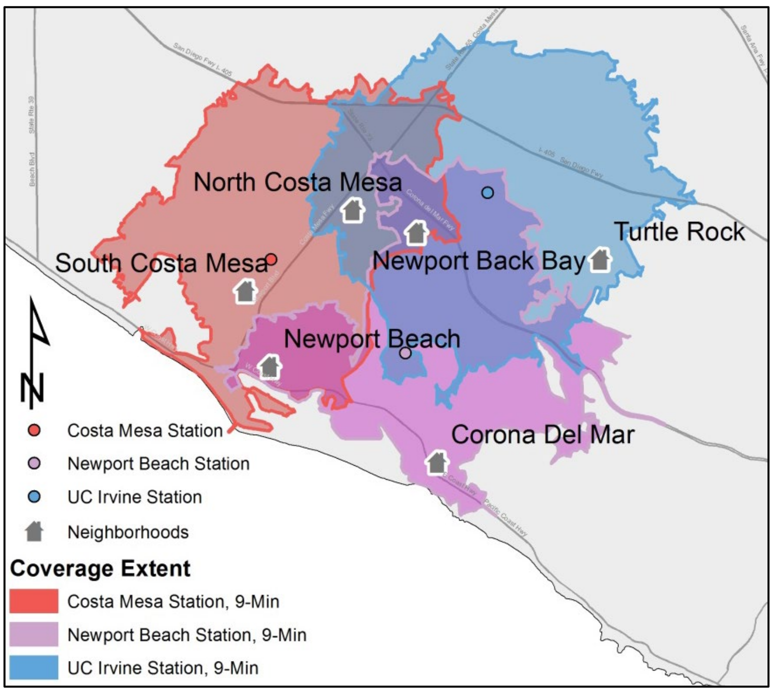
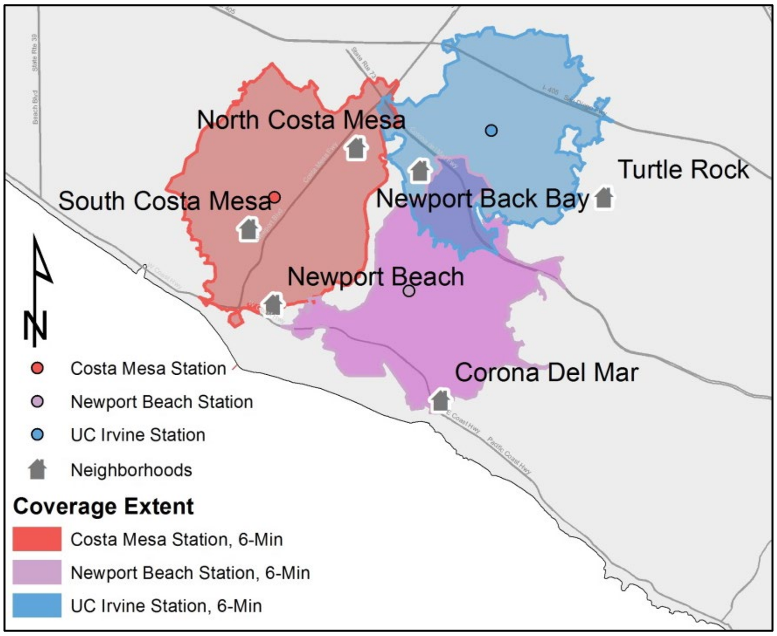


Figure 20 - Sample Evaluation of Coverage at a 6-Minute Drive Time for Orange County Beach City Stations

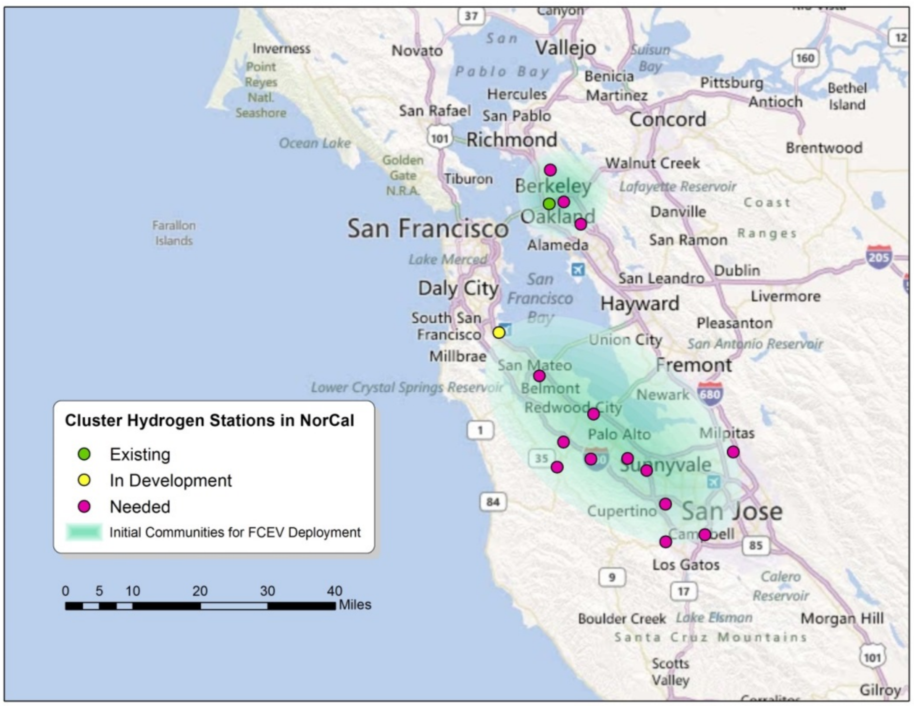


A visual representation is provided in Figure 19 and Figure 20. In both figures, three hydrogen fueling stations are shown along with the spatial extent of their coverage for 9 minute and 6 minute drive times, respectively. The metrics of 6 and 9 minute drive times are used here for illustrative purposes, though they are two of the six drive times (ranging from one to fifteen minutes) utilized in CHIT's analysis of coverage provided by the funded and operational hydrogen fueling network in California. Several neighborhoods in the region are also highlighted. Typically, a given neighborhood is considered to have greater coverage when stations are reachable within a shorter drive time and when multiple stations are reachable within the limits of convenience.

By inspection of Figure 19 and Figure 20, it can be seen that Turtle Rock has the least coverage in this example as potential FCEV drivers can only reach the UC Irvine station within a nine minute drive and have no stations available within six minutes. The Corona Del Mar and South Costa Mesa neighborhoods have slightly greater coverage; they can each reach one station within a shorter six minute drive but do not have multiple options even at the nine minute extent. The Newport Beach and North Costa Mesa communities can each only reach one station within six minutes, but have two options within nine. Finally, the Newport Back Bay community has the greatest coverage since it can reach one station in six minutes and all three within nine.

In order for both the FCEV market and the hydrogen fueling market to be successful, coverage provided by the fueling stations must match well to the geographical locations of the expected market. In California, this typically means that the stations' coverage must be matched to the locations where the expected FCEV first adopters live. In addition to these home-based coverage stations, long-distance connector stations (such as along the north-south corridor on I-5) and travel/vacation destination stations (such as in Santa Barbara, Truckee, and other locations) need to be present in order to ensure FCEV drivers are able to travel around the state just as freely as gasoline vehicle drivers. The earliest effort to establish the set of stations that could meet the coverage needs of the first adopter market was the CaFCP's *A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles*, published in 2012. The roadmap identified five clusters (shown in green shading in Figure 21 and Figure 22) and the locations of stations within those clusters to provide sufficient coverage enabling the launch of California's FCEV market.[74] In addition, several connector and destination station locations were identified (though not shown in the figures).

Figure 21 - Northern California Clusters and Suggested Station Locations in CaFCP's 2012 Roadmap[75]



74 CaFCP 2012
75 Ibid.

Figure 22 - Southern California Clusters and Suggested Station Locations in CaFCP's 2012 Roadmap[76]

The locations identified in the CaFCP Roadmap were arrived at through a combination of computer modeling, carried out by STREET, and an iterative process of consensus-building among auto manufacturers. As shown in Figure 23, STREET has the capability to optimize prospective station placement along major roads within a given community. The goal of STREET's optimization is to maximize coverage by minimizing the aggregate drive time to stations for FCEV early adopters within a given market. The stations identified through the roadmap effort provided a starting point for targeted development; State grant programs such as the Energy Commission's several PONs utilized the roadmap and STREET as a guide for determining selection of awards in competitive bid processes.

[76] Ibid.

Figure 23 - Core Functionality of STREET as related to Placement of Hydrogen Fueling Stations[77]

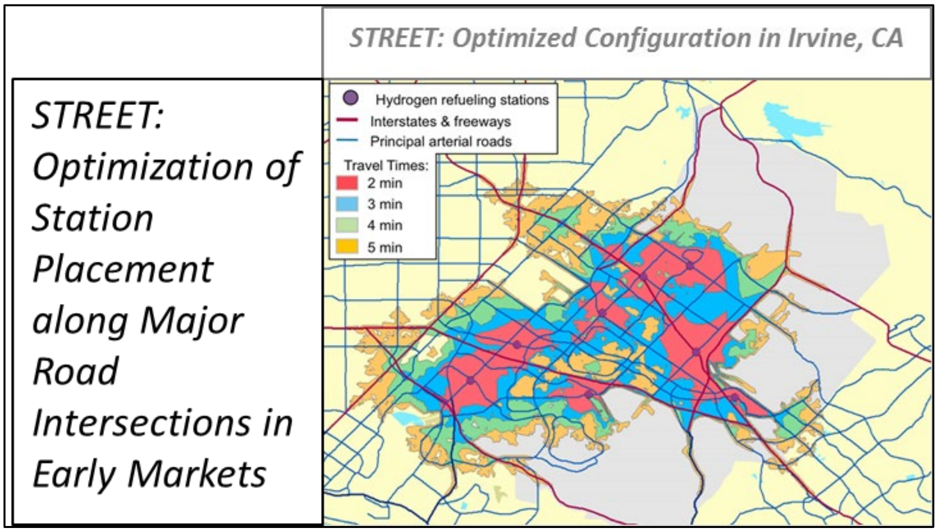
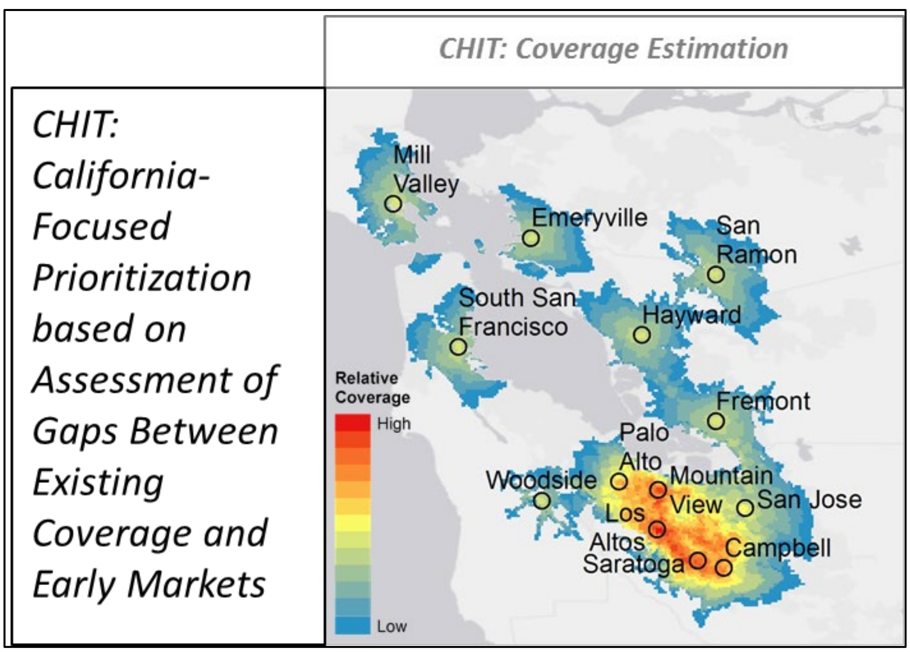


Figure 24 - Core Functionality of CHIT to Assess Relative Degrees of Coverage Provided by the Funded Hydrogen Fueling Network[78]



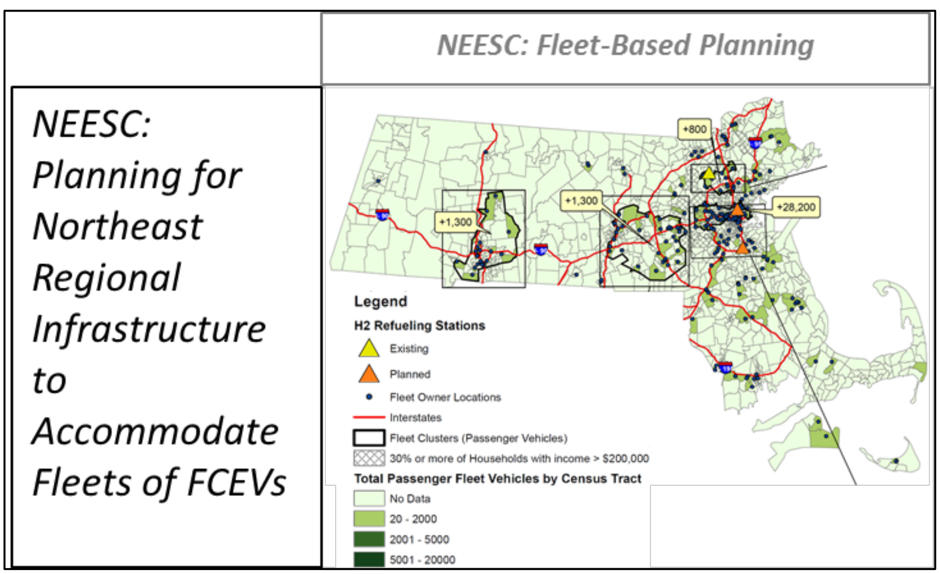
As the network developed through the competitive bid process, several of the stations outlined in the CaFCP roadmap were established, along with several additional stations. In order to continually evaluate the coverage provided by the funded network and help determine locations where the Energy Commission's next grant solicitation(s) should concentrate, ARB developed

[77] Stephens-Romero 2010
[78] ARB 2016a

CHIT. CHIT performs assessments of the degree of coverage provided by the state's funded hydrogen fueling network and identifies areas where it does not match well with the expected intensity of the local FCEV early adopter market. This is termed the coverage gap in CHIT evaluations. Figure 24 shows CHIT's assessment of the coverage provided by the sub-network of funded stations in the San Francisco Bay area. Today, CHIT is used by the ARB in annual reporting and to make recommendations to the Energy Commission for the design of its hydrogen fueling station solicitations. It is also used within the latest solicitation's (GFO-15-605) scoring method to help the Energy Commission determine its final awards.[79]

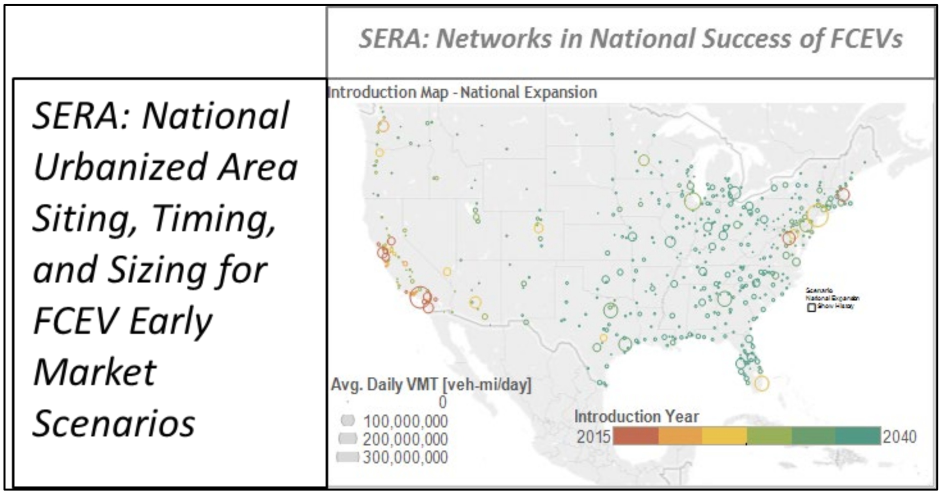
Coverage-based analyses are also being used for station network design and planning in other areas of the country. In the northeast states, staff of the Northeast Electrochemical Energy Storage Cluster (NEESC) have been developing a plan for locating hydrogen fueling stations across several states.[80] As opposed to California's current efforts to support a private light-duty passenger vehicle market, the NEESC strategy focuses on light-duty fleets. As shown in Figure 25, the planning considers the locations and sizes of existing (non-FCEV) fleets, locations of existing support for hydrogen refueling, and demographic indicators to identify strategic locations where placement of FCEV fleets and associated refueling infrastructure may be most successful. In addition to this effort, Air Liquide and Toyota have publicly announced their plans to develop a dozen publicly-available hydrogen fueling stations in the northeast states, though their full plans and strategies have not been made publicly known.[81]

Figure 25 - NEESC FCEV Fleet-Based Planning Strategy[82]



[79] Energy Commission 2016b
[80] NEESC 2015. Northeast Electrochemical Energy Storage Cluster. Station Maps. June 2015. http://h2usa.org/station-maps. Accessed September 26, 2016.
[81] Air Liquide 2016
[82] NEESC 2015

Figure 26 - National-Scale Planning through NREL's SERA Model[83]



NREL has been studying strategies for expanding hydrogen fueling infrastructure from the initial networks in California and the Northeast to a nationwide system. NREL utilizes its Scenario Evaluation, Regionalization, and Analysis (SERA) model to complete this task.[84] While SERA considers aspects of coverage through an analysis of an Early Adopter Metric, it also introduces consideration of individual station capacity and timing of individual station development. Analyzing and optimizing scenarios accounting for these various aspects of fueling network planning at such a large scale is especially challenging and NREL makes use of access to supercomputer clusters available through the national laboratories in order to develop its outputs.

Capacity evaluations like those in SERA introduce the second major aspect of hydrogen fueling network planning and analysis. Namely, a well-planned set of locations for hydrogen stations may still be insufficient to provide reliable and convenient fueling opportunities if the stations are not sized appropriately (locally or on the full network scale) for the expected size of the FCEV adopter market. Additionally, to help ensure the viability and stability of the fueling and vehicle markets' growth, the timing of increasing station capacity needs to be carefully considered. ARB's CHIT tool also provides determination of expected capacity need and for the purposes of GFO-15-605 can assess the suitability of proposed station designs for the potential local market. This determination relies on projections of statewide FCEV on-road vehicle populations that are published by ARB each year.

In accordance with AB 8, for the past three years ARB has published its Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fueling Station Development.[85] Each year, the report provides ARB's latest information for the number of FCEVs on the road in

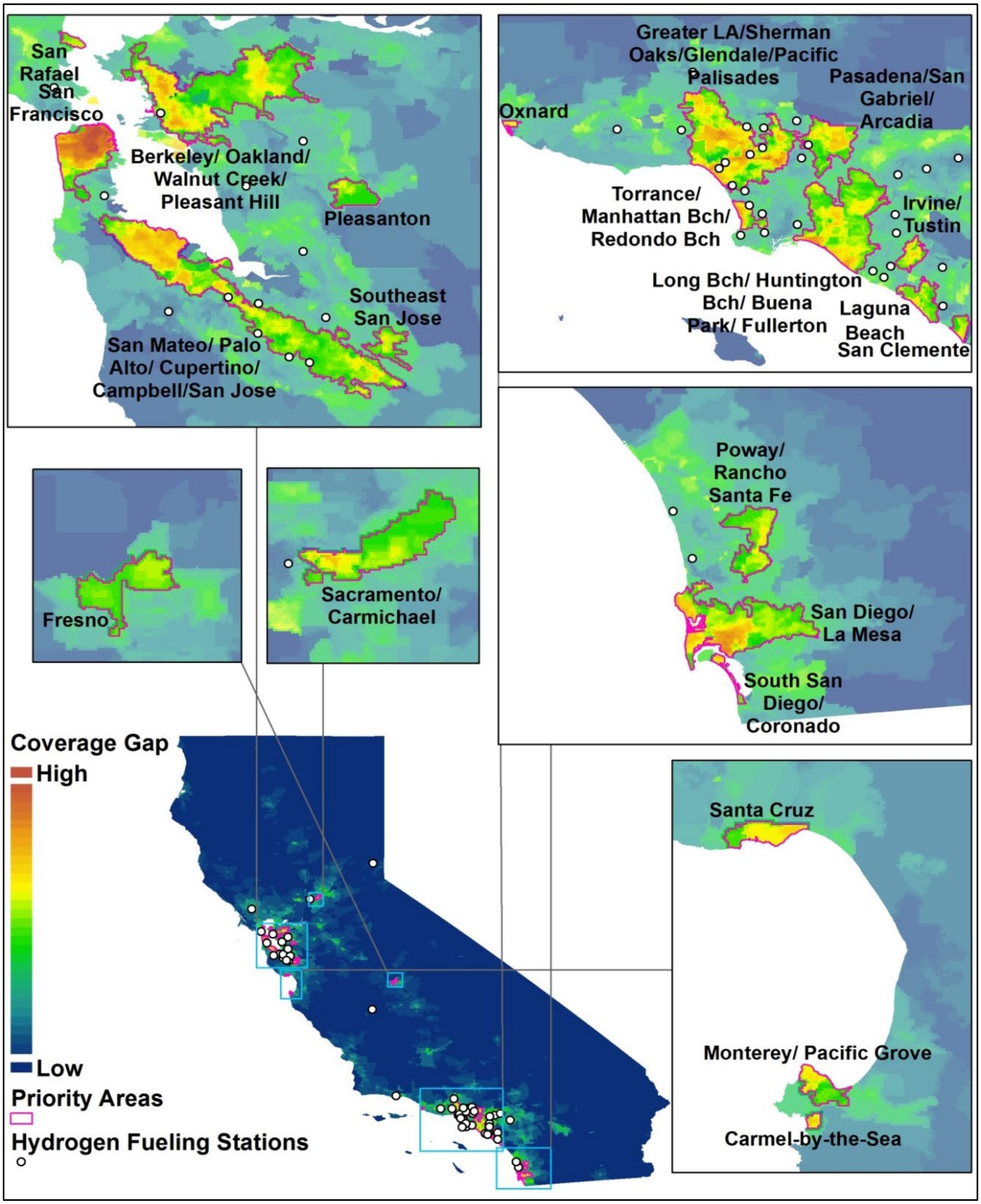
[83] NREL 2011. National Renewable Energy Laboratory. Scenario Evaluation, Regionalization & Analysis (SERA). January 2011. http://en.openei.org/wiki/Scenario_Evaluation,_Regionalization_&_Analysis_(SERA). Accessed September 26, 2016.
[84] Ibid.
[85] Assembly Bill No. 8

California, auto manufacturer plans for future FCEV deployments (based on an annual survey), evaluation of hydrogen stations currently operating and under development in California, and an assessment of needs for new stations that includes consideration of coverage, capacity, and technical specifications. In the 2016 Annual Evaluation, ARB presented its analysis of needs considering the 50 existing open and funded stations. Figure 27 provides the analysis of coverage gap as determined by CHIT and accounting for these 50 stations.[86] In the figure, brighter red areas have a greater need for coverage provided by new stations while deep blue areas have a very low need for new stations. Outlined Priority Areas signify "hot spots" where high coverage gap values coalesce and are significantly different from their surroundings. From discussions with stakeholders including auto manufacturers, several of the identified areas are in agreement with expectations for near-term priority development of local FCEV markets. ARB is currently working to include new considerations in CHIT evaluations that stakeholders have discussed in feedback to the agency. In particular, consideration of station availability, driving habits, and the timing of adding new stations to Priority Areas are all areas under current review.

Other models for planning a hydrogen fueling network can be found in technical literature. Several models make an argument for station placement along common travel routes as opposed to near the homes of first adopters. Others seek to optimize the opportunity that can be afforded by including dispatchable mobile refuelers in the network.[87,88,89,90,91] ARB is currently investigating how these perspectives can improve the State's hydrogen fueling infrastructure planning efforts. Additionally, the past efforts including the development of the CaFCP's Roadmap have included substantial participation and feedback from stakeholders in the automotive and hydrogen fueling industries. ARB continues to communicate with these stakeholders and the public to ensure that its analysis methods meet the planning needs of the FCEV and hydrogen fueling markets. In particular, ARB's development of CHIT has included stakeholders and the public through several scheduled events and private meetings; future developments of the tool will similarly consider this guidance.

[86] ARB 2016a
[87] Ogden 2010. Ogden, Joan, Cunningham, Joshua, and Nicholas, Michael.,Roadmap for Hydrogen and Fuel Cell Vehicles in California: A Transition Strategy Through 2017. February 2010.
[88] Nicholas 2010a. Michael A. Nicholas. 2010, "Driving Demand: What can gasoline refueling patterns tell us about planning an alternative fuel network?," Journal of Transport Geography, 18, 738-749.
[89] Kuby 2009. Kuby, M., Lines, L., Schultz, R., Xie, Z., Kim, J., and Lim, S. 2009, "Optimization of hydrogen stations in Florida using the flow-refueling locations model," International Journal of Hydrogen Energy, 34(15), 6045-6064.
[90] Kelley 2013. Scott Kelley and Michael Kuby. 2013, "On the way or around the corner? Observed refueling choices of alternative-fuel drivers in Southern California," Journal of Transport Geography, 33, 258-267.
[91] Nicholas 2010b. An Analysis of Near-Term Hydrogen Vehicle Rollout Scenarios for Southern California. Davis: Michael Nicholas and Joan Ogden, 2010.

Figure 27 - ARB's Analysis of Coverage Gap through CHIT as presented in the 2016 Annual Evaluation[92]



[92] ARB 2016a

XIV.C. Dispensed hydrogen production pathways and station design strategies

Although all hydrogen stored onboard light-duty FCEVs is in gaseous form at 700 bar (with the exception of some legacy vehicles still on the road today), there are many methods of producing, transporting and distributing, and finally dispensing the hydrogen. In total, there are no less than ten unique pathways that are currently utilized for producing hydrogen in California's hydrogen fueling network, as shown in Figure 28 (groupings of pathways in the figure follow the modeling methods of ARB's VISION model). Steam methane reformation (SMR), whether on-site or at a central facility, makes up a large portion of the total planned hydrogen throughput in the state. While the full process is more complex, SMR is essentially the conversion of methane in natural gas to hydrogen through combination with steam; typically, the actual SMR step is followed by a water-gas shift (WGS) reaction to convert product carbon monoxide (CO) into carbon dioxide (CO_2) and provide additional hydrogen yield.

Equation 1- Conversion of methane in natural gas to hydrogen

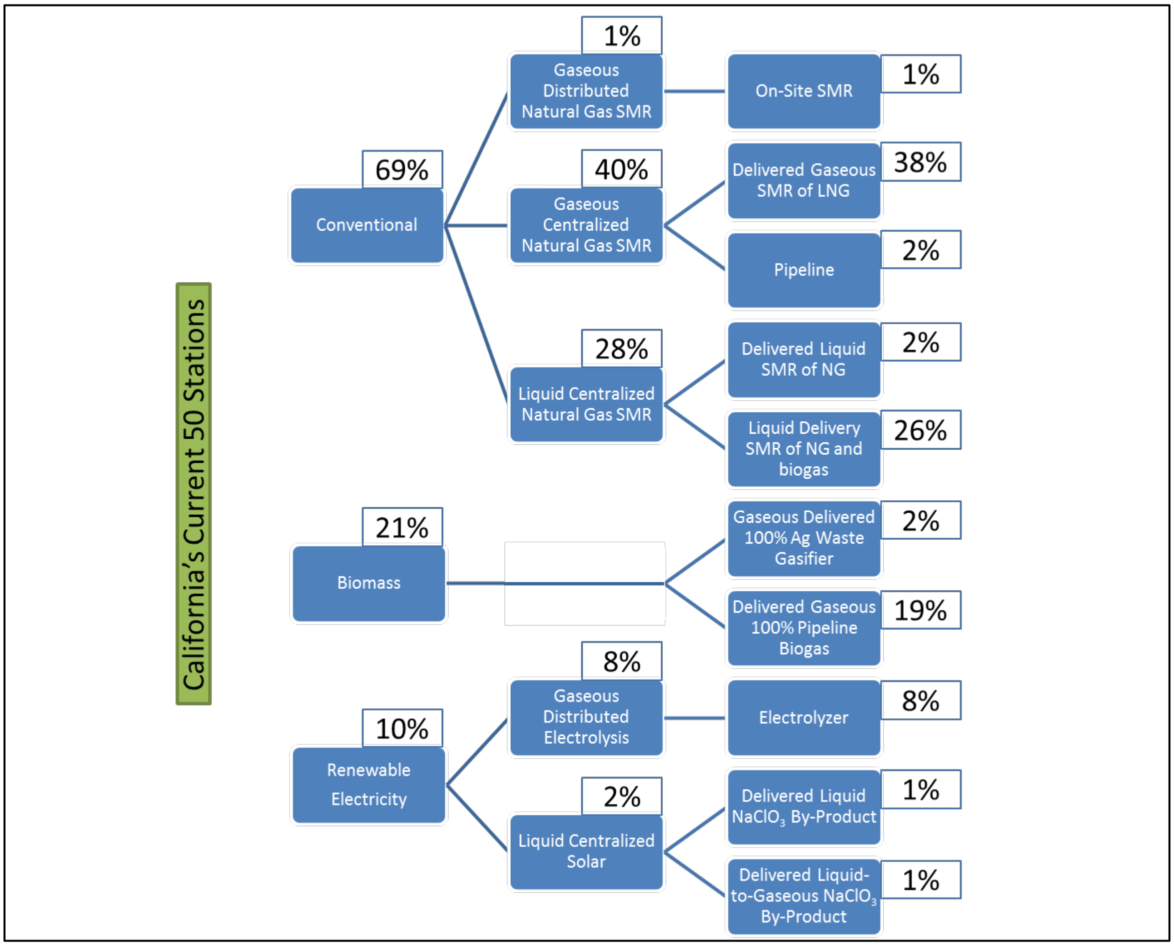
$$CH_4 + H_2O \xrightarrow{\text{yields}} CO + 3H_2 \qquad \text{SMR}$$

$$CO + H_2O \xrightarrow{\text{yields}} CO_2 + H_2 \qquad \text{WGS}$$

$$CH_4 + 2H_2O \xrightarrow{\text{yields}} CO_2 + 4H_2 \qquad \text{TOTAL}$$

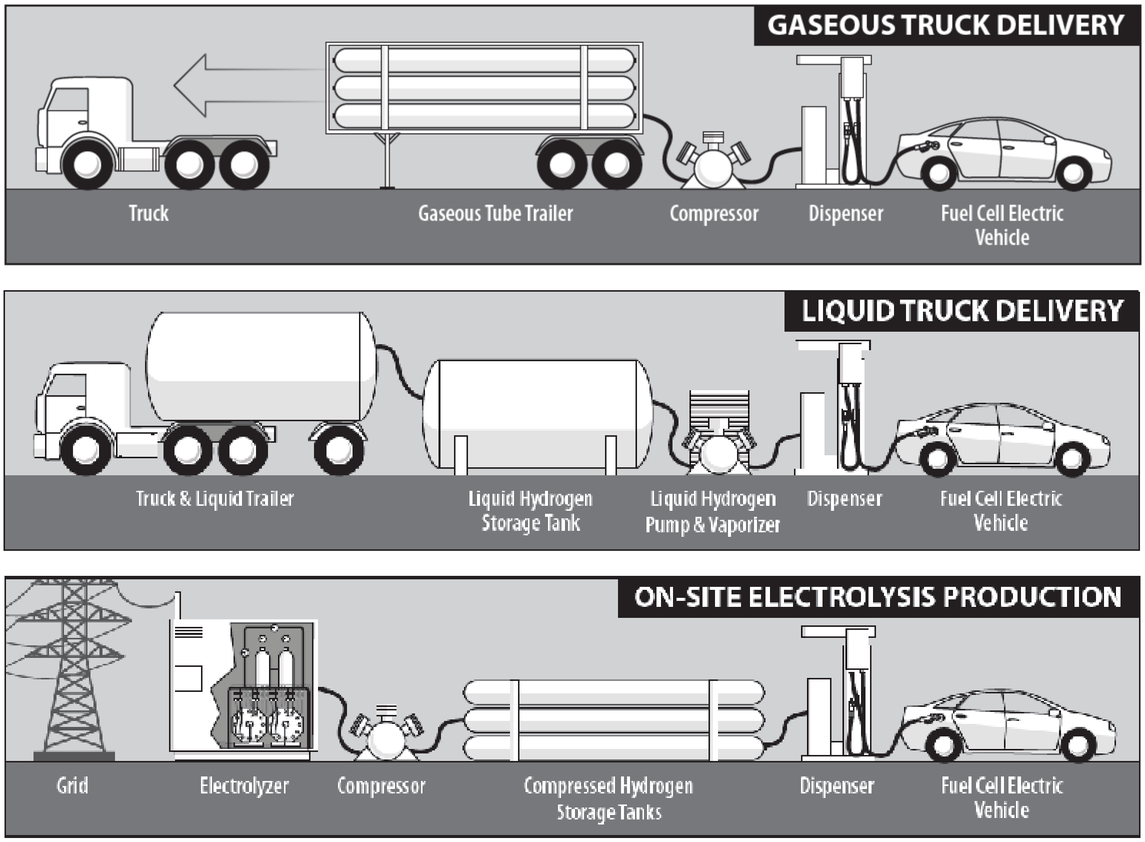
The reactions above describe the basic steps in the SMR process. The actual source of the natural gas can vary, including conventionally recovered natural gas, biogas, agricultural waste gas, and other sources like those shown in Figure 28. Additionally, hydrogen can be produced by methods not involving SMR. Certain industrial processes generate hydrogen as a byproduct gas, which can be captured and distributed for FCEV consumption. Hydrogen can also be produced by electrolysis, which involves passing an electric current through water to generate hydrogen and oxygen. Hydrogen can additionally be produced at what is known as a trigeneration facility. While it is no longer in operation, the former Fountain Valley station featured this method. The Fountain Valley trigeneration system was sited at a wastewater treatment facility. Hydrocarbon-rich gasses from the on-site digesters were passed to a high-temperature fuel cell. This fuel cell could perform reformation of the hydrocarbons, generate electricity from the resulting hydrogen and CO_2, generate waste heat to be used in the digesters, and provide a slipstream of hydrogen to be purified for dispensing into FCEVs. One station in California even features hydrogen delivered directly via pipeline from a central SMR production facility; this previews what may be one of the most cost-effective methods of hydrogen transport in a future with wide-ranging FCEV adoption. While California's hydrogen fueling network has been supplied with hydrogen from a wide variety of production methods, there are many others detailed in literature and are too numerous for an exhaustive review in this document.

Figure 28 - Hydrogen Production Pathways Utilized in California's Hydrogen Fueling Network (Shares are per Kilogram Dispensing Capacity)



Hydrogen fueling station design can depend on the final physical state (liquid or gaseous) and location of the source hydrogen production facility. For example, hydrogen delivered to a fueling station in liquid form requires the station to be equipped with a vaporizer in order to convert the hydrogen to gaseous state before dispensing into a vehicle. Meanwhile, if hydrogen is delivered to the station in gaseous form, this piece of equipment is not required. (Note that there are multiple other design considerations that represent tradeoffs in cost and technical capability between individual station designs; the optimal choice typically depends on the station developer's strategy and perceived local throughput needs). Figure 29 provides some examples of different station design types, and highlights some of the major differences between the types of stations currently participating in California's hydrogen fueling network. Note that multiple production pathways shown in Figure 28 may employ the same basic station design concepts, as long as the hydrogen delivery method is similar.

Figure 29 - Examples of Hydrogen Fueling Station System Design Variations by Production Pathway[93] (originally attributed to NREL)



Especially during the early years of FCEV deployment, establishing a hydrogen fueling network is expected to be a capital-intensive endeavor. Additionally, operating costs are expected to be high as throughput volumes of hydrogen at dispensers are not large enough to induce benefits of production scale, resulting in high procurement costs for station operators (and potentially high costs to the consumer). The grant solicitation programs enabled by AB 8 allow the State to help reduce the industry's financial burden during this period of unknown market development pace and high investment risk. Table 8 provides the most recently published projection of capital costs for the 50 stations currently in California's planned network.[94] Indications from stakeholders are that these early-market costs are much higher than they may be as market volumes grow. As the network is still developing, the Energy Commission's grant solicitations provide funds for up to 85% of the capital costs, with individual funding levels depending on an incentive structure that rewards faster station development.

Figure 30, based on NREL's Hydrogen Station Cost Calculator calibrated to the station costs in Table 8, provides projections of the potential reductions in cost over the next decade.[95] Note

[93] Energy Commission 2015
[94] Ibid.
[95] Ibid.

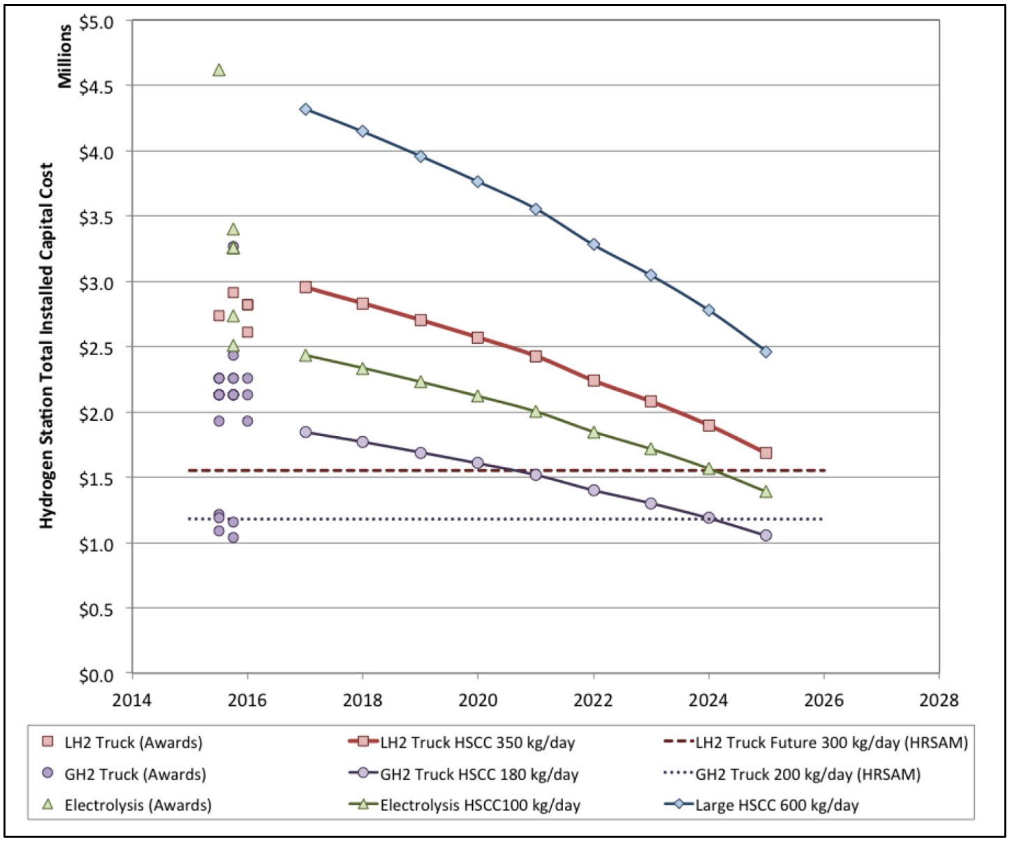
that in Table 8, Systems 1 and 4 are both 180kg/day stations with delivered gaseous hydrogen (with equipment and operations from two different providers with different strategies of transferring and storing fuel on-site), System 2 is a 350 kg/day station with liquid delivery, and System 3 is a 130 kg/day station with hydrogen produced on-site through electrolysis. An additional cost estimate is provided in Figure 30 for a very large station design (600 kg/day), which could enter the market sometime in the next decade if FCEV deployment volumes continue to grow; at this large nameplate capacity, this type of station is likely to be a liquid truck delivery station. Reductions in cost shown in the figure are based on validated general cost reductions observed in other industries and are the result of both industry learning and growing production volume. Even still, for the purposes of the 2015 Joint Agency Staff Report, NREL generated Figure 30 with an additional contingency factor that slowed cost reduction compared to standard models. Based on Figure 30, existing station design costs may fall by as much as 40-50% within the next decade.

Table 8 - Hydrogen Fueling Cost Projections as Reported in December 2015[96]

<table>
<tr><th colspan="5">Equipment</th></tr>
<tr><th rowspan="2">Equipment List</th><th colspan="4">Delivered Cost ($)</th></tr>
<tr><th>System 1</th><th>System 2</th><th>System 3</th><th>System 4</th></tr>
<tr><td>Ground Storage (gaseous or liquid)</td><td>$ 370,000</td><td rowspan="8">$ 1,314,000</td><td>$ 222,000</td><td>$ 162,426</td></tr>
<tr><td>High-Pressure Tubes</td><td>$ 135,000</td><td>$ 53,000</td><td>$ 237,000</td></tr>
<tr><td>Electrolyzer</td><td></td><td>$ 1,008,000</td><td></td></tr>
<tr><td rowspan="2">Compressors</td><td>$ 270,000</td><td>$ 147,000</td><td>$ 500,000</td></tr>
<tr><td></td><td>$ 123,000</td><td></td></tr>
<tr><td>Chiller</td><td>$ 150,000</td><td>$ 19,000</td><td>$ 230,000</td></tr>
<tr><td>Dispenser</td><td>$ 270,000</td><td>$ 392,000</td><td>$ 97,680</td></tr>
<tr><td>Point-of-Sale System</td><td>$ 20,000</td><td></td><td>$ 56,405</td></tr>
<tr><td>Connection to Utilities</td><td>$ 12,000</td><td>$ 42,000</td><td>$ 15,000</td><td>$ 200,000</td></tr>
<tr><td>Tubing and Valves</td><td>$ 150,000</td><td rowspan="2">$ 574,000</td><td></td><td>$ 48,635</td></tr>
<tr><td>Misc. Material and Equipment</td><td>$ 230,000</td><td>$ 113,000</td><td>$ 20,000</td></tr>
<tr><td>Total Equipment and Material</td><td>$ 1,607,000</td><td>$ 1,930,000</td><td>$ 2,092,000</td><td>$ 1,552,146</td></tr>
</table>

96 Energy Commission 2016a

Figure 30 - Projections of Potential Future Hydrogen Fueling Station Costs[97]



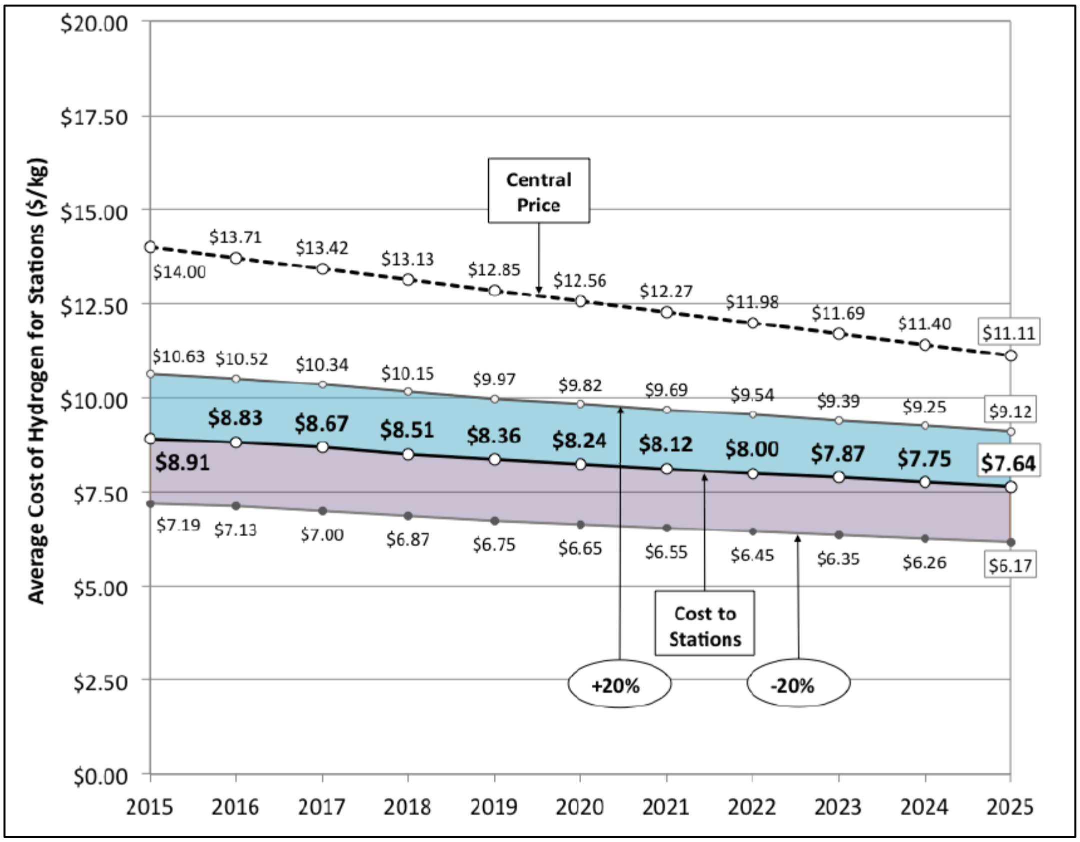
In addition to capital costs, the Energy Commission's grant solicitations currently provide funds to cover Operations and Maintenance costs (up to $300,000).[98] A major motivator for this additional funding coverage is the high cost of hydrogen procurement to the station operator. This has been identified as a key factor in the economic viability of individual stations, especially during the early years of the FCEV deployment when hydrogen sales volumes are not expected to be very large. In addition, the high cost of hydrogen has a nearly proportional and direct effect on the cost that the FCEV driver may see at the pump. Figure 31 shows the current average price of hydrogen procurement as reported by operators of California's open stations in 2015, potential reductions in procurement cost over time, and uncertainty bounds on this cost.[99] In addition, the effect on the price to FCEV drivers at the pump is indicated by the "Central Price" trajectory.

The difference between the "Cost to Stations" and the "Central Price" would cover amortization of the station's capital equipment cost, operations and maintenance costs including staff salaries, all applicable taxes, fees, and financing costs, and profit margin. Though not shown in Figure 31, $11.11 per kilogram of hydrogen in 2025 is projected to be roughly equivalent to

[97] Ibid.
[98] Energy Commission 2016b
[99] Energy Commission 2015

gasoline for expected vehicle technologies at that time; within a 20% margin of error, hydrogen may become cost-equivalent with gasoline as soon as 2021 (at $9.82 per kilogram) or as late as 2029 (at around $12 per kilogram). These conclusions are based on projections of gasoline costs rising from $2.89 per gallon in 2015 to $4.81 per gallon in 2025, conventional engine efficiencies rising from 28.6 mpg to 42.1 mpg, and FCEV efficiency rising from 72 mi/kg to 93.3 mi/kg over the same period.

Figure 31 - Hydrogen Cost Projections to Station Operators and to FCEV Drivers (shown as "Central Price")[100]



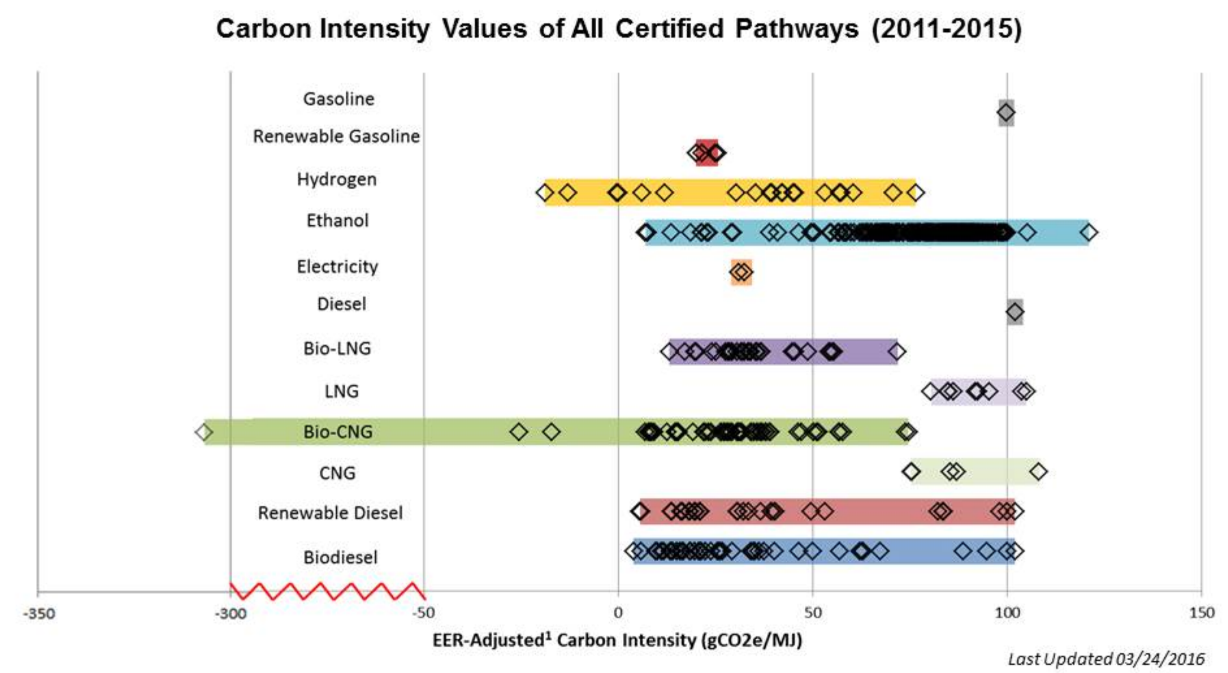
XIV.D. Renewable hydrogen and sustainability

California's hydrogen fueling network includes a range of station design types that are supplied by hydrogen produced through several different methods, as discussed above. These various pathways also result in various rates of carbon emissions and renewable energy implementation. ARB's Low Carbon Fuel Standard (LCFS) program has performed analyses of several hydrogen production pathways that are currently in-use or proposed for use in California (in addition to a handful of early prospective pathways that eventually developed with slight alterations in today's station network). As shown in Figure 32, when accounting for the efficiency benefit of FCEVs over conventional internal combustion engines (ICEs), all hydrogen pathways have lower rates of

[100] Ibid.

carbon emissions than gasoline.[101] In fact, some hydrogen pathways have been evaluated as having a negative carbon intensity (their lifecycle effectively sequesters carbon dioxide) and are among the least carbon emitting pathways analyzed for transportation fuels. The carbon emissions savings potential of hydrogen and FCEVs has been recognized as a significant element in ARB's efforts to reduce transportation-related GHG emissions and the governor's overall climate plan.

Figure 32 - Summary of ARB's LCFS Program Evaluations of Hydrogen (and Other Fuel) Production Pathway Carbon Intensities[102]



Each marker represents an individual certified fuel pathway carbon intensity (CI), adjusted by the Energy Economy Ratio (EER). The length of each bar indicates the range of carbon intensity that may be achieved by a fuel pathway. The wide range of carbon intensities is due to the life cycle emissions methodology of the LCFS; variations in feedstock types, origin, raw material production, processing efficiencies, and transportation all contribute to an individual producer's fuel pathway CI. All valid CI values are shown, including those certified before 2016 which are set to expire on December 31, 2016. New and recertified pathways will be added to the figure as they are approved and posted.

[1] The alternative fuel's CI value is divided by its Energy Economy Ratio (EER) in order to obtain the EER-adjusted CI value, representing the emissions which occur from the alternative fuel *per MJ of conventional fuel displaced.*

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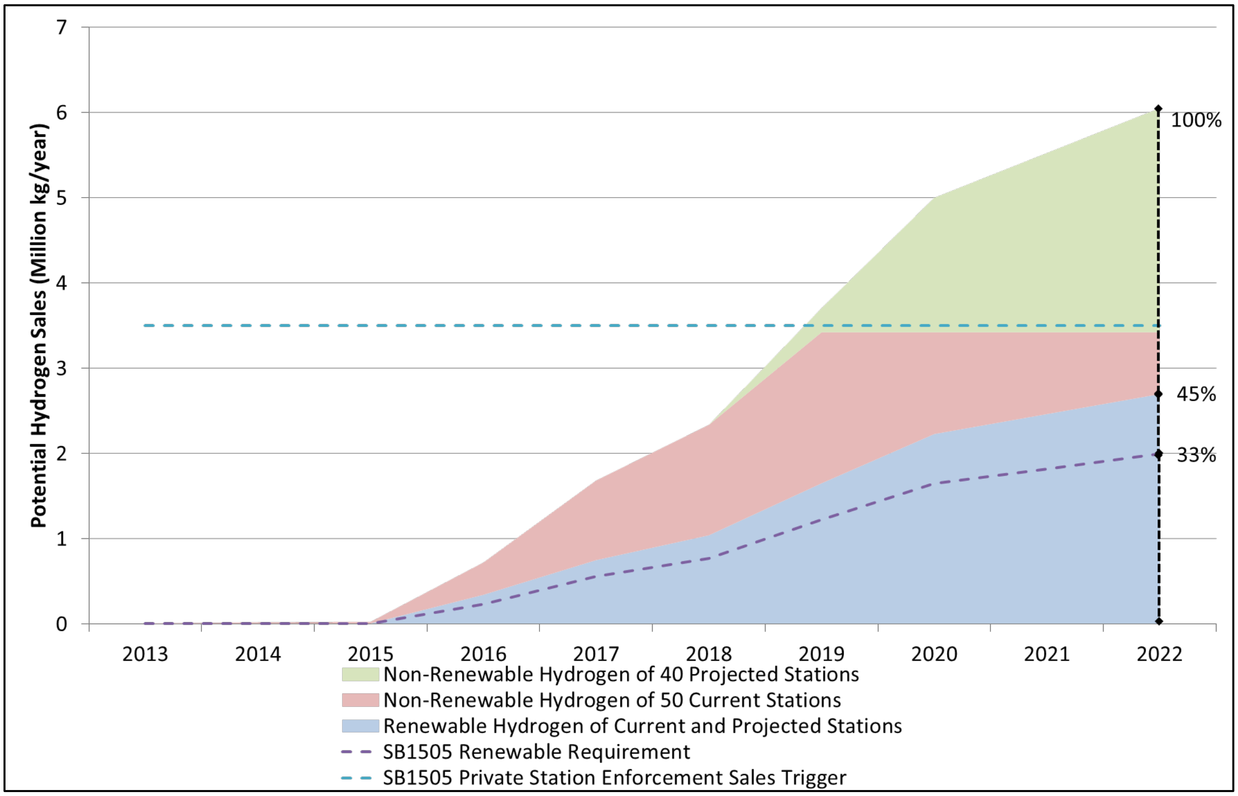
[101] ARB 2016b. California Air Resources Board. LCFS Pathway Certified Carbon Intensities. March 2016. https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm. Accessed September 26, 2016.
[102] Ibid.

Figure 33 - Renewable Energy Implementation in California's Current 50 Funded Hydrogen Stations and Projections for Business-As-Usual in the Future[103]



In addition to addressing the carbon intensity of California's transportation sector, hydrogen fuel also addresses goals for renewable energy sourcing and sustainability of transportation fuel. Senate Bill 1505 (SB1505; Lowenthal, Chapter 877, Statutes of 2006) proposed a requirement that all hydrogen fuel sold in the state by operators receiving State co-funding should have at least 33% of its process and feedstock energy source by renewable resources.[104] Additionally, once total sales reached 3.5 metric tons per year, the requirement would also apply to stations that are completely privately funded. ARB has not yet introduced a related regulation, though staff are currently working to include these provisions into the LCFS program. Additionally, the Energy Commission's grant solicitations have historically required that all funded stations meet this 33% minimum, independent of any potential SB 1505-related regulation.[105] Figure 33 shows ARB's analysis of the current and projected (under business-as-usual assumptions) renewable content in California's dispensed hydrogen transportation fuel. Once all 50 stations are complete, it is expected that California's network will exceed the 33% metric, with an aggregate potential for 45% renewably-sourced hydrogen.[106]

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[103] ARB 2016a
[104] Senate Bill No. 1505 (Lowenthal, Statues of 2006, Chapter 877).
[105] Energy Commission 2016b
[106] ARB 2016a

XV. Forecasts for Hydrogen Infrastructure

XV.A. Characterizing future hydrogen stations

The retail hydrogen stations being deployed today in California are the first examples of stations that have the capability to meet customer expectations of convenience, familiarity, and reliability. As discussed earlier, they also represent a great deal of technical advancement from the first set of stations that were deployed in the state. However, further advancements are still expected as the FCEV and hydrogen fueling markets grow over the coming years. As the FCEV market expands, demands on individual stations will become even greater and station specifications and design will have to accommodate the evolving market.

One of the most commonly expected trends for the future is that individual station daily fueling capacity will need to increase. As discussed in the section above, business-as-usual assumptions of station fueling capacity will not allow the State's funding programs to meet projected demand. While additional (private or public) funds may increase the growth potential in the future, larger capacity stations will also play a key role in assuring the state's fueling network capacity keeps pace with vehicle deployments. One major motivating factor is that larger stations not only make sense for the health and utility of the network, but they also make more financial sense for station operators.[107] Larger stations enable greater sales (assuming sufficient market demand) and therefore quicker payback periods and more attractive value prospects for investors and business owners. As shown in Table 9, which projects potential economic performance for various station designs in 2025, larger stations have more attractive financial performance and are more likely to be viable enterprises without State incentive funding. Note that the smallest stations, around 100 kg/day, may not be self-sufficient even by 2025; the revenue potential is simply too small to recover from the initial capital cost. Thus, station designs are likely to evolve to larger daily capacities and there may be a corresponding shift in production and delivery method to pathways that are better suited to the larger station design.

Table 9 - Financial Performance for 2025 Stations without Incentives and with Capital Incentive Sufficient to Achieve a 10 Percent IRR[108]

	600 kg/day Delivered Liquid	350 kg/day Delivered Liquid	180 kg/day Delivered Gas		100 kg/day Electrolysis	
Capital incentive ($M)	$0.00	$0.00	$0.00	$0.04	$0.00	$0.80
Profitability index	3.97	3.03	1.99	2.16	-0.32	1.07
IRR	16.8%	13.6%	9.1%	10.0%	N/A	10.0%

In addition, today's hydrogen fueling stations typically include only one dispenser and are only able to fill a single vehicle at a time. While vehicle deployments are just starting, this provides sufficient capability at hydrogen stations; there are not yet enough vehicles on the road that long lines at hydrogen dispensers are a concern. However, as deployment rates accelerate as

[107] Energy Commission 2015
[108] Ibid.

shown in Figure 15, there will be an increasing need to assess, especially in the areas with the highest market potential, the need for and economic feasibility of including additional dispensers at a single station and to make any equipment upgrades necessary to allow simultaneous filling.

Ultimately, in a future with widespread adoption of FCEVs, hydrogen fueling stations will very closely resemble today's gasoline fueling stations. Multiple islands, each with multiple dispensers capable of fueling simultaneously are expected to become the norm. This implies another potential change in siting hydrogen fueling stations. Today, nearly all stations are co-located at an existing gasoline station, which incurs its own set of additional negotiating, contracting, and permitting challenges. ARB expects that once very large stations become the norm (greater than 500 kg/day), standalone hydrogen stations may start to become a financially viable proposition and perhaps even a necessity for station design. These standalone stations may be placed on greenfield property where no fueling station currently exists or they may be conversions of existing gasoline stations. However, with the uncertainty of projected vehicle deployment rates, it is too early to pinpoint when this transition may occur or when the first example of such a standalone station is likely to appear.

Similar to the capability to perform simultaneous fills, stations are also likely to become increasingly capable of performing several back-to-back fills quickly and reliably. With many designs in today's station network, certain equipment (mostly the high-pressure storage bank) requires a recharge period after a certain number of back-to-back fills. Requirements for back-to-back fill capability without a recharge delay have evolved in Energy Commission grant solicitations from three to a current requirement of five fills in an hour.[109] ARB is aware that some stations are actually capable of providing even more back-to-back fills than the requirement. Additionally, the anticipated daily cycle of demand, even with large numbers of FCEVs on the road, implies that a given dispenser does not need to be capable of performing an unlimited number of back-to-back fills before requiring a recharge. However, back-to-back fill capability is not consistent across the current network and there is still room for improvement as the network grows.

Finally, ARB is confident that as hydrogen fueling networks continue to be established and expand in California, the U.S., and other parts of the world, there will be an increased move towards standardized and listed station designs and components. As hydrogen station deployment accelerates and production volumes increase, there will be a need for standardized definitions of component designs, capabilities, and manufacturing. Today, several groups are working to develop standards describing station design and performance requirements, but ARB has identified a need for harmonization amongst standards, especially those defined in separate regions. In addition to increased standardization, ARB has seen increased interest in listing of station components and designs, such as with a certification company like UL. Station developers have seen that permitting may be faster and more likely successful in certain jurisdictions with UL listing of stations and components. Given the significant impact that permitting times can have on overall station development schedules, ARB anticipates much of the industry moving towards listing becoming more commonplace than it is today.

[109] Energy Commission 2016b

XV.B. Future development of the hydrogen fueling network

In addition to advancements and new paradigms in individual station design, the planning and development of the hydrogen fueling network is likely to evolve as FCEV deployment progresses. To date, the State's efforts have been directed towards establishing a base level of coverage in areas with high potential for early market adoption of FCEVs. Although this focus will enable the launch of the FCEV market, it is not expected to be a sufficient network design for long-term viability and growth. For example, redundancy of coverage is currently considered through CHIT's evaluation of degrees of coverage, but it will likely become an increasingly important factor when more FCEVs are on the road and primary markets branch off into nearby secondary markets.

Additionally, the currently funded network of 50 stations enables inter-regional travel between northern and southern California thanks to the station at Coalinga. Similar to redundancy in a local market, redundancy on this inter-regional corridor is necessary; multiple fueling options along the trip help minimize the risk of running out of fuel because any given station is unavailable. Moreover, the Coalinga station is the first true connector station in the state. More connectors are needed for travel along other similarly long routes, such as between the LA basin and Las Vegas, and between the San Francisco Bay Area and Oregon. Other connectors for inter-regional travel at smaller scales will also be necessary, such as between Riverside and San Diego, between the Sacramento Valley and the San Francisco Bay Area, and others. Connector stations may even eventually evolve to have their own design specifications separate from local market-serving stations, given the nature of the type of travel they enable.

Finally, destination travel has also been enabled by the currently funded network, with stations in Santa Barbara and Truckee. These stations allow travel to two of California's many popular vacation and sightseeing destinations. As the network grows, customers will continue to expect increasing utility from the hydrogen fueling network and will expect to be able to reach all the same vacation and travel destinations as drivers of gasoline vehicles. Connector stations will help address this for some of California's more remote destinations, but stations located at the vacation locales will also be necessary to ensure availability of fueling. Moreover, the current focus on coverage in California's network development doesn't necessarily emphasize redundancy of stations in these destination locations (though it does not preclude it, either). Eventually, redundancy will be necessary at vacation destinations, just like in the core adopter markets. In some cases, this could actually have the additional benefit of building a local secondary market; there are already indications of the potential for this type of development in Santa Barbara.

XV.C. Future sources of hydrogen for FCEVs

Much of the hydrogen currently dispensed for light-duty transportation is produced by conventional reformation of methane or reformation of biogas; a non-trivial amount is also supplied by renewable electrolysis, typically on-site at the fueling station. Much of the conventionally produced hydrogen is currently sourced from the facilities that also supply hydrogen to other industries, such as oil refineries, semiconductor manufacturers, and food transportation companies. The hydrogen provided for vehicle fueling has at times been described as marginal excess within the industry. ARB is aware that most hydrogen production and liquefaction facilities are located outside of California and concentrated in the East Coast and Northeastern states. While this presents uncertainty for the future of sourcing hydrogen for high volumes of FCEV deployment, it also presents an opportunity for future development in line with the State's goals for renewably-sourced and low-carbon energy.

One concept that is currently gaining wide-ranging support at both the State and federal levels is the concept of hydrogen as an energy carrier to enable increased implementation of renewables on the electric grid. The base concept is a more holistic vision of the entire energy system, with hydrogen as intermediary between many primary and final energy resources. Several variations of this concept have gone by different names, such as power-to-gas (P2G) or hydrogen at scale (H2@Scale, per DOE).[110,111] This type of system anticipates significant over-generation of electric power and energy in future scenarios with high penetration of renewable (solar, wind, etc…) resources on the electric grid. In order to capture this energy, the excess electric power can be directed towards large-scale deployment of electrolyzers. The electrolyzers convert the electric energy into hydrogen, which can be stored for later use. That later use can include conversion back to electricity through fuel cells at times of low renewable energy availability, conversion to methane and injection into the existing pipeline, injection into dedicated hydrogen pipelines, upgrading of biofuels, or distribution to hydrogen fueling stations for transportation fuel. In June of 2016, DOE revealed hydrogen at scale to be a candidate for its next "Big Idea;" if adopted by the White House administration, significant effort at the DOE can be dedicated to the concept.

In addition, many bio-derived and bio-mimicking hydrogen production pathways are currently under research. Conversion of biomass and bioliquids, through advanced fermentation pathways, are currently under development. Processes that directly utilize sunlight in synthetic photosynthesis are also progressing at the laboratory scale and may eventually play a significant role in increasing the degree of renewable energy implementation for hydrogen production. While ARB is tracking these developments, there is currently too much uncertainty to project the degree to which each of these options may supply the future hydrogen fueling network.

XVI. California's Hydrogen Infrastructure Initiatives

XVI.A. State roles and collaboration

California has long been a leader in the nation and even the world in the implementation of hydrogen fueling infrastructure and deployment of FCEVs. Arriving at today's retail fueling network has taken decades of policy, research, demonstration, development, and leadership in public and private organizations at all levels. At the State level in particular, several agencies work in cooperation to support the role of FCEVs in meeting the governor's climate and air

[110] CHBC 2015. California Hydrogen Business Council. Power-to-Gas: The Case for Hydrogen White Paper. October 2015. https://californiahydrogen.org/sites/default/files/CHBC%20Hydrogen%20Energy%20Storage%20White%20Paper%20FINAL.pdf.

[111] US DOE 2016. United States Department of Energy. H2@SCALE: Deeply Decarbonizing our Energy System. July 2016. http://www.energy.gov/sites/prod/files/2016/07/f33/fcto_webinarslides_h2_at_scale_072816.pdf.

pollution goals and to help the industry overcome the hurdles of establishing and growing early FCEV and hydrogen markets.

In addition to the ZEV regulation itself, the ARB currently has two main roles as related to deployment of light-duty FCEVs. The ZEV regulation incentivizes the early and rapid development and deployment of FCEVs and BEVs as solutions to meeting the State's greenhouse gas reduction goals and to meet federal ambient air quality standards. In order to support the consumers who purchase or lease an FCEV, the ARB also manages the Clean Vehicle Rebate Project, which provides a rebate to ZEV purchasers. For further discussion of complementary policies and rebates applicable to ZEVs, see Appendix E. In addition, with the passage of AB 8, ARB collaborates extensively with the Energy Commission to plan and develop the early hydrogen fueling network. ARB's official role in this process is to track and analyze the progress of FCEV and hydrogen fueling deployment and to annually provide guidance to the Energy Commission on areas where additional funding for new infrastructure is most needed.[112] ARB also provides recommendations of the capacities and station design features that are necessary at that time. While this is ARB's official role, the agency also works closely on a day-to-day basis with the Energy Commission and other agencies to work on addressing challenges in the early network deployment as they arise and are identified.

Under AB 8, the Energy Commission is responsible for administering funding incentives to support the development of the early hydrogen fueling network.[113] AB 8 allows the Energy Commission to utilize up to $20 million per year through 2023, until at least 100 stations are built or the network exhibits self-sufficiency. To date, all incentives administered by the Energy Commission have been in the form of cost-sharing grant programs, with the State providing up to 85% of capital costs and up to $300,000 to cover operations and maintenance expenses.[114,115] The Energy Commission does have the flexibility under AB 8 to consider alternative funding structures should it find sufficient reason to do so. Examples of alternatives include loan loss guarantees, market assurance grants, low or no-cost loans, and tax incentive structures. Like the ARB, the Energy Commission collaborates with colleagues across agencies in capacities beyond this official role in order to ensure success of the early State co-funded hydrogen network and FCEV market.

The Governor's Office of Business and Economic Development also has a key role in the coordinated State effort to establish hydrogen fueling statewide. In 2014, GO-Biz established a ZEV coordinator to facilitate public-private partnerships towards this common goal. The ZEV coordinator has been responsible for maintaining day-to-day contact with hydrogen fueling station developers to track and gather detailed information about the development process at individual stations and for the network as a whole. The ZEV coordinator has also been instrumental in building consensus among industry members and State agencies for key developments in the hydrogen station network, like the recently implemented practice of "Soft Opening" new stations. The ZEV coordinator also leads support in working with local

[112] Assembly Bill No. 8
[113] Ibid.
[114] Energy Commission 2016b
[115] Energy Commission 2015

jurisdictions where hydrogen stations are planned. The ZEV coordinator has helped educate local officials new to hydrogen fuel, explained the benefits for the local community and state, and expressed the State's commitment to greenhouse gas reduction goals with FCEVs as a key enabling technology.

Finally, the California Department of Food and Agriculture's Division of Measurement Standards (DMS) has been closely involved with the testing and certification of hydrogen station equipment. Currently, DMS tests and certifies new hydrogen dispenser equipment accuracy under the California Type Evaluation Program (CTEP). This program, which defines standards for dispenser accuracy classes, has allowed for the world's first retail sale of hydrogen by the kilogram to occur in California. In addition, DMS tests hydrogen fuel quality at stations on a regular basis, at times and conditions typically defined as requirements within the Energy Commission's grant solicitations. Like the remaining agencies, DMS also remains an active participant in ongoing discussions of anticipated challenges for the hydrogen fueling network and proposed solutions, especially for issues of certification and testing of new stations.

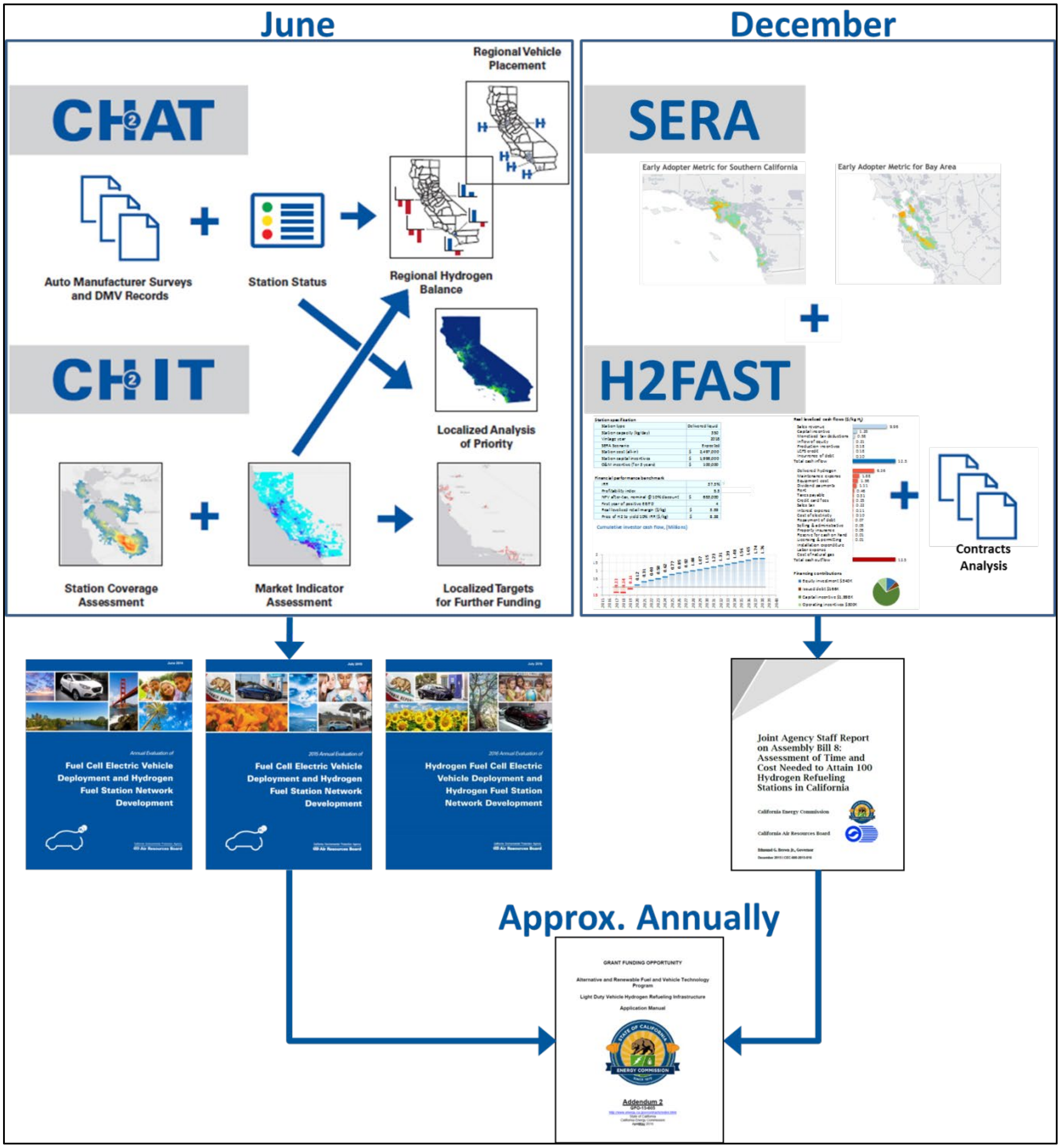
XVI.B. State initiatives

XVI.B.i. AB 8

In 2013, the State of California passed Assembly Bill 8. Among numerous other provisions, AB 8 directed ARB and the Energy Commission to cooperatively establish the state's base hydrogen fueling network. AB 8 established the availability of up to $20 million annual in funds that could be managed by the Energy Commission towards this effort. Additionally, AB 8 established a bi-annual cycle of analysis and reporting to guide the decision-making process for continued investments year after year. Under AB 8, ARB is charged with analyzing the progress and projections of FCEV deployment and hydrogen fueling station development.[116] Every June, ARB synthesizes its analysis into an Annual Evaluation delivered to the Energy Commission that provides recommendations for location, capacity, and technical capability of new stations to be funded under AB 8. In order to complete this analysis, ARB has created the CHIT/CHAT tools, which together track the progress and allow ARB to perform geospatial analysis of future needs. In addition, ARB's analysis relies on up-to-date FCEV registration data from DMV, annual auto manufacturer surveys of future ZEV deployment plans, and open-source geospatial demographic data, primarily obtained from the U.S. Census Bureau.[117]

[116] Assembly Bill No. 8
[117] ARB 2015a

Figure 34 - Annual Cycles of Analysis, Reporting, and Funding Under AB 8



Every December, the Energy Commission leads the development of a Joint Agency (with ARB) Staff Report. The Staff Report is intended to provide insight on typical costs and timing of developing hydrogen fueling stations. In addition, this analysis is synthesized into an estimate of the total time and State investment necessary to bring the network to either at least 100 fueling stations or the point where the network is self-sufficient. In order to make these assessments, the first Joint Agency Staff Report incorporated geospatial analysis through NREL's SERA model, financial performance analysis through H2FAST, and Energy

Commission-led analysis of grant contracts and individual project progress.[118,119] Figure 34 shows the annual cycle of analysis, which leads to the two annual reports. Ultimately, the content of these reports guides the development of the Energy Commission's (approximately) annual grant solicitations for hydrogen fueling infrastructure, such as the current GFO-15-605.

XVI.B.ii. ZEV Action Plan

In 2012, Governor Brown issued Executive Order B-16-12, requiring the State of California to accelerate ZEV adoption, with a goal of 1.5 million ZEVs deployed in California by 2025. In response, an interagency working group headed by the Governor's Office released the first ZEV Action Plan in 2013, outlining several key actions for several State agencies to complete in order to ensure the Governor's goals for ZEV adoption.[120] Over the next few years, the agencies worked towards these goals alongside their existing ZEV-related programs, partnering with stakeholders across other agencies at various jurisdiction levels (State, County, City, etc…) and within industry as necessary. In 2016, the ZEV Action Plan was updated to report on progress made in the intervening time and provide any necessary adjustment of the Action Plan items. Action items in the 2016 update will help California state agencies retain focus and direction in efforts to support the growing FCEV market and hydrogen infrastructure network and include the following:[121]

- Facilitate highway signage directing FCEV drivers to stations
- Increase availability of hydrogen stations in areas of low adoption and disadvantaged communities
- Incentivizing renewable hydrogen production
- Continue oversight of hydrogen fueling station operations and retail advertising and sale of hydrogen fuel, including development of new technologies and techniques for validating station performance and fuel quality
- Encourage integration of hydrogen production, storage, and dispensing into demand-side management of electric infrastructure and enable wider integration of renewables into the electric grid
- Coordinate with local jurisdictions to continue development of infrastructure plans and make use of available federal funding opportunities
- Explore deployment of hydrogen fueling stations at rest stops and Caltrans facilities
- Expand outreach efforts, including to local authorities and first responder agencies
- Participate in multi-state and international efforts to advance hydrogen and FCEV adoption and readiness
- Encourage State agency integration of FCEVs into their fleets

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[118] Energy Commission 2015
[119] Energy Commission 2016a
[120] Gov 2013. Governor's Interagency Working Group on Zero-Emission Vehicles. 2013 ZEV Action Plan. February 2013.
[121] Gov 2016. Governor's Interagency Working Group on Zero-Emission Vehicles. 2016 ZEV Action Plan. October 2016.

XVI.B.iii. HyStEP

As a means to support swift deployment of hydrogen fueling stations, the State of California has developed and begun implementing the Hydrogen Station Equipment Performance (HyStEP) program. Stations that are built in California are required to adhere to the dispenser protocol standard SAE J2601-2014.[122] The J2601 standard defines acceptable hydrogen fueling pressurization rates, accounting for ambient conditions and system state, such as the temperature of hydrogen exiting the chiller and the starting pressure in the storage tank onboard the vehicle being fueled. Before a station can be opened to the public, the ability of the dispenser to follow these safety-based protocols must be validated.

While the standard exists, there is no entity that formally certifies individual dispensers are able to meet the protocol's requirements. For the past several years, the solution has been for individual auto manufacturers to individually coordinate with station developers and perform serial testing of a new station's dispenser. This testing would provide confirmation of acceptance of the station's dispenser by each individual auto manufacturer. While this provided comprehensive testing, it was often costly (both to the station developer and auto manufacturer) and would require an extended period of time to complete, as schedules would need to be coordinated between several business entities and re-testing would often be required, as shown in the top half of Figure 35.

In order to develop a path to a more expedited station confirmation process, several agencies and partners in California initiated the HyStEP program, built around the development of an appropriate testing device. With funding provided by the DOE Fuel Cell Technology Office under the H2FIRST project, Sandia National Laboratories and NREL contracted with Powertech Labs to develop and build the HyStEP device. Specifically, the device has been designed to carry out the test methods of CSA HGV 4.3, which is a prescribed testing method to measure that stations follow SAE J2601-2014.[123,124] The HyStEP device is additionally able to test IrDA communications per the vehicle-station communications protocol SAE J2799.[125] The ultimate goal is that the HyStEP device (or a similar future version) could be utilized by a certification agency or private entity to test new station dispenser performance and provide authoritative confirmation that the dispenser is able to operate within the expected bounds of the standard protocol. The vision, as shown in Figure 35, is for the single HyStEP test to be capable of performing the same validation within a single week as is currently completed within several weeks under the serial auto manufacturer testing.

Currently, HyStEP is operated by ARB with staff from DMS to test new station dispenser performance. The device was first delivered to the State in December of 2015 and performed validation testing (of the device's own performance) at the Santa Barbara and Diamond Bar

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122 SAE 2014a. SAE International. J2601: Fueling Protocols for Light-Duty Gaseous Hydrogen Surface Vehicles. July 2014. http://standards.sae.org/j2601_201407/

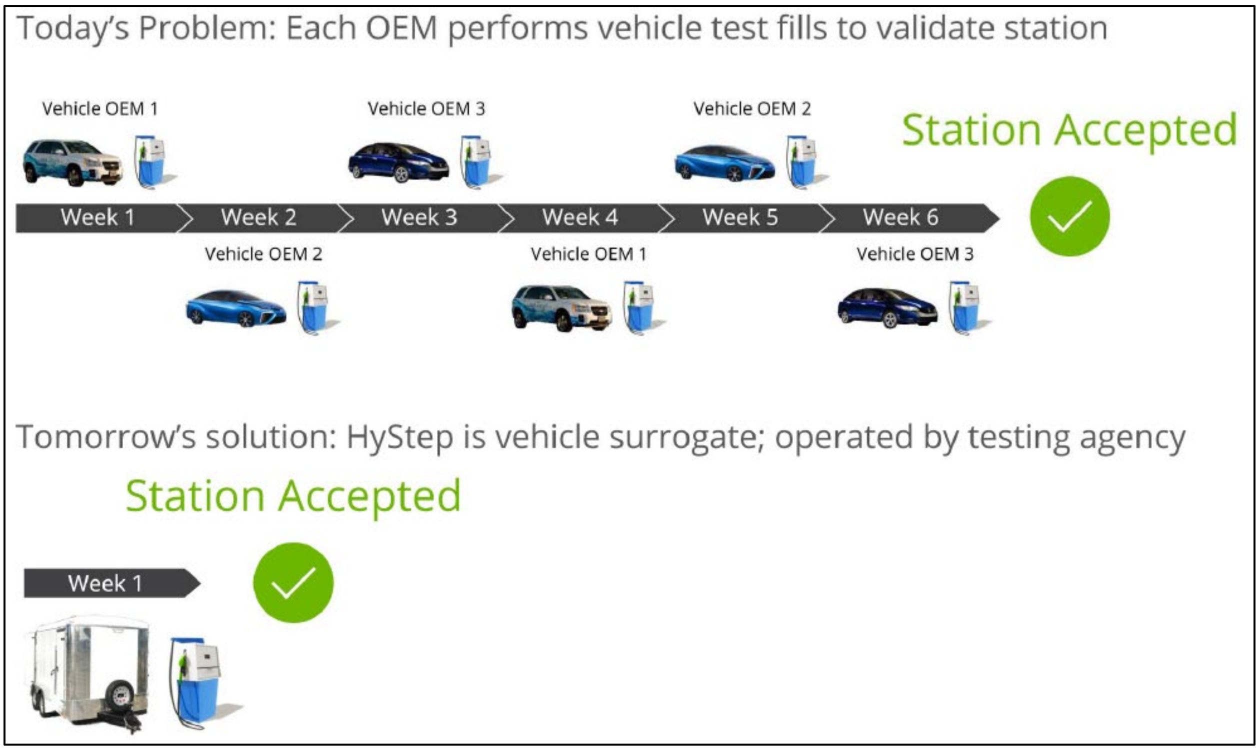
123 Ibid.

124 CSA 2016. CSA Group. ANSI/CSA HGV 4.3-2016- Test Methods for Hydrogen Fueling Parameter Evaluation. 2016. http://shop.csa.ca/en/canada/hydrogen-gas-vehicle-and-fueling-installations/ansicsa-hgv-43-2016/invt/27033762016

125 SAE 2014b. SAE International. J2799: Hydrogen Surface Vehicle to Station Communications Hardware and Software. April 2014. http://standards.sae.org/j2799_201404/

stations with the participation of several auto manufacturers to provide comparative data. On May 27, 2016, the auto manufacturer advisory group of the CaFCP also provided a letter of support for the device and program, indicating acceptance of the device as a supplement to current auto manufacturer testing.[126] To date, the HyStEP device has also tested the dispensers at the CSULA, Riverside, Woodland Hills, and Anaheim stations; several more station tests are expected by the end of the year. ARB expects to initiate drafting a plan to develop an independent certification program based on HyStEP, without requiring concurrent auto manufacturer testing.

Figure 35 - Current Serial-Testing of New Station Commissioning and Potential Single Device Testing with HyStEP[127] (originally attributed to Terry Johnson of Sandia National Laboratories, Pacific Northwest National Laboratory, and the H2Tools program)



XVI.B.iv. HFS and CTEP

Similar to the HyStEP program, California has also been a leader in developing methods and programs to test and validate hydrogen dispenser meter accuracy. In order for fuel retailers to sell hydrogen to retail customers by the kilogram (as opposed to relying on signed service contracts), dispensing meters must be certified as capable of measuring dispensed fuel to within acceptable tolerances. Prior to 2014, no agency in the state had developed a meter accuracy testing method, device, or program. Thus, several agencies worked together to develop the

[126] CaFCP 2016. California Fuel Cell Partnership OEM Advisory Group. Letter to HyStEP Stakeholder Partners. May 2016.
[127] ARB 2016a

Hydrogen Field Standard (HFS) and new hydrogen-specific subsections of the California Type Evaluation Program (CTEP), which provided the first capability in the world to certify hydrogen fueling dispensers as accurate enough to sell hydrogen fuel by the kilogram.

The program, currently operated by the Division of Measurement Standards at the California Department of Food and Agriculture, certifies station dispenser accuracy within one of four different classes, as shown in Table 10. The accuracy classes are expanded versions, based on those previously adopted into NIST Handbook 44.[128] At the time of developing the HFS program, California recognized that the standards in Handbook 44 were too stringent for dispenser meters readily available on the market. Thus, less stringent standards were also incorporated into the HFS program. These expanded standards will sunset over time, so that industry remains incentivized to develop increasingly capable hydrogen fuel meters. To date, all certified dispensers have met the 5% accuracy class.[129]

Table 10 - Accuracy Class Definitions used in HFS Program

Accuracy Class	Acceptance Tolerance	Maintenance Tolerance
2.0	1.5 %	2.0 %
3.0 *	2.00%	3.00%
5.0 *	4.00%	5.00%
10.0 **	5.00%	10.00%

In order to carry out the certification program, the HFS device was developed through the cooperative effort of ARB, the Energy Commission, CDFA, and NREL. The device, shown in Figure 36, is operated by CDFA and is now used to certify the accuracy of all dispensers used at California's hydrogen fueling stations. As part of CTEP, certification of hydrogen dispenser accuracy with HFS is established for a given dispenser design. A hydrogen dispenser manufacturer thus has a particular design type-certified at the first station utilizing that design in the state. Type certification of a hydrogen dispenser requires several days to complete. Once certified to a given accuracy class, other copies of that design installed at other locations can then be certified to meet the same accuracy class with an abbreviated set of tests. This helps accelerate station commissioning and deployment. In addition, the actual dispenser testing may be performed by Registered Service Agents rather than CDFA, which allows flexibility in scheduling. Many local jurisdictions are registered as RSAs with CDFA, and to date one station developer has also become an RSA, offering their testing services to other developers.

[128] NIST 2015. National Institute of Standards and Technology. Handbook 44: Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices. November 2015. https://www.nist.gov/pml/weights-and-measures/publications/nist-handbooks/handbook-44
[129] DMS 2016

Figure 36 - HFS Device Being Set-Up to Perform a Station Accuracy Confirmation Test

XVI.B.v. LCFS

ARB's LCFS provides standards and a credit trading market for a broad range of fuel providers to produce and distribute transportation fuels that have progressively lower carbon content. While the program has thus far had a major focus on fossil fuel providers, recent activity has broadened the potential scope for inclusion of hydrogen fuel producers and retailers. Recently, ARB staff provided draft changes to the program which included provisions to count hydrogen as a mandatory regulated fuel (as opposed to an opt-in fuel), allow the fuel retailer to be the primary recipient of credits (as opposed to the fuel producer as is the case for fossil fuels), and incorporate aspects of SB1505's requirements for hydrogen production to include at least 33% renewable feedstock and process energy.[130] These draft changes allow the existing LCFS program to be harmonized with the SB1505 requirements that have not yet been enacted through regulation and potentially provide means of improving the business case for hydrogen station developers and the cost of ownership for FCEV drivers.

In addition, in late 2015, the LCFS program began receiving increased interest from the hydrogen fueling industry. In November, AC Transit, which operates the Emeryville combined light-duty and bus hydrogen fueling station, became the first entity to join the LCFS program and produce credits through the production of hydrogen. The solar-powered electrolysis pathway

[130] ARB 2016c. California Air Resources Board. Preliminary Draft of Proposed Regulatory Amendments, Low Carbon Fuel Standard. June 2016.

that provides a share of the hydrogen dispensed on the light-duty side of the station was certified by LCFS staff with a 0 gCO_2/MJ carbon intensity.[131] Subsequently, two other companies, LyTen and Fuel Cell Energy, had their hydrogen production pathways provisionally certified.[132] A provisional certification signifies LCFS staff validation of the pathway's calculated carbon intensity, though no facility has yet been built to demonstrate the technology. All of these pathways were certified with very low carbon intensities; several were even negative, signifying the pathway is effectively capable of sequestering carbon in the fuel production process. In its June 2016 Annual Evaluation, ARB discussed the potential impact that participation in the LCFS program can have on the business case for hydrogen fueling station operators. As indicated in Table 11, these low-carbon hydrogen production pathways have the potential to generate significant revenue that can represent a cost savings to the station operator and potentially the end consumer.

Table 11 - Carbon Intensities and Potential Revenue for new Hydrogen Pathways in LCFS Program[133]

			Assumed Value per Credit $100
Fuel Pathway	Applicant	Carbon Intensity (gCO2/MJ)	LCFS Value ($/kg)
HYGN009	LyTen	29.84	$2.30
HYGN006	AC Transit	0	$2.66
HYGN011	Fuel Cell Energy	-0.82	$2.67
HYGN008	LyTen	-46.91	$3.22

XVI.B.vi. Fuel Quality

Finally, the State has actively participated in the development of procedures and programs to certify hydrogen dispensed at fueling stations meets requirements as described in the standard SAE J2719.[134] Table 12 lists the contaminants whose presence is required to be tested for under J2719. All grants awarded by the Energy Commission require hydrogen quality testing prior to a station becoming open and at least once every three months thereafter.[135] CDFA may also perform quality testing in response to any consumer reports of problems with hydrogen quality at specific dispensers.

Although a testing period of at least every three months is typically sufficient to ensure long-term achievement of high purity standards, there have been a few cases in which customers have received hydrogen fuel with high amounts of impurities. This has at times required auto

[131] ARB 2015b. California Air Resources Board. Staff Summary Method 2B Application Gaseous Hydrogen via Electrolysis (Solar) AC Transit, Emeryville, California. November 2015. https://www.arb.ca.gov/fuels/lcfs/2a2b/apps/act-emca-sum-110515.pdf
[132] ARB 2016b
[133] ARB 2016a
[134] SAE 2015. SAE International. J2719: Hydrogen Fuel Quality for Fuel Cell Vehicles. November 2015. http://standards.sae.org/j2719_201511/
[135] Energy Commission 2016b

manufacturers to tow the vehicles (under warranty) to their repair centers and spend significant amounts of time and effort flushing the fuel cell and hydrogen storage systems in order to remove the impurity. Typically, the impurities have not caused permanent damage to the fuel cell system, though certain impurities do have this potential. Thus, several agencies in California are working together along with private industry partners and the national laboratories in order to develop a device that could test hydrogen purity in real-time as the hydrogen is dispensed. Such a device would be in-line with the fueling dispenser hose, and would test for specific “canary species” that indicate degraded hydrogen purity. Such a device would not be expected to be able to carry out the full suite of testing for all contaminants as shown in Table 12 (which typically takes weeks to complete), but would provide station operators with an early warning system and allow them to shut down fueling operations before impurities are dispensed into several FCEV drivers’ tanks.

Table 12 - Hydrogen Fuel Contaminants Specified in J2719[136]

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
Compressors	Oils

[136] SAE 2015

XVII. References

AFDC 2016, U.S. DOE Alternative Fuels Data Center, data as of 09/29/2016, http://www.afdc.energy.gov/fuels/electricity.html

Air Liquide 2016. Air Liquid Announces Locations of Several Hydrogen Fueling Stations in Northeast U.S.A. April 2016. https://www.airliquide.com/united-states-america/air-liquide-announces-locations-several-hydrogen-fueling-stations-northeast.

ARB 2015a. California Air Resources Board. 2015 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. July 2015. https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf.

ARB 2015b. California Air Resources Board. Staff Summary Method 2B Application Gaseous Hydrogen via Electrolysis (Solar) AC Transit, Emeryville, California. November 2015. https://www.arb.ca.gov/fuels/lcfs/2a2b/apps/act-emca-sum-110515.pdf.

ARB 2016a. California Air Resources Board. 2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. July 2016. https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf.

ARB 2016b. California Air Resources Board. LCFS Pathway Certified Carbon Intensities. March 2016. https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm. Accessed September 26, 2016.

ARB 2016c. California Air Resources Board. Preliminary Draft of Proposed Regulatory Amendments, Low Carbon Fuel Standard. June 2016. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/proposed_regorder_060216.pdf.

Assembly Bill No. 118 (Nunez, Statues of 2007, Chapter 750).

Assembly Bill No. 8 (Perea, Statutes of 2013, Chapter 401).

CaFCP 2012. California Fuel Cell Partnership. A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles (Technical Version). June 2012. http://cafcp.org/sites/default/files/A%20California%20Road%20Map%20June%202012%20%28CaFCP%20technical%20version%29.pdf.

CaFCP 2016. California Fuel Cell Partnership OEM Advisory Group. Letter to HyStEP Stakeholder Partners. May 2016.

CAISO 2014. California Independent System Operator. “Vehicle Grid Integration Roadmap” February 2014. http://www.caiso.com/documents/vehicle-gridintegrationroadmap.pdf

CHAdeMO 2016. CHAdeMO Association Europe, Press Release, June 1, 2016 http://www.chademo.com/wp/wp-content/uploads/2016/06/2016-06-01_High_power_CHAdeMO.pdf

Charin 2016, Charin.org, website accessed September 29, 2016, http://www.charinev.org/ccs-at-a-glance/ccs-specification/

CHBC 2015. California Hydrogen Business Council. Power-to-Gas: The Case for Hydrogen White Paper. October 2015. https://californiahydrogen.org/sites/default/files/CHBC%20Hydrogen%20Energy%20Storage%20White%20Paper%20FINAL.pdf.

CPUC 2012, California Public Utilities Commission, Press Release, April 27, 2012, http://docs.cpuc.ca.gov/word_pdf/NEWS_RELEASE/165145.pdf

CSA 2016. CSA Group. ANSI/CSA HGV 4.3-2016- Test Methods for Hydrogen Fueling Parameter Evaluation. 2016. http://shop.csa.ca/en/canada/hydrogen-gas-vehicle-and-fueling-installations/ansicsa-hgv-43-2016/invt/27033762016.

DMS 2016. California Department of Food and Agriculture Division of Measurement Standard. CTEP Certificate of Conformance Database Search. https://www.cdfa.ca.gov/dms/ctep.html. Accessed September 26, 2016.

DOD 2013. Department of Defense. “DoD Plug-In Electric Vehicle Program” March 2013. http://electricvehicle.ieee.org/files/2013/03/DoD-Plug-In-Electric-Vehicle-Program.pdf

Energy Commission 2015. California Energy Commission. Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California. December 2015. http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf.

Energy Commission 2016a. California Energy Commission. Draft Joint Agency Staff Report on Assembly Bill 8: 2016 Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California. January 2017.

Energy Commission 2016b. California Energy Commission. Grant Funding Opportunity Alternative and Renewable Fuel and Vehicle Technology Program Light-Duty Hydrogen Refueling Infrastructure Application Manual. July 2016. http://www.energy.ca.gov/contracts/GFO-15-605/00_Solicitation_Manual_GFO-15-605_2016-07-11.doc.

EPRI 2013, Electric Power Research Institute, Electric Vehicle Supply Equipment Installed Cost Analysis, December 6, 2013 http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000577

EPRI/NRDC 2015, Electric Power Research Institute and National Resources Defense Council, *Environmental Assessment of a full Electric Transportation Portfolio*, September 17 2015, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=3002006881

Ewanick 2016. Ewanick, Joel, First Element. “Status of the World’s First Retail Hydrogen Network and What’s Ahead.” Advanced Clean Cars Symposium: The Road Ahead. 27

September 2016. South Coast Air Quality https://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/moving_toward_network_expansion_joel_ewanick.pdf

GM 2016, General Motors, 2017 Bolt EV, http://www.chevrolet.com/bolt-ev-electric-vehicle.html accessed September 22, 2016

Gov 2013. Governor's Interagency Working Group on Zero-Emission Vehicles. 2013 ZEV Action Plan. February 2013. https://www.opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf.

Gov 2014. Governor's Interagency Working Group on Zero-Emission Vehicles. 2016 ZEV Action Plan. October 2016. https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf.

Green Car 2016. Green Car Reports. Price cut and monthly sales spike for Toyota Mirai fuel-cell sedan. September 2016. http://www.greencarreports.com/news/1106296_price-cut-and-monthly-sales-spike-for-toyota-mirai-fuel-cell-sedan. Accessed September 26, 2016.

ICC 2016. International Codes Council, 2016 Green Building Standards Code 2016, http://codes.iccsafe.org/app/book/toc/2016/California/Green/index.html

ICCT 2016. International Council on Clean Transportation, *Sustaining Electric Vehicle Market Growth in U.S. Cities,* October 2016.

INL 2014, Idaho National Laboratory, "What Kind of Charging Infrastructure Did Nissan Leaf Drivers in The EV Project Use and When Did They Use It?" The EV Project, INL, 2014 https://avt.inl.gov/sites/default/files/pdf/EVProj/LeafHomeAwayL1L2DCDayNightCharging.pdf

INL 2015, Idaho National Laboratory, "Characterize the Demand and Energy Characteristics of Residential Electric Vehicle Supply Equipment", June 2015 https://avt.inl.gov/sites/default/files/pdf/EVProj/CharacterizeEnergyDemandResidentialEVSE.pdf

InsideEv 2016. InsideEV.com, website accessed September 29, 2016, http://insideevs.com/abb-joins-charin-150-kw-charging-coming-soon-350-kw-targeted-future/

Kuby 2009. Kuby, M., Lines, L., Schultz, R., Xie, Z., Kim, J., and Lim, S. 2009, "Optimization of hydrogen stations in Florida using the flow-refueling locations model," International Journal of Hydrogen Energy, 34(15), 6045-6064.

Kelley 2013. Scott Kelley and Michael Kuby. 2013, "On the way or around the corner? Observed refueling choices of alternative-fuel drivers in Southern California," Journal of Transport Geography, 33, 258-267.

LBNL 2013. Ernest Orlando Lawrence Berkeley National Laboratory "Los Angeles Air Force Base Vehicle to Grid Pilot Project" June 3-8, 2013. https://drrc.lbl.gov/sites/all/files/lbnl-6154e.pdf

Navigant 2015. Navigant Research, "Electric Vehicle Market Forecasts Global Forecasts for Light-Duty Hybrid, Plug-In Hybrid, and Battery Electric Vehicle Sales and Vehicles in Use: 2015-2024", Navigant Research, Quarter 4, 2015, https://www.navigantresearch.com/research/electric-vehicle-market-forecasts

Navigant 2016. Navigant Research. Level 1, Level 2, DC Fast Charging, and Wireless Charging for Residential and Commercial Applications: Global Market Analysis and Forecasts, Quarter 2, 2016, https://www.navigantresearch.com/research/electric-vehicle-charging-services

NEESC 2015. Northeast Electrochemical Energy Storage Cluster. Station Maps. June 2015. http://h2usa.org/station-maps. Accessed September 26, 2016.

Nicholas 2010a. Michael A. Nicholas. 2010, "Driving Demand: What can gasoline refueling patterns tell us about planning an alternative fuel network?," Journal of Transport Geography, 18, 738-749.

Nicholas 2010b. An Analysis of Near-Term Hydrogen Vehicle Rollout Scenarios for Southern California. Davis: Michael Nicholas and Joan Ogden, 2010.

NIST 2015. National Institute of Standards and Technology. Handbook 44: Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices. November 2015. https://www.nist.gov/pml/weights-and-measures/publications/nist-handbooks/handbook-44.

NREL 2011. National Renewable Energy Laboratory. Scenario Evaluation, Regionalization & Analysis (SERA). January 2011. http://en.openei.org/wiki/Scenario_Evaluation,_Regionalization_&_Analysis_(SERA). Accessed September 26, 2016.

NREL 2014. National Renewable Energy Laboratory, "California Statewide Plug-In Electric Vehicle Infrastructure Assessment", May 2014 http://www.energy.ca.gov/2014publications/CEC-600-2014-003/CEC-600-2014-003.pdf

NYSERDA 2016. New York State Energy Research and Development Authority, web-site accessed October 19, 2016, https://www.nyserda.ny.gov/Researchers-and-Policymakers/Electric-Vehicles/Info/Charging-Station-Hosts

Ogden 2010. Ogden, Joan, Cunningham, Joshua, and Nicholas, Michael. 2010,Roadmap for Hydrogen and Fuel Cell Vehicles in California: A Transition Strategy Through 2017. February 2010. file:///C:/Users/amartine/Downloads/2010-UCD-ITS-RR-10-04.pdf.

SAE 2014a. SAE International. J2601: Fueling Protocols for Light-Duty Gaseous Hydrogen Surface Vehicles. July 2014. http://standards.sae.org/j2601_201407/.

SAE 2014b. SAE International. J2799: Hydrogen Surface Vehicle to Station Communications Hardware and Software. April 2014. http://standards.sae.org/j2799_201404/.

SAE 2015. SAE International. J2719: Hydrogen Fuel Quality for Fuel Cell Vehicles. November 2015. http://standards.sae.org/j2719_201511/.

Senate Bill No. 1505 (Lowenthal, Statues of 2006, Chapter 877).

Stephens-Romero 2012. Stephens-Romero, Shane D., Brown, Tim M., Kang, Jae E., Recker, Wilfred W., and Samuelsen, G. Scott. 2010, "Systematic planning to optimize investments in hydrogen infrastructure deployment," International Journal of Hydrogen Energy , 35, 4652-4667.

Tesla 2016. Tesla Motors, Tesla Model 3, https://www.tesla.com/model3, accessed September 22, 2016

US DOE 2015, United States Dept. of Energy, "Costs Associated With Non-Residential Electric Vehicle Supply Equipment", Nov. 2015 http://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf

US DOE 2016. United States Department of Energy. H2@SCALE: Deeply Decarbonizing our Energy System. July 2016. http://www.energy.gov/sites/prod/files/2016/07/f33/fcto_webinarslides_h2_at_scale_072816.pdf.