California Fuel Cell Partnership
DRIVING FOR THE FUTURE

California Fuel Cell Partnership
3300 Industrial Blvd.
Suite 1000
West Sacramento, CA 95691
(916) 371-2870

www.fuelcellpartnership.org
info@cafcp.org

September 30, 2013

California Energy Commission
Dockets Office, MS-4
Re: Docket No. 13-ALT-02, 2014-2015 Investment Plan Update
1516 Ninth Street
Sacramento, CA 95814-5512

Commissioner Scott:

The California Fuel Cell Partnership is pleased to provide input for the upcoming 2014-2015 Investment Plan. We appreciate the California Energy Commission's continued support for developing hydrogen fueling infrastructure and the hard work behind each of the previous Investment Plans and subsequent PONs. Thank you for your leadership in helping develop the commercial market for fuel cell electric vehicles (FCEV) and fuel cell electric buses (FCEB).

We will submit the recent CaFCP plans outlining the next steps for commercialization of both light duty FCEVs and heavy duty FCEBs to the 2014-2015 Investment Plan docket for your convenience, to serve as guides for moving forward. The network of 68 stations identified in *A California Road Map* as necessary to enabling consumer FCEV sales is still our primary need for launching the FCEV market. Recently funded retail-oriented hydrogen stations will help us achieve the Road Map goals, but more stations are needed to develop the network and prevent current stations from becoming stranded assets.

A Road Map for Fuel Cell Electric Buses in California describes the next steps needed for moving the fuel cell bus industry from the final demonstration to an early market. CEC support is vital to achieving the objectives within the plan and establishing the identified Centers of Excellence. Together these two Road Maps are presented as pathways toward achieving California's environmental, economic and energy independence goals.

Government funding support is necessary to enable the market launch of both FCEVs and FCEBs. Hydrogen infrastructure for FCEVs is not home or fleet based; it requires an established and publicly accessible retail infrastructure before people will purchase or lease a vehicle. *A California Road Map* outlines why initial public investments, such as the funding proposed in this investment plan, are necessary and can be accomplished in an efficient and effective manner. To support the development of this initial infrastructure network, CaFCP members agree with the $20M in funding for public hydrogen fuel stations in the 2014-2015 Investment Plan, as presented by CEC during the May 8, 2013 workshop. We suggest additional support for transit-only FCEB hydrogen fuel stations to take the next steps toward the early commercial market. The following feedback is intended to provide specific input on how funding might best be directed to reach commercialization goals.

"Alternative Fuel Production" – Consider creating a funding category that allows for the development and implementation of large scale (>500kg/day) renewable hydrogen fuel production technologies in California. This will benefit cost reduction of these technology pathways and the "at the pump" cost of renewable hydrogen fuel when fuel cell vehicles are launched in the market in 2015-2017 and beyond.

"Alternative Fuel Infrastructure" – CaFCP supports the proposed $20M for public hydrogen stations for light duty FCEVs to expand the station network toward the 68 station goal. Considering the hydrogen fuel station market is still young and developing rapidly, we suggest CEC develop PONs that provide the greatest flexibility for bidders and integrates feedback from industry experts. The workshops CEC held and draft PONs CEC issued over the past few years provided considerable input and feedback for reference.

"Alternative Fuel Vehicles" – Consider including a placeholder for funding the Clean Vehicle Rebate Project (administered by ARB) specifically for FCEVs. It will be important to have sufficient funding available for consumers leasing or purchasing FCEVs as they come into the market in 2015.

"Medium and Heavy Duty Demonstration" – Designate $9.7M in the 2014-15 and 2015-2016 Investment Plans to cover a portion of the incremental cost for Northern and Southern public transit agencies to purchase a total of 80 heavy duty zero emission fuel cell buses in 12-year revenue service. These buses are expected to operate at 2 Centers of Excellence, as described in the CaFCP's "*A Road Map for Fuel Cell Electric Buses in California*".

"*Other Categories: Emerging Opportunities*" – Consider aligning future PONs with federal Funding Opportunity Announcements (FOA), particularly the timelines related to US Department of Energy FOAs for hydrogen dispensing, stationary storage, sealing and hydrogen generation technology, forecourt compressor, and APU and GSE applications. As CEC has done with previous federal ARRA funding, this will leverage significantly greater dollars and improve opportunities for success. With recent PONs stating the need to use CSA HGV 4.3 test methods to evaluate stations, CEC should consider allocating sufficient funding to validate a testing device before it can be used on stations and/or provide support to station operators (as part of O&M) to test to the most recent edition of SAE J2601.

"Other Categories: Workforce Training and Development" – Consider increasing support of training organizations for first and second responders. CaFCP is working with US DOE to expand these activities with existing training organizations, which could further leverage resources.

"Market and Program Development: Regional Alternative Fuel Readiness and Planning" – Consider eliminating or lowering the cost share requirement percentage for cities and communities, and related supporting non-profit organizations. This would likely result in increased interest and applications for CEC provided funding in this category.

CEC continues to demonstrate California's leadership in nurturing alternative fuels and advanced vehicle technology, and positions the state to benefit from the environmental, economic and energy independence opportunities that fuel cell electric vehicles offer. Thank you again for the opportunity to provide comments. Please do not hesitate to contact me at cdunwoody@cafcp.org or Bill Elrick at belrick@cafcp.org if you have any questions or require clarification.

Sincerely,

Catherine Dunwoody
Executive Director

CC: Charles Smith

Attachments: *A Road Map for Fuel Cell Electric Buses in California*
A California Road Map

A Road Map for Fuel Cell Electric Buses in California

A zero-emission solution for public transit.

March 2013

California Fuel Cell Partnership
3300 Industrial Blvd, Suite 1000
West Sacramento, CA 95691
916-371-2870
www.cafcp.org

California FUEL CELL PARTNERSHIP
DRIVING FOR THE FUTURE

EXECUTIVE SUMMARY

California has made great strides towards improving its air quality over many decades, but transportation remains the state's dominant source of air pollution. If California is to meet its air quality improvement and emissions reduction goals, it must begin developing the commercial markets for zero-emission vehicles (ZEVs) now, including fuel cell electric buses (FCEBs). The magnitude of these changes will require the complete transformation of transportation to zero or near-zero technologies by 2050.

The California Fuel Cell Partnership and its members believe the introduction of fuel cell electric buses in California is key to achieving these goals. However, the environmental benefits of zero-emission vehicles and the policy goals which promote them can only be achieved if the capital and operating costs of FCEBs can be accommodated through local, state and federal budgets. An investment in the deployment of FCEBs, at production volumes rather than multiple small demonstrations, realizes the next critical step towards FCEB commercialization by enabling the cost reductions required for widespread adoption.

A Road Map for Fuel Cell Electric Buses in California establishes a plan for the introduction of FCEBs in California by:

- Illustrating the connection to state policy objectives
- Providing a review of existing demonstrations with an emphasis on California sites
- Analyzing the state of the technology for the vehicles and fueling infrastructure, using the federal government's Technology Readiness Level (TRL) and published DOE/DOT performance, cost and durability targets.

This road map provides a specific strategy and investment cost for the implementation of ***two Centers of Excellence*** in Northern and Southern California. Two centers will allow for economies of scale sufficient to achieve 2016 DOE/DOT targets and begin to overcome the primary barriers to market: the capital cost of the vehicles and the cost of fuel.

Lastly, *A Road Map* offers recommended state and federal actions required to support this strategy and move forward.

The California Fuel Cell Partnership is a collaboration of organizations, including auto manufacturers, energy providers, government agencies and fuel cell technology companies, that work together to promote the commercialization of hydrogen fuel cell electric vehicles. By working together, we help ensure that vehicles, stations, regulations and people are in step with each other as the technology comes to market.

INTRODUCTION

While California has made great strides towards improving its air quality over many decades, residents living in several regions still experience the worst air quality in the nation.[1] Transportation remains the state's dominant source of air pollution. About 96% of the vehicles in California use petroleum-based fuels, and produce 50% of the criteria pollutants and 38% of greenhouse gas emissions.

Transportation-related air pollution will need to be reduced by 90-95% below 2010 levels by 2050 if these regions are to meet national health-based air quality standards as required by federal law,[2] and greenhouse gas emissions from transportation will need to fall by 85%. Both are necessary to meet California's 2050 climate goals.[3] The magnitude of the changes needed in the coming decades will require the complete transformation of transportation to zero or near-zero technologies by 2050. If California is to meet its emissions reductions goals it needs to begin developing the commercial markets for zero-emission vehicles (ZEVs), including buses, now.

Light-duty passenger vehicles and heavy-duty vehicles -especially buses- powered by hydrogen fuel cells will be an important element in California's plan to achieve its targets for air quality and pollution reductions. The critical role of zero-emission buses is acknowledged in Governor Brown's *2013 ZEV Action Plan*.[4]

California has gained considerable experience with the development and demonstration of zero-emission vehicle (ZEV) technologies through its zero-emission bus (ZBus) program. Fuel cell buses have consistently demonstrated superb operating performance in their ability to maintain sustained power and acceleration in a wide spectrum of operating conditions, smooth and quiet operation, and unmatched fuel efficiency.

The ZBus program takes advantage of the fact that transit agencies tend to be first adopters of advanced heavy-duty vehicle technologies. Such programs enable the private sector to adopt these technologies. Supporting ZEBs will not only help local transit agencies contribute to reduced on-road emissions, it will also help develop the technology for use in other medium and heavy-duty platforms.

These environmental benefits and policy goals can only be achieved, however, if buses are available at capital and operating costs that meet the budgets of transit as well as state and federal agencies. Achieving these targets is possible with the deployment of fuel cell electric buses (FCEBs) at production volumes rather than through small demonstration fleets, an approach supported by the funding model for zero and near-zero emission buses in the federal transportation bill "Moving Ahead for Progress in the 21st Century Act" (MAP-21).[5]

A Road Map for Fuel Cell Electric Buses in California was created by members of the California Fuel Cell Partnership to address the question: **"How can FCEBs become one of the advanced vehicle technologies that transit agencies will choose to fulfill California's goal of decreasing transportation air pollution?"** This strategy document characterizes the steps necessary to move from the pre-commercial phase of FCEB deployment and manufacturing (2012-2015) to the early commercial phase (2016- 2017) to a commercial model in 2018 and beyond, including the requisite fueling infrastructure. It draws the best available information from members and other stakeholders involved with the deployment of fuel cell buses and fueling stations.

---

[1] American Lung Association, State of the Air 2012. http://www.stateoftheair.org/.

[2] CARB, SCAQMD & SJVAPCD, June 27, 2012. Vision for Clean Air: A Framework for Air Quality and Climate Planning, Public Review Draft. http://www.arb.ca.gov/planning/vision/vision.htm. **Note**: Interim targets for NOx under State Implementation Plans (SIPs) seek 80 percent reductions below 2010 levels by 2023, and nearly 90 percent reductions by 2032

[3] *Ibid.*, Also see: Governor Schwarzenegger Executive Order S-3-05, June 1, 2005., Also see: Governor Brown Executive Order B-16-2012, March 23, 2012.

[4] Available at: http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf.

[5] Available at: http://www.fmcsa.dot.gov/about/what-we-do/MAP-21/Map21.aspx.

California context, policy goals

In 1990, as one of its strategies, the California Air Resources Board (ARB) adopted an ambitious program to dramatically reduce the environmental impact of light-duty vehicles through the gradual introduction of zero-emission vehicles (ZEVs). The state's commitment to zero-emission vehicles reflects the understanding that advanced vehicle technology is necessary to achieve public health goals, including reductions in criteria pollutants and greenhouse gas emissions. It also reflects the fact that several regions continue to exceed state and federal air quality standards.

Following the implementation of the ZEV program, the ARB created the Zero-Emission Bus (ZBus) regulation in January 2000 which mandated ZBus demonstration fleets, leading to a 15% purchase requirement for transit agencies with fleets larger than 200 urban buses.[6,7] Industry responded to the ARB regulation with competitive development activities and a series of improved bus designs, including fuel cell electric buses (FCEBs). The development of the hybrid fuel cell electric bus led to ZBuses with a 250- to 300-mile range and fuel economy nearly twice that of conventional technology. Worldwide, more than 10 bus manufacturers have incorporated hybrid fuel cell electric drive trains into their buses, which have accumulated millions of miles in daily revenue service. The largest demonstration test programs in North America are located in the San Francisco Bay Area, which is served by a fleet of 12 FCEBs; and Whistler Village in Canada, where 20 FCEBs make up the majority of the bus fleet. In recent years, the 15% purchase requirement of the ZBus regulation was placed on hold to allow for technology enhancements, cost reduction and more definitive demonstration data from the most recent series of FCEBs.

To encourage further progress with California's environmental, technology, and energy goals, Governor Brown signed Executive Order B-16-2012 on March 23, 2012 directing state agencies to support and facilitate the rapid commercialization of ZEVs. The order directs the ARB, California Energy Commission (CEC), California Public Utilities Commission (CPUC) and other relevant agencies to collaborate with the Plug-in Electric Vehicle Collaborative (PEVC) and the California Fuel Cell Partnership (CaFCP) in working toward these major milestones:

- **2015** - Communities are ready for plug-in and hydrogen vehicles and infrastructure
- **2020** - California will have established adequate infrastructure to support 1 million ZEVs
  - Widespread use of ZEVs for public transportation and freight transport
- **2025** - More than 1.5 million ZEVs will be on the roads and the market is expanding

The commercial launch for passenger FCEVs in Northern and Southern California has been addressed in the recent California Fuel Cell Partnership document, *"A California Road Map,"* which focuses on the locations and funding for a network of hydrogen fueling stations to support the state's goals. This document lays out a parallel path for FCEBs.

[6] "Urban bus" defined in the California Code of Regulations, Title 13, Section 2023 (a) (13).
[7] Current Zero Emission Bus Regulation is California Code of Regulations, Title 13, Section 2023.3 or http://www.arb.ca.gov/msprog/bus/zeb/zbusregorderfinal.pdf.

Fuel cell electric bus technology

A *proton exchange membrane* fuel cell electrochemically combines hydrogen and oxygen from the air to produce electricity, heat and water. To obtain the desired amount of electrical power, individual fuel cells are combined to form a fuel cell stack. In the case of a fuel cell electric bus, a fuel cell engine (including fuel cell stack and supporting sub-systems) is integrated with a hydrogen fuel storage system and electric drive components to achieve the required performance for the bus duty cycle. Figure A below illustrates this design.

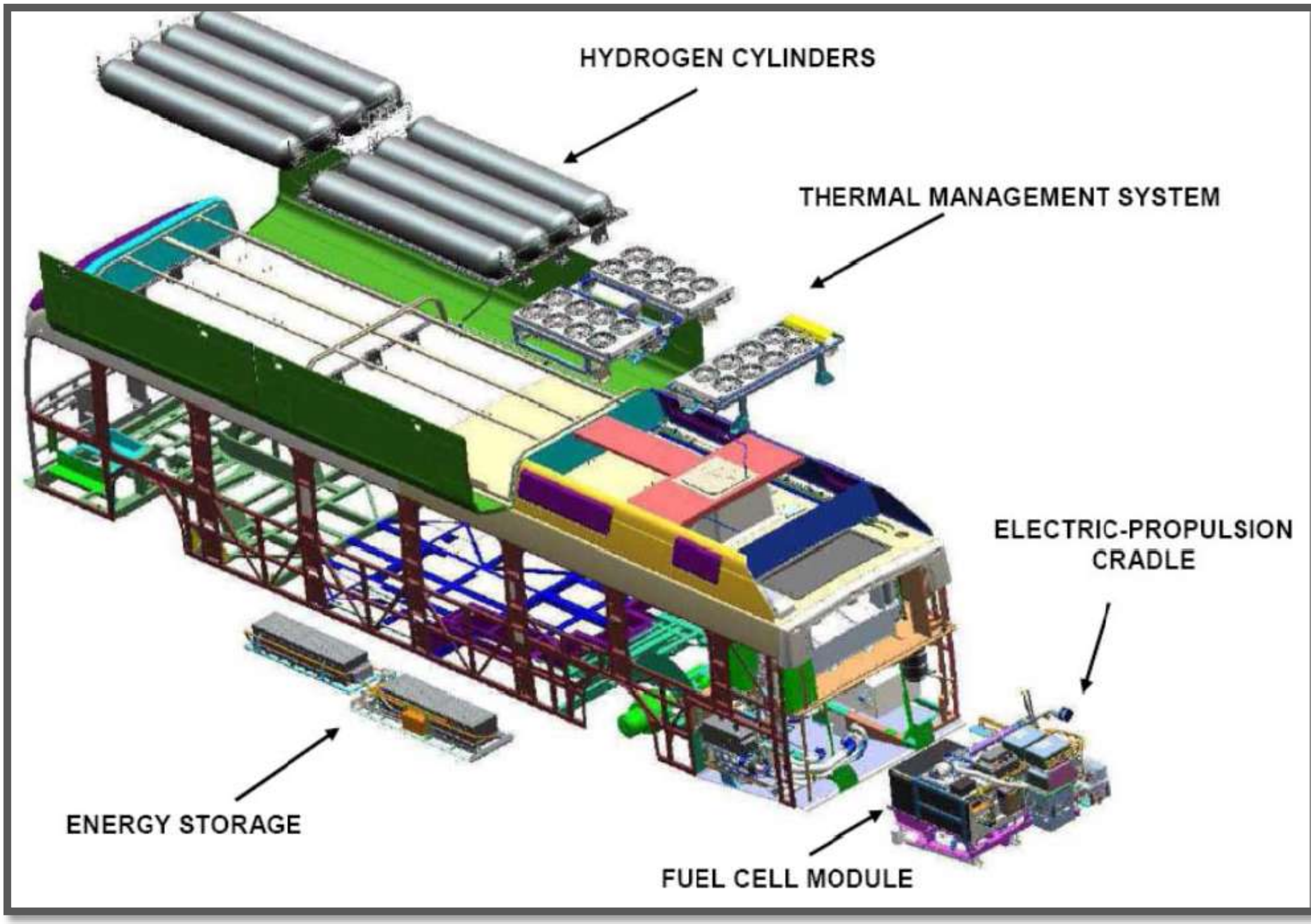


Figure A. FCEB components – Source: Ballard Power Systems

These buses operate with no local emissions, reduced noise, and a substantial reduction in greenhouse gas emissions on a well-to-wheel basis without some of the performance, range and route flexibility issues seen in other zero emission technologies.[8]

[8] Urban buses: alternative powertrains for Europe (study): http://www.fch-ju.eu/news/fch-ju-launches-its-study-urban-buses-alternatives-power-trains-europe.

History

After the concept of hydrogen fuel cell buses was first proven in the 1990s in Chicago (USA), Vancouver (Canada) and Munich (Germany), the Clean Urban Transportation for Europe (CUTE) program was established as the first coordinated multi-city fuel cell bus transportation demonstration in 2003. Thirty fuel cell buses were placed in 10 European cities for an initial period of two years. All the buses used the same Mercedes-Benz Citaro platform with a Ballard fuel cell system as the sole non-hybrid power propulsion system. Additionally, the cities of Perth, Australia and Beijing, China each operated three buses of the same design and technology. U.S.-funded efforts included three Gillig buses with the same drive system demonstrated in revenue service in California by the Santa Clara Valley Transportation Authority (VTA) in Silicon Valley. Combined, these buses traveled more than two million miles in revenue service.

During the same 1999-2005 period, a UTC Power powered 30-foot prototype hybrid electric-drive fuel cell bus was introduced at SunLine Transit in Thousand Palms, CA using batteries to store captured excess energy. This configuration used regenerative braking to capture the kinetic energy of vehicle movement to recharge the battery, which then could be used for acceleration as well as reducing transient loads on the fuel cell system. Following this demonstration, AC Transit in Oakland introduced three Van Hool hybrid electric fuel cell buses using a larger UTC fuel cell system. SunLine Transit also received and operated a bus of the same design, as did Connecticut Transit. To date, one of these UTC fuel cell system modules has surpassed 12,000 hours of operation in revenue service, and continues to perform at rated power, with two other systems approaching this same durability milestone.[9]

Subsequent designs have been developed by industry and there are now more than 80 full-size FCEB's currently in operation in various locations in North America, Europe, Asia, and South America.[10]

PATH TO COMMERCIALIZATION

To provide perspective on the commercial development path of FCEBs, Table 1 lists the nine Technology Readiness Levels (TRL) of FCEBs, as developed by the National Renewable Energy Laboratory (NREL). NREL created these levels using the U.S. Department of Energy's Technology Readiness Assessment Guide as a model.[11] A similar concept[12] is used by the manufacturing industry to work towards target prices and technical goals for different FCEB components.

---

[9] As of August 1, 2012.
[10] For an overview of global FCEB programs, go to: http://www.gofuelcellbus.com/index.php/the-collaborative/all-active-demonstrations/.
[11] DOE Technology Readiness Assessment Guide, G 143.3-4a, https://www.directives.doe.gov/directives/0413.3-EGuide-04a/view.
[12] Manufacturing Readiness Levels (MRL).

Table 1 - NREL Technology Readiness Levels for FCEB Commercialization[13]

Technology Readiness Level	TRL Definition	Description
TRL 9	Actual system operated over the full range of expected conditions	The technology is in its final form. Deployment, marketing, and support begin for the first fully commercial products.
TRL 8	Actual system completed and qualified through test and demonstration	The last step in true system development. Demonstration of a limited production of 50 to 100 buses at a small number of locations. Beginning to implement transition of maintenance to transit staff.
TRL 7	Full-scale validation in relevant environment	A major step up from TRL 6 by adding larger numbers of buses and increasing the hours of service. Full-scale demonstration and reliability testing of 5 to 10 buses at several locations. Manufacturers begin to train larger numbers of transit staff in operation and maintenance.
TRL 6	Engineering/pilot-scale validation in relevant environment	First tests of prototype buses in actual transit service. Field testing and design shakedown of 1 to 2 prototypes. Manufacturers assist in operation and typically handle all maintenance. Begin to introduce transit staff to technology.
TRL 5	Laboratory scale, similar system validation in relevant environment	Integrated system is tested in a laboratory under simulated conditions based on early modeling. System is integrated into an early prototype or mule platform for some on-road testing.
TRL 4	Component and system validation in laboratory environment	Basic technological components are integrated into the system and begin laboratory testing and modeling of potential duty-cycles.
TRL 3	Analytical and experimental critical function and/or proof of concept	Active research into components and system integration needs. Investigate what requirements might be met with existing commercial components.
TRL 2	Technology concept and/or application formulated	Research technology needed to meet market requirements. Define strategy for moving through development stages.
TRL 1	Basic principles observed and reported	Scientific research and early development of FCEB concepts.

Using this chart, FCEB technology in California is currently at level seven or "full-scale validation in relevant environments," and requires two more levels to become a fully commercial product. To reach level eight, action is required and this document details what steps are needed.

FCEB Programs in Operation

At publication, 15 fuel cell electric buses operate in revenue service in California among several transit agencies, including:

- AC Transit and other San Francisco Bay Area transit agencies[14]
- SunLine Transit

[13] "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012". L. Eudy, K. Chandler, C. Gikakis (2012). Available at: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fceb_status_2012.pdf.
[14] Golden Gate Transit, San Mateo Transit, San Francisco MTA, Santa Clara Valley Transportation Authority.

Focusing on the typical platform of a full-size urban bus, it is instructive to consider the performance of the VanHool buses at AC Transit, and the American Fuel Cell bus at SunLine Transit, since both represent the current capabilities of FCEB platforms in California. These demonstrations show that ZBuses are approaching the performance expectations of the transit agencies:

- Bus availability of 85% for the SunLine American FCEB for more than four of the eight months in service[15]
- Availability of the AC Transit FCEBs that progressively improved to 97% in March and April 2012[16]
- Increasing "miles between road calls" (MBRC), with most of the road calls due to issues other than the fuel cell system
- Fuel economy of up to 7.84 mpdge (miles per diesel gallon equivalent)[17]
- Fuel cell system durability beyond 12,000 hours[18]

Despite improving performance among FCEBs, capital and operating costs remain a barrier to commercialization.

Hydrogen Fueling Stations

Supply of hydrogen is a major component of fuel cell electric bus fleet implementation. The National Fuel Cell Bus Program (NFCBP), which includes the AC Transit and SunLine Transit FCEB programs, provides early indications that the infrastructure might be an appropriate focus of early planning, and current experience bears that out.

SunLine Transit's hydrogen station in Thousand Palms is the longest running hydrogen transit bus fueling station in operation in the U.S (Figure B), beginning operations in April 2000. This station serves as a dual-use (shared dispenser) station for both buses and passenger vehicles using 35 MPa hydrogen fuel (H35).[19] The station has on-site production of hydrogen through the use of an auto-thermal reformer, with a production capacity of 212 kilograms (kg)/day.[20] The three FCEBs currently in daily revenue service fill in about 25 minutes per bus. Excluding the capital cost for hydrogen station implementation, the combined cost of operations and maintenance (O&M) and hydrogen is approximately $12.50/kg dispensed.

---

[15] Eudy, L., Chandler, K., Gikakis, C., Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012, NREL report November 2012.
[16] Source: UTC Power Dashboard Report Data provided to NREL.
[17] Eudy, L., Chandler, K., Gikakis, C., Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012, NREL report November 2012.
[18] Hours accumulated without stack replacement on a fuel cell system that came from the previous generation AC Transit FCEBs, the new second generation system is integrated in 9 of 12 FCEBs and have a longer expected durability. Source: UTC Power.
[19] Per NIST Handbook 130- 2013 Edition: H35 is the definition for hydrogen fuel with a pressure of 35MPa, 350 bar or 5000psi. Handbook available at: http://www.nist.gov/pml/wmd/pubs/hb130-13.cfm.
[20] Chandler, K., Eudy, L., June 2008. SunLine Transit Agency Hydrogen-Powered Transit Buses: Third Evaluation Report and Appendices, http://www.nrel.gov/hydrogen/pdfs/43741-2.pdf.

Figure B. SunLine Transit fueling station

AC Transit's hydrogen station in Emeryville is currently the largest and most-modern transit bus fueling station in the U.S (Figure C). The station, which started operation in August 2011, serves as a dual-use station where passenger vehicles can access a public dispenser outside the bus yard. The separate bus and car dispensers share much of the station's hydrogen equipment, capitalizing on the need for each of the transit and private-use vehicle markets. The station has a scalable capacity, with a baseline capacity of 360 kg of hydrogen fuel per day for buses at 35 MPa and 240 kg per day for cars at both 35 and 70 MPa, an amount sufficient to fuel 12 fuel cell buses and between 40 and 60 cars.[21] Excluding the implementation and capital costs for the hydrogen station equipment, the combined cost of O&M and hydrogen to fuel buses at this station is approximately $10.50/kg dispensed.

The performance of this station to fill multiple buses consecutively at a speed of six to eight minutes per fill -a rate equivalent to diesel bus fueling- is achieved through the use of fast-fuel technology. Should AC Transit decide to increase the number of FCEBs, the station system is designed to easily expand its capacity to accommodate up to 24 buses by adding additional compression and gaseous storage equipment. A second station in Oakland will open in late 2013 with a design capacity to fuel 12 buses rapidly and in succession. It also can be expanded to fuel 24 buses. Typical scheduling and service requirements make it necessary to fuel the buses between 11 p.m. and 5 a.m. to enable the buses to stay in continuous service from 5 a.m. to 11 p.m.

Figure C. AC Transit fueling station (Photo courtesy of L. Eudy, NREL)

For comparison, BC Transit's hydrogen station in Whistler, Canada is the largest transit bus fueling station in North America. It began operation in November 2009, serving only buses. The station can

[21] Currently restricted to 20 cars per day.

scale up to fuel more than 30 buses with 35 MPa hydrogen fuel with its baseline capacity of 1,400 kg of hydrogen fuel per day. Currently the station fills 20 transit FCEBs for daily revenue service, with a combined cost of O&M and hydrogen at approximately $11.70/kg dispensed.[22]

The station's performance in filling multiple buses consecutively at a speed of 2.5 to 5 kg/min -10 to 15 minutes per fill, a rate equivalent to diesel bus fueling- is achieved through the use of liquid hydrogen pump technology.

COMMERCIAL AND TECHNICAL TARGETS

The Department of Energy and the Department of Transportation's Federal Transit Administration (FTA) collaborated with private and public entities to establish commercial targets for fuel cell electric buses, using the 2012 status of FCEBs in operation as the benchmark, as shown in Table 2.[23]

At a summary level, the technical performance targets (e.g. range or fuel economy) have been achieved or are within line of sight without major technology advances. Daily bus roll-out availability has improved with the current generation of fuel cell buses, despite the use of more complex electronic and battery systems. For example, the American Fuel Cell Bus (AFCB) at SunLine reported 83% availability from March until December 2012,[24] and the Whistler fleet has averaged 70 -75% availability over 1.5 million miles in revenue service. [25] Durability has increased significantly with the UTC Power fuel cell module, having achieved 12,094 hours in operation with an older design that continues in revenue service in three FCEBs.[26] The major fuel cell system manufacturers have made technology improvements to the fuel cell system stacks that are expected to achieve the commercial targets set out by the U.S. DOE within the next few years.

---

[22] Per input of BC Transit and Air Liquide, based on operation of 20 FCEBs for 365 days/year, $20 million to supply fuel, O&M and equipment until March 2014, see: http://www.bctransit.com/fuelcell/download/20071210_fuelcell_buses.pdf.

[23] U.S. DOE Fuel Cell Bus Targets. http://hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf.

[24] Eudy, L., Chandler, K., "American Fuel Cell Bus Project: First Analysis Report"– Preliminary report, to be published.

[25] Source: Ballard Power Systems.

[26] 9,945 hrs (next highest time), 7,666 hrs (3rd highest time), continuing operating in revenue service. Source: UTC Power.

Table 2 – 2012 DOE/DOT FTA performance, cost, and durability targets for fuel cell transit buses.

	Units	2012 Status	2016 Target	Ultimate Target
Bus Lifetime	years/miles	5/100,000[1]	12/500,000	12/500,000
Power Plant Lifetime[2,3]	hours	12,000	18,000	25,000
Bus Availability	%	60	85	90
Fuel Fills[4]	per day	1	1 (< 10 min)	1 (< 10 min)
Bus Cost[5]	$	2,000,000	1,000,000	600,000
Power Plant Cost[2,5]	$	700,000	450,000	200,000
Hydrogen Storage Cost	$	100,000	75,000	50,000
Road Call Frequency (Bus/Fuel Cell System)	miles between road calls	2,500/10,000	3,500/15,000	4,000/20,000
Operation Time	hours per day/days per week	19/7	20/7	20/7
Scheduled and Unscheduled Maintenance Cost[6]	$/mile	1.20	0.75	0.40
Range	miles	270	300	300
Fuel Economy	miles per gallon diesel equivalent	7	8	8

[1] Status represents data from NREL fuel cell bus evaluations. New buses are currently projected to have 8 year/300,000 mile lifetime.
[2] The power plant is defined as the fuel cell system and the battery system. The fuel cell system includes supporting subsystems such as the air, fuel, coolant, and control subsystems. Power electronics, electric drive and hydrogen storage tanks are excluded.
[3] According to an appropriate duty cycle.
[4] Multiple sequential fuel fills should be possible without an increase in fill time.
[5] Cost projected to a production volume of 400 systems per year. This production volume is assumed for analysis purposes only, and does not represent an anticipated level of sales.
[6] Excludes mid-life overhaul of power plant.

The capital cost of a full-size FCEB is currently more than $2 million,[27]significantly higher than the targets in Table 2, primarily due to customized designs and low bus-manufacturing volumes. Based on industry input, the $1 million target can be achieved through a limited production of FCEBs of the same design, while the $600,000 target requires commercial volumes. These factors led to recent industry and government discussions regarding the deployment of a few centralized fleets, allowing production runs large enough to amortize investments in production tooling and optimize the manufacturing process.

Relative to the fueling infrastructure, the station designs at AC Transit (Linde) and BC Transit in Whistler (Air Liquide) meet the performance requirements for a larger fleet. The challenge lies in meeting a fuel cost of $4-7,[28] at which the fuel cost per mile will be competitive with conventional buses. For the early

[27] Based on a fuel cell dominant configuration meeting all performance requirements.
[28] "Building a Commercially Viable National Fuel Cell Electric Bus Program," Fuel Cell and Hydrogen Energy Association, March 2011. Available at: http://cafcp.org/sites/files/Building%20a%20Commercially%20Viable%20National%20Fuel%20Cell%20Transit%20Bus%20Program.FINAL_.v10.03-25-11.pdf.

hydrogen stations at transit agencies with smaller FCEB fleets (1 to 12 FCEBs), the throughput for fuel and related fuel savings are insufficient to cover the higher upfront capital cost and O&M cost of the station, and government funding will help offset this. In a commercial market (TRL 9), these costs will be offset by high throughput of hydrogen supplied for larger fleets.

PROPOSED STRATEGY

Establishing two Centers of Excellence in California is the next step in the introduction of FCEBs to the California transit bus market. In March 2011, the Fuel Cell & Hydrogen Energy Association submitted a white paper to DOT Secretary Ray LaHood proposing “five regional Centers of Excellence on the east and west coasts, the mid-west, and the south or southeast, building upon existing experience and core competencies.” Although this program was not adopted explicitly in MAP-21, the principles of the program are sound and these Centers of Excellence should be considered for Northern and Southern California. In creating these programs and realizing the goal of 40 buses per fleet, industry input indicates that production runs of 40 FCEBs will be large enough to reduce the capital cost per bus at or below $1.0 million and fleet size will be sufficient to enable a fuel cost per mile competitive with a conventional bus.

Centers of Excellence in California

Similar to the automotive strategy of concentrating deployment on a limited number of sites for early stage commercialization, the best path forward for implementing fuel cell electric buses in California is to focus on the development of *two Centers of Excellence in California*, one in the north and the other in the south. The key tenets of these programs are:

- A single fuel cell hybrid bus configuration at each site, manufactured under a serial production run of 40 units over one to two years
- Vehicles that comply with transit agency requirements and are operated in normal revenue service on scheduled runs (e.g. no compromise or deviation in service)
- A 12-year operating period
- A single hydrogen fueling station with throughput sufficient to provide throughput sufficient to achieve a fuel cost per mile comparable to conventional buses
- Vehicles introduced in the 2015-2016 timeframe
- Regional training and education for transit staff and community stakeholders

Fueling Infrastructure

Each Center of Excellence will have a single fueling station capable of meeting the requirements in Table 3.

Table 3 - Fueling station technical assumptions

Fueling station category	Details
Station lifetime	15-20 years
Fuel quality	SAE J2719
Fuel pressure	35 MPa or 350 bar
Fill time per bus (pending on bus design)	5-8 minutes
Average fill amount per bus	30 kg/day
Station capacity (based on 30 kg/day/bus, 40 FCEBs)	1,200 kg/day
Number of dispensers capable of fueling simultaneously	2 dispensers
Bus fleet fueling window[29]	4-5 hours/day
Station location	Northern and Southern California

When considering the implementation of a hydrogen station, every transit property will be unique with regards to their specific requirements, as it is not a one-size-fits-all situation related to budget and schedule for each specific property. Considering the costs involved, fleets may initially choose to be more flexible with their scheduling requirements to accommodate a broader fueling window.

Currently, the four most feasible hydrogen fuel delivery methods for transit agencies based on the capacity and design assumptions are:

- ***Delivered liquid hydrogen*** with compression and storage on site. Hydrogen production and liquefaction occurs at a central production plant, delivery by truck.
- ***Hydrogen pipeline*** with compression on site. Hydrogen production at a central location connected to an industrial hydrogen pipeline.
- ***On site reformation.*** Hydrogen fuel is generated on site from natural gas with compression and storage on site.
- ***On site electrolysis.*** Hydrogen fuel is generated on site from water using electricity with compression and storage on site.

With the previous assumptions in mind, hydrogen fuel and station equipment suppliers provided input that the fueling station cost for the aforementioned hydrogen fuel delivery methods per location are anticipated to be approximately $5 million or less, which includes $1 million for site improvements and local jurisdiction use requirements to install a H35 (aka 35MPa or 350 bar hydrogen fuel) fueling station. Station operating and maintenance (O&M) costs incurred by transit agencies are $200,000 per year. The cost of fuel delivered to the station is $4-7 per kilogram, depending on hydrogen station location, mode of hydrogen supply and access to production facilities. This fuel cost is equivalent to $2.26 to $4.75 per gallon of diesel fuel, taking into account 1.6 to 2 times better fuel economy of a FCEB over a diesel bus.[30]

[29] Transit agencies refuel their buses at the end of the day within a specific time window to be ready for pull out the next morning.
[30] "Building a Commercially Viable National Fuel Cell Electric Bus Program," Fuel Cell and Hydrogen Energy Association, March 2011. Available at: http://cafcp.org/sites/files/Building%20a%20Commercially%20Viable%20National%20Fuel%20Cell%20Transit%20Bus%20Program.FINAL_.v10.03-25-11.pdf.

Budget

Assuming a 12-year operating period, a cost of $1 million per bus, maintenance facility upgrade of up to $2 million (retrofits of three to four service bays to accommodate a 40-bus fleet), mid-life powerplant overhauls for all buses of $80,000/bus[31] and infrastructure capital costs of approximately $5 million per site,[32] the cost for each Center of Excellence would be $50.2 million including rolling stock and infrastructure. Table 4 details the costs.[33] For comparison, the cost of purchasing a fleet of forty conventional buses is $19.2 million (vehicle cost only).[34] Funding for each Center of Excellence may come from federal, state and local sources.

Normal bus operational costs including fuel at $4-7 kg[35] and the operating and maintenance costs for the fueling station (estimated at approximately $200,000/year) may be borne by the transit operator.

Table 4 - Cost overview of one Center of Excellence

Capital equipment	Per Center of Excellence	Capital cost per location
FCEBs	40	$40M
H2 station	1	$5M
Maintenance facility	1	$2M
Mid-life overhaul of bus power plant	40	$3.2M
Total	**n/a**	**$50.2M**

Funding

The new federal transportation bill "Moving Ahead for Progress in the 21st Century Act" (MAP-21) includes a provision that not less than 65% of any funds which are appropriated to the Federal Transit Administration (FTA) for research, development, demonstration and deployment projects be made available for zero and near-zero-emission bus deployment; and not less than 10% of those funds for facilities and related equipment. As the bill authorizes $70 million to be appropriated in both fiscal years 2013 and 2014, if the bill is fully funded, that would mean a minimum of $45.5 million a year for bus deployment, and $7 million for facilities and related equipment, contingent on appropriations. This funding will be programmed through the FTA. A fuel cell electric bus deployment program in California utilizing this federal funding source is consistent with the program's stated objectives.

At the state level, monies invested in the Greenhouse Gas Reduction Fund through carbon auction proceeds could be used in conjunction with FTA funding to address the costs of the rolling stock (buses) and the fueling infrastructure. How these proceeds will be administered has yet to be determined,

---

[31] Includes both fuel cell and battery replacement and/or refurbishment.
[32] Including site improvement costs and local jurisdiction use requirements.
[33] The total cost per location is an approximate cost, as building requirements per location can differ due to local requirements.
[34] Average cost per standard transit bus purchased in 2010-2011 $479,585, "2012 Public Transportation Fact Book" Appendix A: Historical Tables. Available at: http://www.apta.com/resources/statistics/Documents/FactBook/2012-Fact-Book-Appendix-A.pdf.
[35] Depending on the mode of supply.

however, a state entity such as the California Air Resources Board, the California Energy Commission or California State Treasurer's Office could be used to manage and allocate these funds.

Assuming near parity in fuel costs based on the larger-scale fueling station and vehicle throughput, there would likely be a small incremental cost related to vehicle maintenance that the transit property would be expected to incur as part of their operating budget, which is simply based on the introduction of a new propulsion system to the bus fleet. It is also anticipated that this incremental cost will diminish over time as the technicians become familiar with the more durable and easier-to-maintain electric traction motors and all-electric auxiliary systems.

NEXT STEPS AND RECOMMENDATIONS

CaFCP members will work with local, state and federal stakeholders to develop a funding model that supports the road map and implementation of the Centers of Excellence.

Recommendations for State of California Action

Governor Brown convened a "ZEV Summit" in 2012 to address the key issues in implementing his Executive Order for widespread deployment of zero-emission vehicles (ZEVs). Bus and truck stakeholders participated in this process, and this road map is intended to provide guidance for state support of heavy-duty bus fleets and infrastructure consistent with the objectives of the Executive Order.

The Governor's *2013 ZEV Action Plan* identified several bus-related goals, including monitoring the current FCEB demonstration fleet and the development of this road map. Although not identified in the 2013 ZEV Action Plan, California should assist the advancement of ZBuses to Technology Readiness Level 8, the last step before commercialization. The following actions are recommended to reach this goal and the DOE/DOT FTA targets listed in Table 2.

1. Include the concept of two California Fuel Cell Electric Bus *Centers of Excellence* in the 2013 ZEV Action Plan.
2. Continue support of National Renewable Energy Laboratory data collection to record and communicate progress towards the DOE/DOT FTA 2016 targets, critical to the public credibility and transparency of the FCEB program.
3. Validate and verify (using a third party) the incremental cost over traditionally configured buses and the prospects for FCEB commercialization.
4. Study the effect of zero-emission buses on ridership. Include the extent to which car owners abandon driving in favor of public transit and the extent to which the quality of ride impacts the decision.
5. Study the health benefits of replacing conventional buses with zero-emission buses in inner-city neighborhoods and the benefits that would accrue to Title VI Environmental Justice communities.
6. Integrate this large-scale production run/deployment concept into the Air Resources Board zero-emission bus regulatory planning.
7. Utilize state funding for alternative fuels and carbon reduction programs to leverage maximum funding opportunities with the federal government.
8. Work with the federal government to identify and put in place the funding and timing conditions required to implement the Centers of Excellence strategy in Northern and Southern California with the following recommended timeline.
    a. Develop and release procurement documentation (Q2 2014)

b. Complete procurement contracting (Q4 2014)
c. Station commissioning (Q2 2016)
d. Vehicle commissioning (Q2 2016)

To implement these recommendations, industry, for their part, must be willing to provide credible and defensible data so that funding agencies have confidence that the commercial and technical targets can be achieved, and that the funding allocation is sufficient.

Recommendations for Federal Government Action

The actions recommended below build on the achievements of the Federal Transit Administration's National Fuel Cell Bus Program and its efforts to achieve the emission and efficiency goals identified in the Electric Drive Strategic Plan. These recommendations are in-line with the strategy outlined in the Fuel Cell & Hydrogen Energy Associations' white paper that develops a nationwide path toward commercialization of FCEBs. Strong state and federal collaboration will play a significant role in achieving these goals.

1. Work directly with California agencies to identify and put in place the funding conditions required to implement this strategy; consider making funding available under MAP-21 legislation for FCEB Centers of Excellence in ozone, CO and/or particulate matter (PM 2.5[36]) nonattainment or maintenance areas in California.[37]
2. Identify funding that covers the cost difference between the 2016 target FCEB cost and typical cost of transit buses for the involved transit agencies that operate the Centers of Excellence.
3. Explore how the federal government can make funding available for hydrogen infrastructure implementation at Centers of Excellence.
4. Continue support of National Renewable Energy Laboratory data collection, critical to the public credibility and transparency of the FCEB program. (Q1, 2013 – Q4, 2016)

CONCLUSION

California requires the introduction of zero emission technology vehicles, including fuel cell electric buses, in order to meet its air quality improvement and emissions reduction goals. These buses have proven their value with millions of miles in revenue service around the world over the last two decades across a diverse set of operating environments. There have been significant technology advances in the performance, reliability and durability of the buses to the point where they have achieved, or are approaching, commercial targets and meeting end-user expectations.

The establishment of two Centers of Excellence is the next step in the introduction of the technology and consistent with California's leadership in the adoption of zero-emission vehicles. These centers will provide a means for reducing the costs and overcoming the remaining commercial barriers that prevent widespread adoption of fuel cell electric buses in the state, country and worldwide.

[36] MAP-21: http://www.fhwa.dot.gov/map21/cmaq.cfm.
[37] U.S. EPA non-attainment zones: http://www.epa.gov/oaqps001/greenbk/ancl.html.

A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles

The realization of fuel cell electric vehicles and supporting infrastructure requires a road map for investments in fuel cell electric vehicles and hydrogen fueling stations.

June, 2012

California Fuel Cell Partnership
3300 Industrial Blvd, Suite 1000
West Sacramento, CA 95691
916-371-2870
www.cafcp.org

Table of Contents

The California Fuel Cell Partnership is a collaboration of organizations, including auto manufacturers, energy providers, government agencies and fuel cell technology companies, that work together to promote the commercialization of hydrogen fuel cell vehicles. By working together, we help ensure that vehicles, stations, regulations and people are in step with each other as the technology comes to market.

A California Road Map:
The Commercialization of Hydrogen Fuel Cell Vehicles

Executive Summary

In 1990, the State of California launched an ambitious agenda to introduce zero-emission vehicles to reduce pollution and improve public health. Today, it is part of a larger effort to minimize petroleum dependence and increase energy security, while reducing green house gases that contribute to climate change. In response to rapidly approaching milestones to reach these goals in this agenda, automakers are preparing for the commercialization of fuel cell electric vehicles (FCEVs) in California in 2015, when customers are expected to be able to purchase and lease FCEVs from local dealerships. Early market consumers will need to be confident that sufficient fueling is available, whether near their home, their work, or where they like to travel.

A California Road Map represents a collaborative and collective effort by stakeholders from industry, academia, non-governmental organizations and government to design a pragmatic road map for hydrogen station placement, enabling the deployment of tens of thousands of fuel cell electric vehicles in California. This report outlines the necessary steps for the vehicle and infrastructure market as it progresses through pre-commercial (2012-2014) and early commercialization (2015-2017). It also incorporates the best available information from each of the stakeholders, including market-based assessments, models, and tools as well as professional experience with launching advanced vehicles and new infrastructure.

The infrastructure deployment strategy described in this road map relies on ten years of lessons learned by industry and government during the initial deployment of FCEVs. This real-world experience was complemented by significant contributions from the University of California at Davis for stakeholder and cluster model research, and the STREET computer modeling developed by the University of California at Irvine. This multi-pronged approach established the minimum number stations needed to provide convenient and reliable fueling for early FCEV customers. Initial station deployments will focus on key markets, linking these geographic clusters into regional networks, and further expanding into new vehicle markets and targeted destinations.

Based on this strategy, including projections of the number of fuel cell vehicles and extensive marketing assessments by automakers, five clusters were identified in California where most early adopters are expected: Berkeley, San Francisco South Bay, Santa Monica and West Los Angeles, coastal Southern Orange County, and Torrance with nearby coastal cities. Additional stations will connect these clusters into a regional network and capture major destinations. In order to launch the early commercial market, this analysis identifies 68 strategically placed stations required to be operational by the end of 2015.

Incentive funding is widely acknowledged as necessary to make the business case for investing in these early commercial stations. Early stations are not expected to be fully utilized, and therefore profitable, even as vehicle sales increase during the early commercialization years. Two possible approaches estimate the required incentive funding: the "capital buy-down" model and the "cash flow support" model. Based on a mix of existing and new stations, varying station sizes, and a cumulative capacity to support approximately 20,000 fuel cell electric vehicles, the total cost to expand to 68 stations and support operations and maintenance for all stations is estimated at $65 million under the "cash flow support" model. The traditional "capital buy-down" model identified a similar overall cost of $67 million.

As the number of vehicles increases, as is projected, the station network must grow in number and capacity to keep up with the fuel demand. *A California Road Map* lays out the path to successfully launch early commercial deployment of vehicles and infrastructure, an early milestone towards long-term market success. The California Air Resources Board's Clean Fuels Outlet (CFO) regulation supports the next phase. CFO triggers once 20,000 fuel cell electric vehicles are deployed statewide or 10,000 are deployed in an air basin, and will remain in place until the number of stations reaches approximately 500. In this manner, the road map launches the market and CFO ensures sufficient fueling infrastructure is available if other approaches fail to result in adequate fueling capacity.

A California Road Map reflects the input and consensus of more than 30 partners, including auto manufacturers, energy companies, fuel cell technology companies, government agencies, non-governmental organizations and universities. These stakeholders strongly agree that continued investment and preparation is necessary to realize the potential of fuel cell electric vehicles and hydrogen infrastructure market in California. While this document establishes the initial steps of seeding the emerging market with 68 stations, it should be seen as part of a continuous plan to reach full-market potential.

Introduction

In 1990, the California Air Resources Board (ARB) adopted an ambitious program to dramatically reduce the environmental impact of light-duty vehicles through the gradual introduction of zero-emission vehicles (ZEV). The State's strong commitment to zero-emission vehicles reflects the understanding that advanced vehicle technology is necessary to achieve public health goals, including reductions in criteria pollutants and long-term climate change emissions. It also reflects the fact that several California regions continue to exceed state and federal health-based air quality standards.

California's growing population and increasing use of motor vehicles place upward pressure on statewide emissions. State and federal laws require strategies to achieve ambient air quality standards as quickly as feasible. More broadly, global environmental and energy challenges, including climate change, energy security, and air quality, require alternatives to today's fossil fuel-based transportation.

Vehicle manufacturers (automakers) have made remarkable progress in advancing vehicle technology. With government and industry support, major automakers are developing a portfolio of advanced technology vehicles that includes hybrid electric (HEV), plug-in hybrid (PHEV), battery electric (BEV) and fuel cell electric vehicles (FCEV).

FCEVs offer several advantages for many vehicle-market segments, including larger-sized vehicles like sport utility vehicles (SUVs) and transit buses. One of the major advantages of FCEVs is the fact that they use hydrogen, a fuel that can be domestically produced from a variety of resources such as natural gas, solar, wind and biomass. Significant quantities of hydrogen have been produced in the U.S. for decades through natural gas reformation, an efficient and well-understood method in the petroleum refining industry. In other words, the technology and means to produce enough hydrogen fuel to support FCEV deployment are available now. Complementing these advantages are the minimal environmental impacts of FCEVs generated through zero tailpipe emissions and high vehicle efficiency as well as the potential to generate hydrogen from renewable resources.

Launching fuel cell electric vehicles and an associated hydrogen infrastructure is a significant undertaking and requires considerable planning and coordination to ensure success. Automakers are testing and leasing FCEVs in real-world environments. To bring FCEVs to a broader market, automakers must begin engineering development three-to-five years in advance along with vehicle testing, automotive supplier development, manufacturing preparation and marketing plans. To execute these capital investments, which amount to billions of dollars, an infrastructure plan must give automakers a high level of confidence that their customers will have access to hydrogen fuel. More broadly, for FCEVs to become commercially available in California, automakers, equipment providers and hydrogen station operators will assume major business risk until sufficient scale is achieved in the market.

To further encourage progress with these environmental, technology, and energy goals, Governor Jerry Brown signed Executive Order B-16-2012 on March 23, 2012 which directs state agencies to support and facilitate the rapid commercialization of zero-emission vehicles (ZEVs). The order directs the California Air Resources Board, California Energy Commission, Public Utilities Commission and other relevant agencies to work with the Plug-in Electric Vehicle Collaborative and the California Fuel Cell Partnership in working towards three major milestones:

- 2015 – Communities are ready for plug-in and hydrogen vehicles and infrastructure
- 2020 – California will have established adequate infrastructure to support 1 million ZEVs
- 2025 – More than 1.5 million ZEVs will be on the roads and the market is expanding

Work to implement the executive order dovetails with the milestones identified here. These include a broad range of readiness activities from permitting streamlining and community education to private sector investment and academic and research institution involvement.

A California Road Map characterizes the steps necessary to move from the current pre-commercial phase of fuel cell electric vehicle deployment (2012-2014) to early commercial phase (2015-2017) by describing gaps and how these can be bridged. This plan draws the best available information from each of the stakeholders, including market-based assessments, models and tools as well as professional experience with launching advanced vehicles and new infrastructure. It does not answer every question related to executing hydrogen infrastructure; instead, it offers the fundamental steps that are necessary to proceed to commercialization.

Road Map Overview

In 1999, the California Fuel Cell Partnership formed as a public-private collaborative to address technical barriers to bringing fuel cell electric vehicles to the commercial market and comply with ARB's zero-emission vehicle regulation. Throughout multiple phases, CaFCP has identified and tackled issues that have included vehicle standards, safety training, building codes and station design. FCEVs have evolved from engineering test vehicles to models being leased through California dealerships. Public transit buses running on hydrogen carry hundreds of passengers every day. Retail gas stations offer hydrogen dispensers that are fully integrated into the site, no longer sitting behind fences as test equipment.

Building on this foundation, CaFCP members are now preparing for commercial deployment. Research and analysis efforts, such as those by UC Davis and UC Irvine, are shaping the "station cluster" concept, and modeling and tools are being used to identify ideal station locations. Partnership with national labs resulted in a best-of-class training program for city planning officials and first responders. CaFCP members have also begun working closely with independent fuel marketers to understand their role and the steps they believe are necessary to deploy stations and vehicles together.

At the core of these commercialization efforts in California is a working group of CaFCP members which includes active automakers as well as several California stakeholders.[1] Together, they have been working

[1] CaFCP automakers include Chrysler, Mercedes-Benz/Daimler, General Motors, Honda, Hyundai, Nissan, Toyota, Volkswagen.

closely to determine the appropriate number of hydrogen stations required for pre-commercial activities (now through 2014) as well as the early commercial launch of fuel cell electric vehicles (anticipated to be in the 2015-2017 timeframe).

The results of an annual survey completed by automakers are a vital planning tool for the working group to properly balance anticipated vehicle sales and infrastructure needs. The California Energy Commission (CEC), California Air Resources Board (ARB) and California Fuel Cell Partnership administered the confidential survey in three consecutive years, compiling it in a manner where no automaker, nor any entity outside the participating government agencies, could discern an individual automaker's response.[2] Table 1 presents data from the most recent survey completed by the CEC and ARB.[3]

Table 1 - Vehicle Sales, Actual & Anticipated, 2011-2017

Survey Year	2011	2012	2013	2014	2015 – 2017
2010-2011	253	312	430	1,389	53,000[4]

These data support infrastructure milestones and decision making, including research and analysis completed by the University of California, including both Davis and Irvine campuses. Furthermore, the data offer insight into automakers' collective assessment of the potential magnitude of initial FCEV sales during the early commercialization phase.

Locations for Hydrogen Fueling Stations

Two guiding principles, station coverage and capacity utilization, underlie the process for determining the number of stations necessary during the early commercialization phases. They represent the bookends of building a new transportation infrastructure for light-duty FCEVs. Coverage improves the customer experience, ensures confidence in the technology, increases vehicle utility and enables broad market participation.[5] In short, station coverage establishes a local network by placing adequate fueling outlets in key markets. Capacity utilization supports technology development, minimizes risk to station operators and builds business models to lower overall station costs. Sufficient utilization ensures station operators have a chance to make their business profitable. These principles must be systematically reconciled during the commercial launch to ensure automakers, infrastructure equipment providers, station operators and government entities maximize the market's potential and protect billions of dollars of private and public investment.

Many technical and non-technical factors will influence the specific placement of a hydrogen station, including footprint, station performance characteristics and complementary uses. For example, retail

[2] CaFCP Progress Report. http://www.cafcp.org/sites/files/FINALProgressReport.pdf.
[3] Energy Commission, Commission Report. September 2011. http://www.energy.ca.gov/2011publications/CEC-600-2011-006/CEC-600-2011-006-CMF.pdf.
[4] For competitive reasons, detailed volume assessments have not been provided to date for the 2015-2017 timeframe. The survey has been designed to enter one number per key air basin region for this time period.
[5] Greene, David L. (1996) "Survey Evidence on the Importance of Fuel Availability to the Choice of Alternative Fuels and Vehicles," *Energy Studies Review*: Vol. 8: Iss. 3, Article 2.

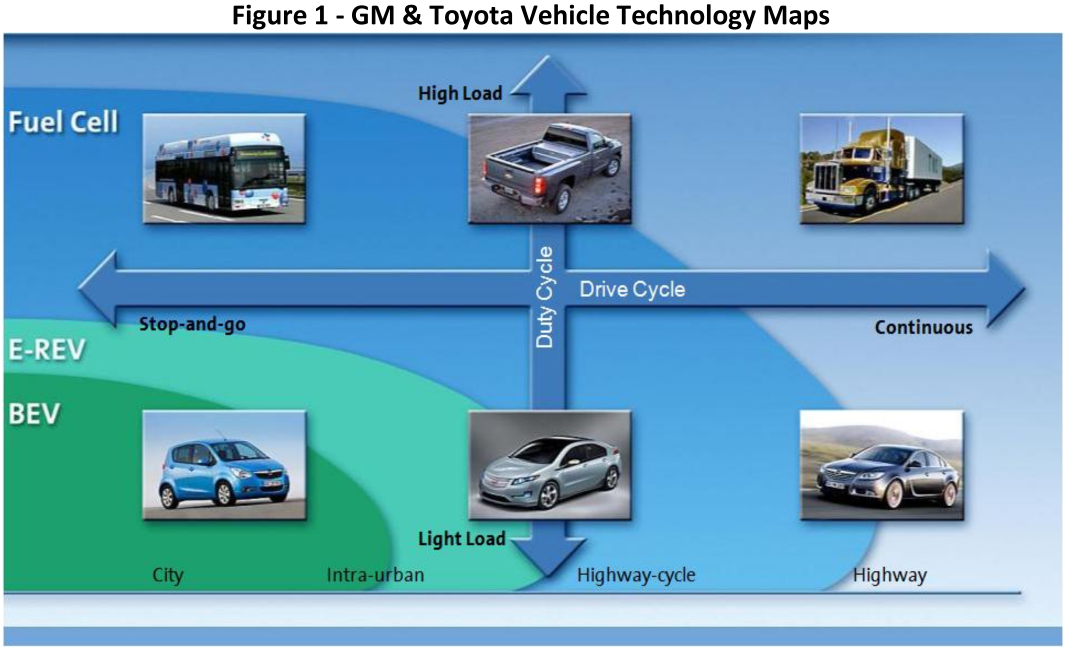
customers will expect high-performing hydrogen stations which mirror their gasoline counterparts with no compromises with respect to availability, throughput and ease-of-use. This also includes the ability to fill and pay for hydrogen fuel in the same fashion as a retail gasoline or natural gas station. In addition, active fuel cell bus programs in the identified target areas might be important enablers to bring hydrogen to a key market by sharing station equipment. These details are not expressively discussed in detail in *A California Road Map*, but are important considerations as the plan is implemented.

Developing Pre-commercial Clusters

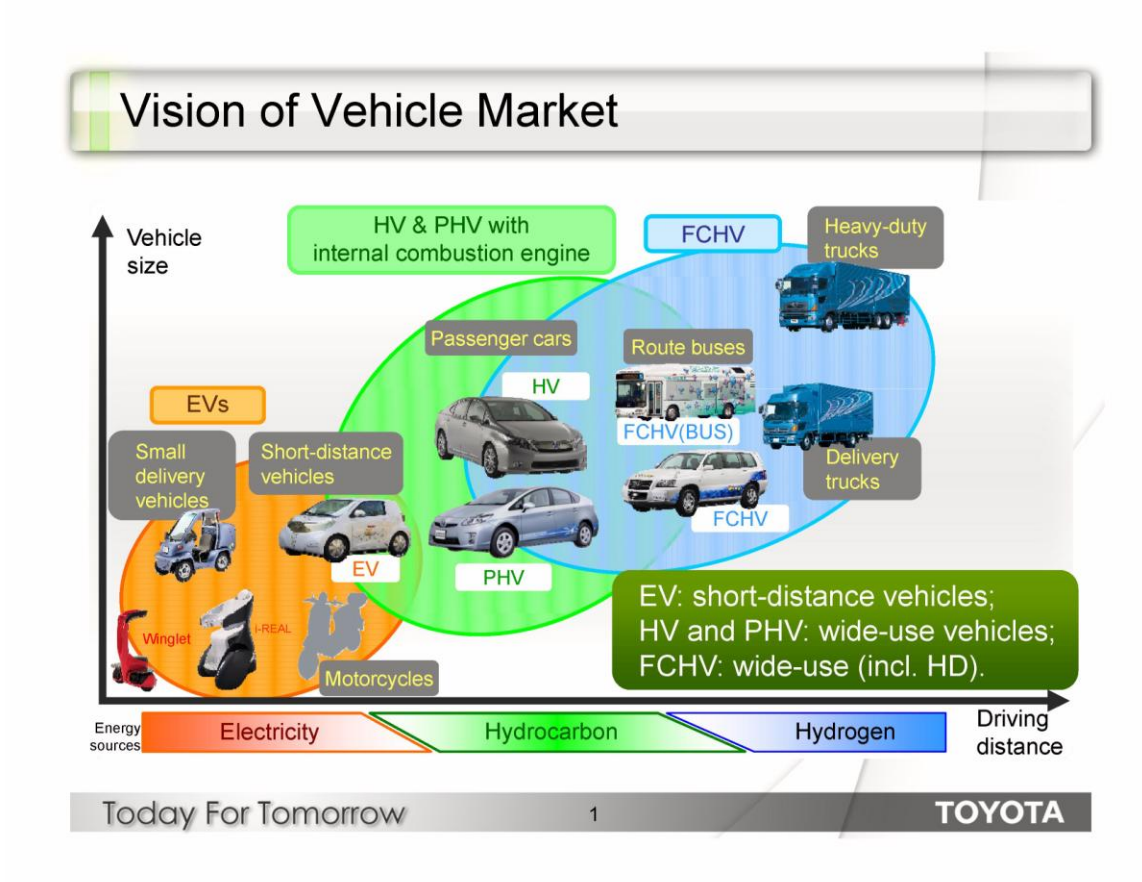
The benefits of a fuel cell electric vehicle center around its "no compromise" features; FCEVs offer the range, quick refill time and size of conventional gasoline vehicles with the performance and zero-emissions of electric vehicles. Automakers consider FCEVs complimentary to their other advanced vehicle technologies such as plug-in electric vehicles (PEVs), as depicted in Figure 1.[6] Both types of electric vehicles share many underlying components, although fuel cells can scale up to support larger vehicles, including heavy-duty platforms like transit buses.

Although the technologies are complementary, only FCEVs are seen as being the most capable of replacing their gasoline counterparts as a household's primary vehicle. However, unlike PEVs, fuel cell electric vehicles are reliant on hydrogen refueling outside the home. Early drivers need to see stations to feel confident with buying an FCEV.

Figure 1 - GM & Toyota Vehicle Technology Maps



[6] GM Fuel Cell Technology & Status, GM presentation at CEC Workshop for the 2010-2011 Investment Plan on Sept 29, 2009. www.energy.ca.gov/2009-ALT-1/documents/2009-09-29_workshop/presentations/GM_Presentation.pdf. Progress and Challenges for TOYOTA's Fuel Cell Vehicle Development, Toyota presentation at CEC Workshop for the 2010-2011 Investment Plan, Sept 29, 2009. www.energy.ca.gov/2009-ALT-1/documents/2009-09-29_workshop/presentations/Toyota_presentation.pdf.
The Honda Clarity Program and Infrastructure Needs, American Honda presentation at CEC Workshop for the 2010-2011 Investment Plan on Sept 29, 2009.
www.energy.ca.gov/2009-ALT-1/documents/2009-09-29_workshop/presentations/Honda-CEC FY10-11 Investment Plan Wkshop-H2.pdf



Images in **Figure 1** are courtesy of GM and Toyota.

In February 2009, the California Fuel Cell Partnership published an "action plan" that detailed the pre-commercial phase roll out of hydrogen stations and vehicles in clusters.[7] This cluster concept builds on early work pioneered by the Department of Energy (DOE) through their Technology Validation Program as well as the Five-Cities Program sponsored by the South Coast Air Quality Management District (SCAQMD).[8,9,10] By creating clusters of stations, the network itself build customer confidence, optimize resources and create the foundation for further network expansion. Following that plan, vehicles and stations were initially concentrated in the South Coast Air Basin, as shown in Figure 2 (see page 12), including Santa Monica and West Los Angeles, Torrance and nearby beach cities, and Irvine and Newport Beach. All the cluster communities have displayed a historical interest in advanced vehicle

---

[7] Hydrogen Fuel Cell Vehicle and Station Deployment Plan: A Strategy for Meeting the Challenge Ahead http://www.cafcp.org/sites/files/Action%20Plan%20FINAL.pdf.

[8] The DOE Tech-Val program partnered energy companies and automakers to co-locate FCEVs and hydrogen stations in coordinated areas across the US. These early outposts of co-located vehicles and hydrogen stations, in what we now call clusters, were deployed in select states in the US. Clusters within California continue to operate and expand beyond cities such as Burbank, Irvine, Sacramento, and Santa Monica. <http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/fleet_demonstration.html>

[9] The SCAQMD's "Five-Cities" Program co-located hydrogen vehicles and hydrogen stations to demonstrate the technologies in a similar cluster approach.

[10] Greene, D.L. et al., (2008). Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements. Oak Ridge National Laboratory. <http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf>

technologies, existing hydrogen infrastructure, and/or policies that support the further development of the market.[11,12]

Ahead of the early commercial launch phase, deploying to a broader geographic area will be necessary to ensure a sufficient number of early adopters believe the infrastructure is adequate and include a FCEV in their purchasing consideration. Insufficient coverage, by definition, will reduce or remove FCEVs from a customer's purchasing consideration. Therefore, the evaluation of coverage must balance the need to target as large a portion of early adopter market as possible while balancing station operators' requirements, including high station utilization factors. For these reasons, it is necessary to move beyond the initial clusters in the South Coast Air Basin.

In a similar approach to Los Angeles, additional locations target key regions to maximize the market potential while ensuring station operators can succeed. As shown in Figure 3 (see page 12), this includes key clusters in the San Francisco Bay Area, which include important early-adopter communities in the South Bay and Berkeley.[13] The clusters for each region are summarized in Table 2.

Table 2 - Overview of Clusters in California

Region	Clusters
South Coast Air Basin	Santa Monica and West Los Angeles
	Coastal and Southern Orange County
	Torrance and nearby coastal cities
San Francisco Bay Area	South Bay Area
	Berkeley

Broadening the Pre-commercial Clusters

Before 2015, the number of hydrogen stations in the early market communities will need to increase and additional stations will be required to seed new communities. The goal is to increase the number of stations and the geographic coverage to ensure a sufficient number of early adopters believes the infrastructure is adequate to consider purchasing a fuel cell electric vehicle.

Starting with the pre-commercial clusters as the basis, this report used several sources of information to identify other communities where FCEVs are likely to be adopted. The data considered include:

- Demographic information, such as household income and land use considerations

[11] Market data from automaker's FCEV demonstration programs provide an initial insight and verification into future commercial strategies. Confidential information, such as hand-raiser data, vehicle lease programs, or previous advanced vehicle deployments provides insight into individual automaker decisions about the future market potential. In discussions, automakers assess the market individually and must avoid any anti-competitive discussions.

[12] An important factor to also consider is the fact that existing infrastructure has already been deployed in these regions by way of previous demonstration projects.

[13] The Automaker Survey provides fidelity at the air basin level for the 2015-2017 timeframe. Although the largest number of vehicle deployments occur in the Los Angeles and the San Francisco Bay Area air basins, several other air basins have been identified.

- Individual automaker market assessments, including FCEV hand-raiser data[14]
- California Energy Commission/Air Resources Board Vehicle Survey for battery electric vehicles and plug-in hybrid electric vehicles, as noted in the 2011-12 Investment Plan[15]
- Hybrid vehicle, plug-in hybrid electric vehicle, battery-electric vehicle, and natural gas vehicle registrations, such as data for Toyota Prius, Honda Civic NGV, Chevrolet Volt and Nissan Leaf[16]
- Geographic distribution of the Air Resources Board's Clean Vehicle Rebate Program[17]

Table 3 summarizes the communities that stakeholders identified as necessary to broaden the early commercial market in California.

Table 3 - Expanded Hydrogen Station Network

General Area	Communities
South Coast Air Basin	Anaheim
	Diamond Bar
	Pasadena Area
	Long Beach
	Riverside
	Palm Springs
	San Fernando Valley
	Santa Barbara
San Francisco Bay Area	San Francisco - Downtown
	Hayward
	Napa
	Pleasanton
	Sonoma
San Diego	San Diego
Sacramento	Sacramento – Downtown

[14] As noted in Footnote 4, each automaker has access to proprietary information which is not shared due to competitive reasons. For example, GM's Project Driveway generated over 80,000 hand-raisers, including many in California, willing to participate in the program.
[15] California Energy Commission, Commission Report. September 2011.
http://www.energy.ca.gov/2011publications/CEC-600-2011-006/CEC-600-2011-006-CMF.pdf
[16] For competitive reasons, the automakers do not actively share these data in the working group sessions. However, these data may be available to California agencies through the Department of Motor Vehicles.
[17] ARB's Clean Vehicle Rebate Program http://www.arb.ca.gov/msprog/aqip/cvrp.htm. The specific distribution of the rebates can be found in the FY 2009-11 Final Report at http://www.arb.ca.gov/msprog/aqip/cvrp/CVRP_FinalReport_FY09-11.pdf

Figure 2 - Clusters in the Greater Los Angeles Area

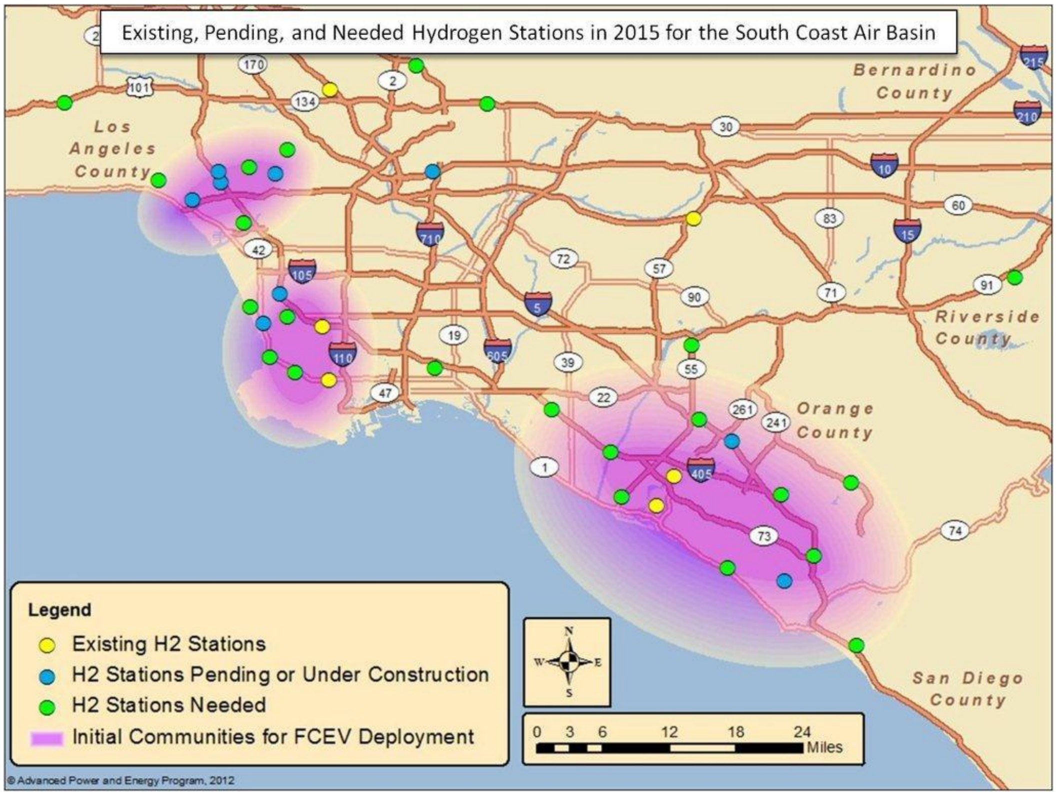
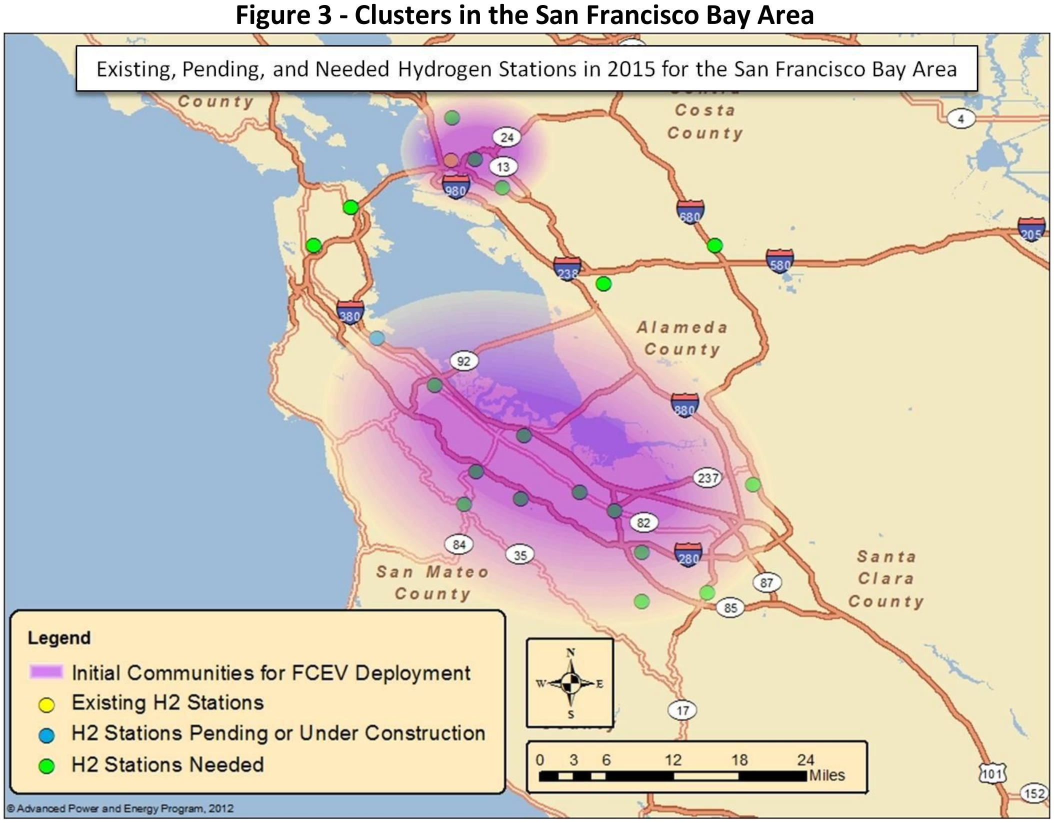


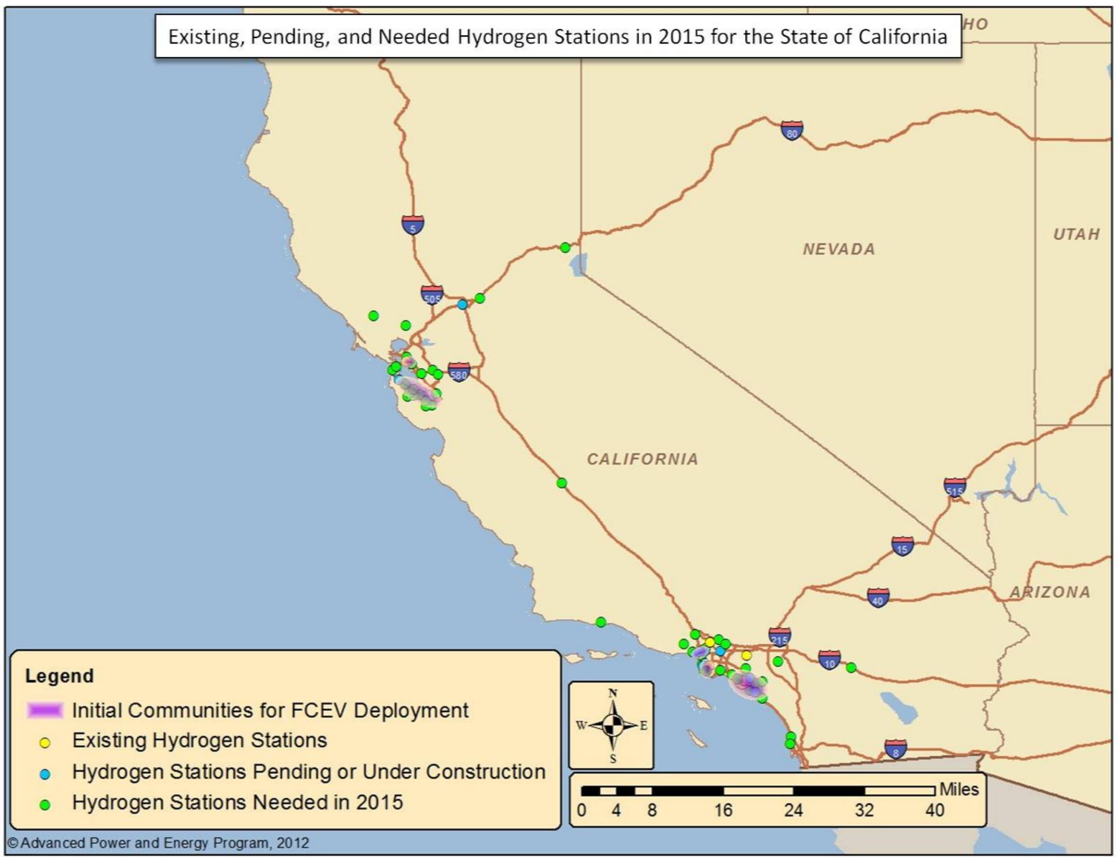
Figure 3 - Clusters in the San Francisco Bay Area



Building a Network

By closely examining where the first customers are likely to live and work, the stakeholders identified the clusters that will provide stations near these locations. The places to visit are fairly universal for most California drivers, therefore, the stakeholders identified “destination station” communities of Santa Barbara, Palm Springs, Sonoma and Lake Tahoe, and a “connector” station in the Central Valley (e.g. connecting Los Angeles and San Francisco), as illustrated in Figure 4. These stations maximize full use of the vehicles throughout the state and help FCEVs appeal to a broader audience.

Figure 4 – Overview of Pre-Commercial Clusters in California



A station’s location, and its ability to encourage customer adoption of FCEVs, represents one half of the equation. The other half is whether anticipated vehicle volumes will provide adequate throughput so that station operators can create a retail hydrogen fuel market.

These communities take full advantage of locations that will be used by local users as well as customers traveling throughout the network. This approach to station placement during early commercialization provides an important foundation towards balancing the coverage and capacity utilization principles. This focuses the earliest vehicle deployments on a few target areas in key California regions. The underlying strategy described here is that building within a handful of target regions provides enough coverage to support anticipated vehicle volumes while ensuring station operators have the ability to create the retail hydrogen fuel market. In other words, it enables all possible potential buyers to purchase an FCEV that meet their needs while making sure the station operators are able to build a business case.

The Total Number of Hydrogen Fueling Stations

To adequately assess the number of stations required to launch the fuel cell electric vehicle market, the automakers engaged researchers at UC Irvine (APEP) and staff at CaFCP.[18] Using APEP's Spatially and Temporally Resolved Energy and Environment Tool (STREET), the team initially analyzed the number of stations that will ensure proper coverage.[19]

A robust network of hydrogen stations within each cluster has been defined as the number and location of strategically located hydrogen stations that a driver can access in six minutes or less of driving, which equates to having hydrogen outlets at 5-7 percent of the existing gasoline stations in the cluster. A six-minute maximum travel time is based on previous optimization research, driver behavior surveys and a need to balance network coverage with network cost.[20] In comparison, current gasoline infrastructure provides access in four minutes of driving time or less in all five cluster regions, though this is considered overbuilt for the needs of consumers.[21,22]

In addition, analyses of alternative fuel stations have concluded that roughly five percent of the existing gasoline stations network would need to offer hydrogen to allay drivers' concerns, a metric which can be applied to each cluster or region.[23] These analyses further state that careful optimization of hydrogen stations is equally as important as the total number of stations offering hydrogen, where optimized locations are determined using driving time with the existing road infrastructure.[24] The STREET analysis offers such optimization while creating a sufficient network for early commercialization. Using these criteria, this assessment determined a cumulative total of 45 stations would be required in the five clusters in California.

To ensure infrastructure is available to customers in these markets, additional hydrogen stations are required to merge the clusters into a regional network. These locations have been identified in an iterative process using locations with FCEV hand-raiser and demographic data, and verifying through direct automaker assessment and feedback on station location. Demographic data are a combination of household income, population and cars per household, with income weighted the most important of the

[18] Advanced Power and Energy Program, University of California, Irvine.
[19] Stephens-Romero, Kang, Brown, Recker, Samuelsen, (2010).Systematic Planning to Optimize Investments in Hydrogen Infrastructure Deployment. *International Journal of Hydrogen Energy*
[20] Ibid.
[21] Nicholas, M. A., Handy, S. L., & Sperling, D. (2004). Using Geographic Information Systems to Evaluate Siting and Networks of Hydrogen Stations. *Transportation Research Record 1880*.
[22] Melaina, M. and J. Bremson (2008). *"Refueling Availability for Alternative Fuel Vehicle Markets: Sufficient Urban Station Coverage." Energy Policy 36(7): 3223-3231*.
[23] Nicholas, M. A., Handy, S. L., & Sperling, D. (2004). Using Geographic Information Systems to Evaluate Siting and Networks of Hydrogen Stations. *Transportation Research Record 1880*.
[24] Melaina, M. and J. Bremson (2008). "Refueling Availability for Alternative Fuel Vehicle Markets: Sufficient Urban Station Coverage." Energy Policy 36(7): 3223-3231.

three. Additional stations within each target region are generally deployed strategically to provide redundancy and consumer confidence where the emerging market is being established. This analysis sought an answer from both sides of the problem by comparing the selected locations against individual automaker market assessments.[25]

Finally, hydrogen stations that provide connectivity from a target region to typical destinations, including destinations which are expected to also serve as early-adopter markets*,* have been identified based on an understanding of where drivers in the target regions typically drive for vacations, excursions, or business.[26] Provision of fuel for long-distance trips is essential to meet customer expectations.[27] By providing a broad fueling network, FCEVs provide the same utility as gasoline vehicles and distinguish themselves from other limited-range, alternative-fuel vehicles. The assessment has determined that 23 additional stations are needed to expand the five clusters into a regional network.

Table 4 on the following page summarizes the total number of stations needed to achieve *A California Road Map's* goal of coverage and capacity. This total includes 17 stations (see Table 6 on page 20) that are currently operating or are under contract with ARB or CEC.[28]

[25] As noted in Footnote 4 and 7, each automaker has access to proprietary market information. Several automakers have shared confidential data with UC Irvine for STREET modeling under a Non-Disclosure Agreement (NDA).
[26] Ibid.
[27] Melaina, M. W. (2003). Initiating hydrogen infrastructures: preliminary analysis of a sufficient number of initial hydrogen stations in the US. *International Journal of Hydrogen Energy*.
[28] This is the cumulative total of stations funded by the California Air Resources Board and California Energy Commission. The total number of stations funded by ARB: www.hydrogenhighway.ca.gov/update/summer09.pdf. The total number of stations funded by CEC: www.energy.ca.gov/contracts/PON-09-608_Revised_NOPA.pdf.

Table 4 – Building a Station Network to Achieve Coverage

Cluster Locations	Total Stations
Santa Monica and West LA	8
Coastal / Southern Orange County	13
Torrance and Nearby Coastal Cities	8
San Francisco South Bay Area	12
Berkeley	4
SUB-TOTAL – CLUSTERS	***45***
Expanded Network Locations	**Total Stations**
Anaheim	1
Diamond Bar	1
Pasadena Area	3
Long Beach	1
Riverside	1
Palm Springs	1
San Fernando Valley	2
Santa Barbara	1
San Francisco - Downtown	2
Hayward	1
Napa	1
Pleasanton	1
Sonoma	1
San Diego	2
Sacramento – Downtown	2
Lake Tahoe	1
I-5 Corridor	1
SUBTOTAL – EXPANDED NETWORK	***23***
TOTAL	**68**

The above table summarizes the total number of stations necessary to launch the early commercial market. It identifies the calculated number of stations in the clusters by STREET as well as the additional network stations necessary located in key markets, connectors, and destinations.

With this assessment, a consensus has developed that California will be best prepared for deployment of FCEVs on a commercial scale if 68 hydrogen stations are strategically located throughout these regions, such that:

- Each FCEV target region establishes a robust network of hydrogen stations within its clusters
- Additional hydrogen stations within each target region begin to merge the clusters into a regional network of stations
- Hydrogen stations provide connectivity from a target region to typical destinations

CEC's Hydrogen Infrastructure Program (AB 118) is expected to provide an additional $29.7 million in hydrogen infrastructure funding in 2012 and 2013. This is expected to support an additional 15-20 stations, bringing the expected total number of planned and operational stations to 37 stations by 2014-2015.[29] Therefore, 31 additional stations are required beyond those currently planned.

Timing the Rollout of Hydrogen Fueling Stations

As the coordinated deployment of vehicles and stations occurs during pre- and early commercialization, stakeholders generally agree that once the coverage principle is met in these regions, station fuel demand growth should then closely follow vehicle sales growth. Slower growth might require fewer or no additional stations, and faster growth might encourage a quicker and broader rollout of hydrogen stations. In other words, if the current projections transpire, 68 stations would be serving thousands of vehicles in the 2016 timeframe, estimated between 10,000-30,000 vehicles as noted in Table 5 on the next page.[30]

[29] Energy Commission. http://www.energy.ca.gov/contracts/transportation.html. Total CEC funding commitments include FY 2010-11 ($10.2M), FY2011-12 ($8.5M), and FY2012-12 ($11M) < http://www.energy.ca.gov/2010-ALT-1/background.html>.

[30] The current estimated capacity of the 68 station network is 21,245kg/day, calculated from existing and expected future installed capacity. This is estimated to be capable of supporting approximately 20,000-25,000 vehicles.

Table 5 – Station Deployment Based on Market Development and Vehicle Roll-out

Year	Start of Year (Station Total)[31]	Added Stations[32]	Number of FCEVs in CA[33]	Expected Station Design Capacity [kg/day]
2012	4	*4*	312	Up to 100
2013	8	*9*	430	100
2014	17	*20*	1389	100-500
2015	37	*31*	*5,000-15,000*	100-500
2016	68	*Market Needs*	*10,000-30,000*	*500*
2017	>84	*Market Needs*	53,000	500
2018	>100	*Market Needs*	>53,000	>500

Note: The OEM Survey only requested years 2015-2017 as a single entry. While the numbers of FCEVs in 2015 and 2016 are not generated in the survey, an estimate value has been used based on a likely roll-out scenario. Based on questions during the CEC workshop, this table has been adjusted to illustrate an estimated range. This table provides a potential station development scenario from 2014-2017, including the average capacity of stations.[34]

With an estimated 53,000 vehicles on the road in the 2017 timeframe, upwards of 100 stations would be necessary to ensure the network has enough capacity for additional vehicles. Therefore, building additional stations or completing station upgrades to meet market demands will likely be necessary by the end 2017 to serve this expected FCEV population.

The Clean Fuels Outlet (CFO) regulation, adopted by the California Air Resources Board in January 2012, would be activated once automakers project 10,000 fuel cell electric vehicles in an air basin or 20,000 across the state.[35] Once these projected volumes are verified, major producers/importers of gasoline must ensure sufficient hydrogen fueling capacity is available to fuel expected FCEV demand.[36] If supply and demand are expected to strictly match, such as the scenario presented in Table 5, approximately 100 stations will be needed by the end of 2017. In this case, the 100 station value represents a combination of the initial 68-station, coverage-based approach and additional stations added by the CFO capacity-based approach.

According to the automaker survey and publicly announced plans, the commercialization of fuel cell vehicles is expected to begin in the 2015-2017 timeframe. While Table 1 (see page 7) identifies anticipated vehicle sales projections, it should be noted that actual vehicle sales will be based on

[31] The number represents only those stations expected to be available.
[32] The 68 station numbers should be characterized as the anchor for this analysis (provided the 2010 Fuel Cell Vehicle Survey). Therefore, the added stations, in italics, describe one potential growth scenario for meeting the coverage needs by the end of 2015 and the capacity needs by the end of 2017.
[33] Based on OEM aggregate survey; 2015-2016 is not defined, but notional estimate provided for illustrative purposes only. Energy Commission, Commission Report. September 2011. http://www.energy.ca.gov/2011publications/CEC-600-2011-006/CEC-600-2011-006-CMF.pdf.
[34] A version of this table was publicly presented to the California Energy Commission during the CEC Application Workshop for Solicitation PON-11-609, Hydrogen Fuel Infrastructure on Feb 22, 2012.
[35] Clean Fuels Outlet Regulation. www.arb.ca.gov/fuels/altfuels/cf-outlets/cf-outlets.htm and www.arb.ca.gov/regact/2012/cfo2012/cfo2012.htm.
[36] It should be noted that Table 5 notes the estimated total number of FCEVs and does not address how projected regional sales might be impacted when CFO is activated.

numerous market-based factors, most notably customer preferences. If customers believe that FCEV technology is mature and fits their needs, and that the station network is sufficient and station performance meets their expectations, then the market is sufficiently enabled so that accelerating FCEV sales will occur. The number of stations operating in 2015-2017 will be crucial to increasing FCEV sales.

If the hydrogen station network is sufficiently robust by 2015, it provides additional certainty and improves the chances that vehicle and station milestones will be met by 2017. On the other hand, if the hydrogen station network is insufficient in the timeframe, FCEVs may be adopted at a slower pace than expected or FCEVs may be adopted at different rates by different markets. This could cause vehicle inventories to be reallocated to regions outside of California, reducing the number of vehicles in the state for a particular calendar year.

Given the investments required to bring an advanced vehicle program to market, along with the necessary infrastructure to adequately support those vehicles, it is critical to minimize the risks to all stakeholders to manageable levels. These considerations also highlight the need to remain flexible during planning efforts, such as the specific station placement. Ensuring the industry is able to adapt to new information or changes in market dynamics will be crucial when building a confident early-adopter market that is prepared to purchase fuel cell electric vehicles. It will require leadership and commitment from all stakeholders through each stage of execution.

The Cost of the Initial Hydrogen Fueling Station Network

Stakeholders have determined that 68 stations in target regions in California by the end of 2015 would provide sufficient coverage to initiate an early commercial market. The majority of these stations are to be placed in three clusters in the greater Los Angeles area and two clusters in the San Francisco Bay area. This strategy balances customer expectations with respect to driving distance and coverage while building confidence in the market development of the vehicle and station technologies.

It should be noted that as station coverage needs for early commercialization are fulfilled, the build-out of additional hydrogen infrastructure is expected to be managed through the Clean Fuels Outlet (CFO) regulation. Building the initial coverage of 68 stations is critical to ensuring a successful market launch, since additional mechanisms like CFO are in place to support further FCEV deployment.

As previously stated, stakeholders estimate 37 stations will be funded and operating in 2015, leaving a gap of 31 needed stations. Satisfying this gap is essential to maintaining continued confidence that California will be ready for an early FCEV market. This section estimates the funding necessary to bridge this gap using two proposed scenarios.

Understanding the overall cost of the network and building the business case are critical to long-term market success. While the business case for an individual station will be defined by the factors discussed below-– the expected station costs (including equipment and installation, operations and maintenance, and financing) and the expected revenue (including pricing and hydrogen demand)-many factors will influence the success of an individual station. *A California Road Map* does not look at how individual station operators might maximize their potential for success; rather, it takes a broader view of the system and what macro-scale factors may impact the funding gap.

Current and Planned Investments for Hydrogen Stations

Table 6 depicts the network of hydrogen fueling stations currently funded and expected to be operational by the end of 2015.[37] In total, ARB and CEC have provided $31 million in cost-share funding for the following stations with $29.7 million allocated for future stations.

Table 6 – Expected Availability for Currently Funded Stations by 2015

Station	Current Status	Capacity (kg/d)	2015 Status	Assessment
Beverly Hills (Air Products)	Planned – 2013	180	Available	Retail Setting
Burbank (City of Burbank)	Operational	100	Available	Non-commercial Setting
Diamond Bar (SCAQMD)	Upgrade (2013)	180	Available	Non-Commercial Setting
Emeryville (AC Transit)	Operational	60	Available	Non-Commercial Setting
Fountain Valley (OCSD)	Operational	100	Unavailable	Unavailable
Harbor City (Air Products)	Planned – 2012	100	Available	Retail Setting
Hawthorne (Air Products)	Planned – 2013	180	Available	Retail Setting
Hermosa Beach (Air Products)	Planned – 2013	180	Available	Retail Setting
Irvine (Air Products)	Planned – 2013	180	Available	Retail Setting
Irvine (UC Irvine)	Upgrade (2012)	180	Available	Non-commercial Setting
Laguna Niguel (Linde)	Planned – 2013	240	Available	Retail Setting
Los Angeles (Cal State LA)	Planned – 2012	60	Available	Non-commercial Setting
Newport Beach (Shell)	Operational	100	Available	Available
San Francisco (SFO)	Planned – 2012	240	Available	Non-Commercial Setting
Santa Monica (Air Products)	Planned – 2013	180	Available	Retail Setting
Torrance (Shell)	Operational	60	Available	Retail Setting
West Los Angeles (Air Products)	Planned – 2013	180	Available	Retail Setting
West Los Angeles (Shell)	Operational	30	Unavailable	Unavailable
West Sacramento (Linde)	Planned – 2013	240	Available	Retail Setting
		ALL STATIONS TOTAL	**19**	
		2015 AVAILABLE TOTAL	**17**	

[37] Based on information from ARB and CEC on 4/20/2012.

Given the existing or planned stations, the assessment in Table 6 identifies three types of station status:

- Available – Commercial Setting: Stations in a commercial setting, such as those located at a retail gasoline location, were assumed to be available in the 2015-2017 timeframe. These hydrogen stations are located in the clusters, or might otherwise be considered anchor stations as the market develops, since early customers are expected to be most familiar with these locations. There is a high likelihood that each of these stations will be upgraded to meet market needs.
- Available – Non-commercial Setting: Stations in a non-commercial setting, such as a university campus or fleet/private setting were also assumed to be available. However, it is anticipated that customers may not be as comfortable with the non-commercial setting, so these stations might support private fleet applications or be used as a backup to a retail location. There is less likelihood that these stations will be upgraded in the future.
- Unavailable - Demonstration stations which have been slated for closure are included. It should be noted this assessment will probably change as station operators and early customers determine the market needs for each location and technology.

Additional funding for hydrogen stations has been allocated by the CEC as well as a future funding allocation from the 2012-2013 AB118 Investment Plan.[38] The total funding allocation for future stations is approximately $29.7 million.[39] It is estimated that up to 20 hydrogen stations will be funded (through the 2012-13 Investment Plan (with all stations being available by the beginning of 2015). The final number of stations will be determined by funding availability, stations proposed, and the cost to install each proposed retail station.

For the above stations, the current incentives from California (i.e., CEC, ARB) for station deployment have focused on driving the cost of equipment down through cost-share grants to hydrogen station equipment developers. Historically, the government cost-share has ranged between 50% and 70%. While this model was successful in making stations cheaper, it did not address operations and maintenance costs incurred by station owners, nor did it leverage the potential private financial models from station developers who are not equipment manufacturers.

Future Funding Requirements for Hydrogen Stations

Compared to gasoline stations, hydrogen stations currently require high up-front capital costs and maintenance expenses. These costs can ultimately be offset by potentially high margins on every kilogram (kg)[40] of hydrogen sold (compared to gasoline margins). For the early hydrogen stations, however, when vehicles numbers are still low, fuel revenues are expected to be insufficient to offset the

[38] Investment Plans can be found at: www.energy.ca.gov/2011-ALT-1/background.html. Draft CEC AB118 2012-2013 Investment Plan: www.energy.ca.gov/2012publications/CEC-600-2012-001/CEC-600-2012-001-SD-REV.pdf.

[39] Energy Commission. http://www.energy.ca.gov/contracts/transportation.html. Total CEC funding commitments include FY 2010-11 ($10.2M), FY2011-12 ($8.5M), and FY2012-12 ($11M). http://www.energy.ca.gov/2010-ALT-1/background.html.

[40] 1 kg of hydrogen fuel has roughly the same energy content as 1 gallon of gasoline. On average, fuel cell vehicles can travel 2.5 times as far on 1 kg of hydrogen as an internal combustion engine vehicle can travel on 1 gallon of gasoline.

costs for many months or years. Some incentive funding is broadly acknowledged as necessary to make a business case in these early commercial stations.

To estimate the incentive funding required to reach 68 stations, the cost of installing new stations must be considered, in addition to the cost of operating and maintaining all the stations. This funding requirement is fully analyzed in the report, *Incentivizing Hydrogen Infrastructure Investment* and is summarized in the following sections.[41] The analysis includes a detailed breakdown of the funding requirements for an average station under different scenarios. The funding requirements were evaluated under two possible incentive approaches, the "capital buy-down" approach and the "cash-flow support" approach.

The California Energy Commission uses the *capital buy-down* approach as the incentive structure for its Alternative and Renewable Fuel and Vehicle Technology Program, in which it provides station developers a grant to "cost-share" the up-front capital expense. To determine the government and private funding necessary to reach the 68 station target, the report's analysis adds operations and maintenance (O&M) costs to the total capital cost for all new stations described in Table 5 (see page 16). Funding for O&M was also included in the analysis for existing stations (i.e., operating or previously funded). In each case, this O&M support was assumed to continue until the net retail margin for a station exceeds its O&M costs.

The analysis also explores *cash-flow support* as an alternative incentive structure, aimed at attracting a broader set of investors to hydrogen station investment. Investors pay for and finance the hydrogen station development in full, but receive an incentive payment when the station begins operations. These payments cover all operating expenses as well as financing payments, and continue until the net retail margin can pay for these costs. For many stations, the need for cash flow support is expected to continue for three-to-five years as more vehicles enter the market. For other stations, such as an underutilized connector or destination station, this may last until the financing is paid off, assumed in this analysis to be within 10 years. The intent is to attract fuel industry investors who are accustomed to using a similar investment model to rapidly achieve positive cash flows from gasoline station investments.

Assumptions for the Hydrogen Station Funding Analysis

The following assumptions have been used in the analysis to reach the 68-station goal. Generally, all stations are expected to be operated in a retail setting and dispense hydrogen that has been centrally produced and delivered to the station.[42]

Table 7 presents the expected capital and O&M costs for a variety of stations, which include:

[41] This white paper is based on analysis conducted within the context of an industry and government collaborative effort, launched in July 2011 to examine investment options for early commercial hydrogen infrastructure in California. The report can be found at: http://www.einow.org/images/stories/factsheets/ein_california_h2_infrastructure_cost.pdf.

[42] In reality, some stations may generate hydrogen onsite or receive hydrogen from a pipeline.

Capital Costs - Capital cost includes equipment purchase, permitting fees, and construction, with an additional ten percent contingency expense added.

Operating Expenses - Because O&M costs can vary significantly due to several factors, such as equipment design, site considerations, and utilization, this analysis uses data aimed at a midpoint between industry-reported cost structures, capturing both variable and fixed cost projections. At average loads, the total O&M costs correspond to the information presented by UC Davis.[43] The breakdown of costs includes baseline maintenance costs of $12,000 per year when there is no use, with an additional 6% expense for every increase in daily load of 25kg/day. In addition, this analysis adds baseline electricity costs of $1,200 per year plus an incremental $0.30/kg compression cost. Other operating expenses include annual property tax (1% of capital cost), rent for the space on a convenience store-style station ($2,500/month), insurance ($1,600/month), and permit fees ($3,680).

Table 7 – Hydrogen Station Infrastructure Costs

Station Timing and Size	Capital Cost	Annual Operating Expenses	
Station Built in 2014		No Load	Max load
100-170 kg/day	$0.9M	$75k	$100k
250 kg/day	$1.4M	$80k	$117k
Stations Built 2015-2017			
250 kg/day	$0.9M	$75k	$112k
400-500 kg/day	$1.5M-$2.0M	$81k[44]	$167k

Station Capacity - To estimate system costs, newly funded and implemented stations will dispense 250 kg/day or 500 kg/day. It should be noted that industry cost projections are available only for these station sizes. These stations balance expected coverage and capacity while targeting capacities expected to be operational in 2015. In practice, smaller stations (e.g., 180 kg/day) may be deployed in some locations and larger stations in others (e.g., 800-1,000 kg/day). Larger stations represent a higher potential for return on investment while the smaller-sized station minimizes cost.

Price of Hydrogen - Currently, there is no retail price of hydrogen as a transportation fuel. For the purposes of this analysis, hydrogen has been estimated to be sold between $8.00-$11.00/kg, including sales tax. This price includes a $6.00/kg wholesale cost,[45] sales tax of 9% ($0.72 to $0.90/kg) and a retail margin of $2.00-$4.00/kg.[46] Hydrogen is not currently subject to fuel excise taxes administered by the

[43] Ogden, Joan et al. (2011). "Analysis of a "Cluster" Strategy for Introducing Hydrogen Fuel Cell Vehicles and Infrastructure in Southern California." University of California, Davis, Institute of Transportation Studies.
[44] Property tax (1% of capital cost) accounts for the slight cost difference between the 250kg and 400-500kg stations with no-load.
[45] While the retail prices of hydrogen cannot be predicted, multiple industry efforts have occurred to estimate the price of hydrogen based on cost information. Wholesale costs will vary by location where analyses have shown that cheaper wholesale hydrogen could enable an $8/kg retail price.
[46] Retail margins are provided for analytical purposes only. Study participants and fuel retailers are each independently responsible for determining the retail margins to be assumed in any analysis and the prices they will charge to the consumer.

State of California Board of Equalization.[47] A price range of $8.00-$11.00/kg, hydrogen is comparable to gasoline priced between $3.20 and $4.40/gallon of gasoline.[48]

Retail Margin: $3.00/kg - While the overall supply market and each individual hydrogen station operator will determine this value, a $3.00/kg margin was assumed for this analysis. This margin balances cost savings to the consumer and profits to the station owner.[49] A $2.00/kg margin may generate insufficient revenue to pay for stations at their current and projected costs, while a $4.00/kg likely makes hydrogen too expensive to market relative to gasoline. It should be noted that the analysis has intentionally chosen lower-cost numbers, both in terms of the cost and utilization scenarios. For example, it appears that, in the compressed natural gas (CNG) sector, market growth and competition will quickly result in significant capital cost reductions, lower O&M costs, and downward price pressure on wholesale hydrogen prices.

Financing - For the purpose of this analysis, a hydrogen station developer would borrow 100 percent of the money needed to install hydrogen-fueling equipment. Discussions with industry financiers confirm this is current practice for gasoline stations. Furthermore, CNG stations, which represent the most comparable equipment and station footprint, have also obtained 100 percent financing.[50]

Loan term: 10 years, 5.5% interest rate - Typically, fueling equipment loans are issued based on a seven-year loan term, but can be extended with justification.[51] A seven-year loan places considerable financial pressure on an early market hydrogen station project. This analysis assumes that a strong package can be put together to obtain a ten-year loan term. In addition, a 5.5% interest rate reflects current rates for similar station financing, as reported by financial organizations in this industry.[52]

Station Utilization - As illustrated in Figure 5, the demand for hydrogen fuel at an individual station is characterized in three deployment scenarios: fast, medium and slow growth. The medium growth curve represents an average fuel-demand load based on the vehicle deployment projection curve provided by the CaFCP in *Progress and 2011 Actions for Bringing Fuel Cell Vehicles to Market in California*.[53] The slow growth curve represents a prolonged vehicle ramp-up scenario, such as a delay in FCEV rollout or a region where FCEVs are more slowly adopted by the market. The fast growth curve reaches full utilization after four years of sales, representing a strong market development in a cluster region. To remain conservative, this analysis uses the medium growth curves for the cluster markets, and the slow growth curves for the other smaller stations. All of these growth curves also incorporate a one-year "lag time" effect to capture the reality that financing and other costs will be incurred from the outset, before

[47] "Selling Hydrogen Fuel in a Pre-Commercial Environment within California". California Department of Food and Agriculture, Division of Measurement Standards. November 2011. www.cdfa.ca.gov/dms/.
[48] One kilogram of hydrogen holds approximately the same energy content as one gallon of gasoline, and FCEVs are about 2.5 times as efficient as conventional gasoline engine vehicles (CARB Low Carbon Fuel Standard 2011 Amendments).
[49] $6.00 wholesale + $3.00 retail margin + $0.81 sales tax = $9.81 retail cost. Comparable to $3.92/gallon gasoline.
[50] Conversation with Patriot Capital Corporation, March 2012. http://www.patriotcapitalcorp.com/about-us.
[51] Ibid.
[52] It should be noted that if a hydrogen station were completely funded by private investment, we would expect the interest rate to be greater than 5.5% because hydrogen infrastructure payback potential has not yet been demonstrated. This analysis assumes that a dedicated cash flow support fund greatly increases the probability of successful loan payback, thereby decreasing risk to the lender and the requisite interest rate.
[53] Published February 2011: http://cafcp.org/sites/files/CaFCPProgressand2011Actions_0.pdf.

the station is open. For all stations, an average utilization of 70% has been used to calculate annual sales and revenues.

Figure 5 – Utilization Growth Scenarios

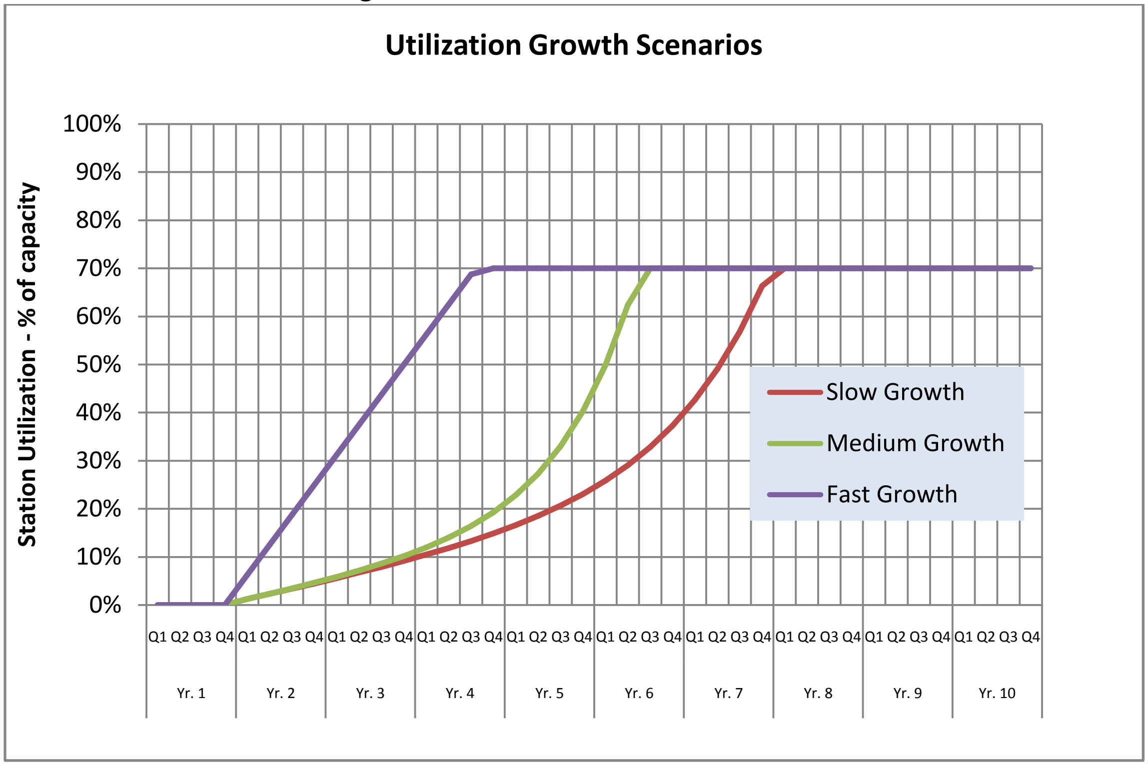


Figure 5 illustrates individual station use shown over time, as a percentage of capacity. For example, a 500 kg/day station owner in a "fast growth" environment could expect to sell an average of 350 kg/day by the end of year 4.

Funding Requirements Estimate

As reported in *Incentivizing Hydrogen Infrastructure Investment,* the model utilized a range of capital cost, utilization, and retail-margin assumptions.[54] The baseline scenario included a mix of existing and new stations of varying sizes, with a cumulative capacity to support the expected number of FCEVs by the end of 2015. These stations are evaluated using the conservative medium and slow-growth curves from Figure 5, with utilization capped at 70 percent, and a $3.00/kg retail margin. This scenario is presented in Table 8 on the following page.

[54] A summary of analysis conducted within the context of an industry and government collaborative effort, launched in July 2011 to examine investment options for early commercial hydrogen infrastructure in California.

Table 8 – Cash Flow Support Scenario for Hydrogen Fueling Stations

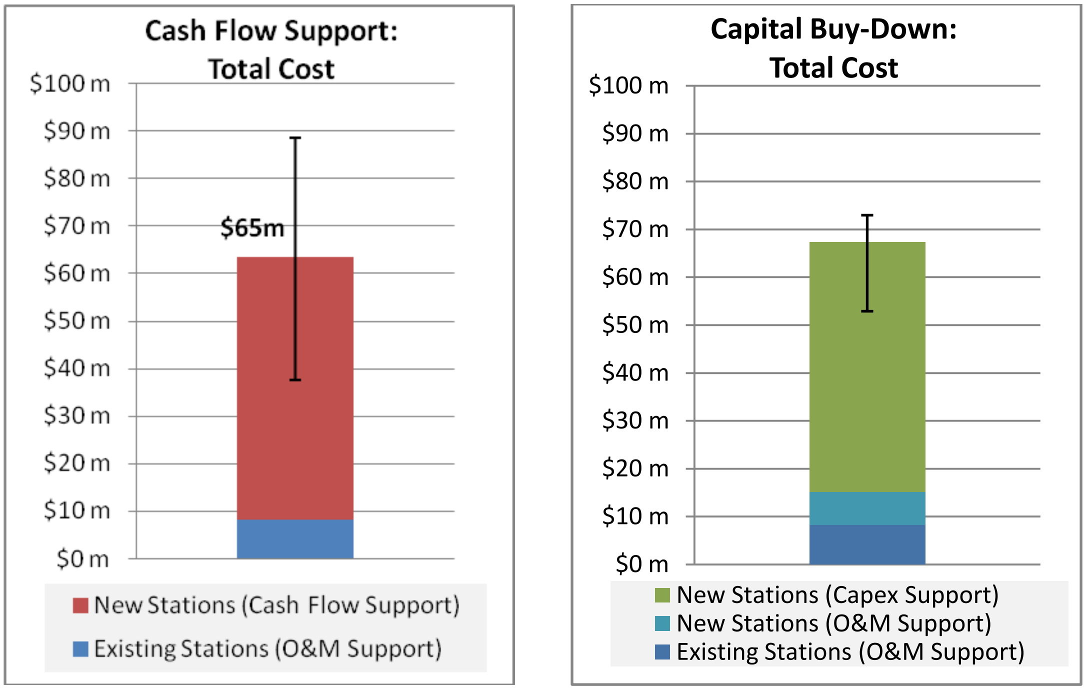
Types of Stations	Type of Cash Flow Support Provided	# of Stations Supported	Total Cash Flow Support
EXISTING STATIONS			
60-240 kg/day stations[55]	Operating Expenses only	**37**	**$8.3M**
ADDITIONAL STATIONS [56]			
500 kg/day station	Full cash flow support	**22**	**$45.1M**
250 kg/day station	Full cash flow support	**9**	**$10.3M**
	TOTAL	**68**	**$63.6M**

The total cost to build and support a network of 68 stations is estimated at $63.6 million. To better reflect the uncertainties captured in this analysis, the estimate was rounded up to $65 million to support the required network. The allocation of this funding would vary by year and by individual station based on market-factors, but would diminish from approximately $13 million-$15 million in the first year to less than $2.3 million in the tenth year as FCEV volumes ramp up. This assumes all stations are funded by cash-flow support incentives.[57] It should be noted this assessment does not offer insight into the funding mechanism (e.g. a public-private partnership), which may require administrative costs, thereby impacting the total funding necessary to support the plan.

To understand the potential funding variability, a sensitivity analysis was completed based on changing capital cost, utilization, and retail margin assumptions for the cash-flow support approach and the capital buy-down approach. As characterized in the error bars in Figure 6, the total cash shortfall can be substantially reduced (to $38 million) if the capital cost of a 500-kg-per-day station is reduced to $1.5 million, every station experiences a medium-growth curve, and station owners earn a $4.00/kg retail margin. On the high end, the cash shortfall rises to $89 million if the capital cost of a 500/kg-per-day station is $2 million, every station experiences a slow-growth curve, and retailers earn a $2.00/kg margin.

[55]Station capacity of 60-240 kg/day only applies to stations funded and announced up to early April 2012. Stations announced later may have larger capacity.
[56] A slow-growth utilization curve is assumed for the existing stations, given the early market presence. For the 2015 additional stations, a medium-growth is assumed for the 500kg station, which are likely to be in the cluster areas, while a slow growth is assumed for the small stations, given they are likely to be in connector or destination locations.
[57] The payments in Year 11 are estimated to be near $0, as loans would be paid off in full and hydrogen sales would cover O&M.

Figure 6 – Cash Flow Support and Capitol Buy-Down



Compared with the cash-flow support approach, the capital buy-down approach creates a similar overall cost, estimated to be $67 million. This includes the same $8.3 million O&M support for the existing stations. The cost of this approach is less variable because it is primarily based on the upfront capital cost of the equipment. Total costs range from $53 million in a low-capital cost, medium growth and high-margin scenario, to a high of $73 million for a high-cost, low-growth and low-margin scenario.

Given the baseline assumptions (i.e., high capital costs, mixed utilization, and $3.00 retail margin), the cash-flow and capital-cost buy-down approaches require essentially the same level of funding support. The cash-flow approach becomes more attractive (i.e., less costly) as market conditions improve, and the capital-cost approach is likely to be better in a market where slower growth may be expected. It is assumed a hybrid between the two approaches will be required to complete the network of 68 stations.

Conclusion & Future Analysis

According to the automaker survey and publicly announced plans, the commercialization of fuel cell vehicles is expected to begin in the 2015-2017 timeframe. While surveys identify anticipated vehicle sales projections, actual vehicle sales will be based on numerous market-based factors, most notably, customer preferences. If customers believe FCEV technology is mature and fits their needs, and that the station network is sufficient and station performance meets their expectations, then the market is sufficiently enabled to support accelerating FCEV sales will occur. Therefore, the number of stations operating in these early years (2013-2017) will be crucial to building market confidence and growing FCEV sales.

If the hydrogen station network is sufficiently robust by 2015, it provides additional certainty and improves the chances that vehicle and station milestones will be met by 2017. On the other hand, if the hydrogen station network is insufficient in the timeframe, FCEVs may be adopted at a slower pace than expected or FCEVs may be adopted at different rates by different markets. This could cause vehicle inventories to be reallocated to regions outside of California, reducing the number of vehicles in the state for a particular calendar year.

Efficient development of hydrogen infrastructure relies on two primary factors: coverage and capacity. In the early years, coverage is the critical component, as fuel cell electric vehicles can only be successfully marketed if fueling stations are available in locations where potential owners see them as convenient. As described throughout this document, 68 stations are expected to provide sufficient coverage to offer FCEV owners in key markets a fueling experience similar to gasoline in key markets. The required funding to complete the nascent network of stations is approximately $65 million.

Many additional factors will influence the benefit of a specific fueling location, such as the performance and reliability of the fueling equipment. As the coverage of stations in a particular cluster becomes adequate, station usage and capacity will be a major consideration. To ensure these stations can meet growing demand, sufficient capacity must be built into the system. Only then can the market transition to the capacity targets defined by CFO and develop into a sustainable market for FCEVs and the hydrogen fueling stations.

To successfully navigate this challenge, stakeholders must also understand related topics that are not fully addressed in *A California Road Map*. For example, fuel cell buses are expected to play a significant role for public transit and can share infrastructure in major metropolitan areas through dual-use station equipment. Material handling and other similar applications can create markets benefiting the development of hydrogen-station equipment components. The execution of this road map will have an immediate impact on high-tech, green jobs and will set the stage for important steps in improving California's air quality. Perhaps, most importantly, the question of how and who will fund the additional $65 million needed must be addressed. The stakeholders agree that continued evaluation of these items will be crucial for identifying solutions to the challenges of bringing FCEVs and hydrogen stations to market.

Emerging fuel cell electric vehicle and hydrogen infrastructure markets will only be realized through the continued collaboration with a broad set of dedicated stakeholders. Significant progress has been made and *A California Road Map* outlines additional steps that stakeholders must take to achieve market success.