Vision for Rollout of Fuel Cell Vehicles and Hydrogen Fuel Stations

July 2008

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This document establishes CaFCP's current consensus vision of next steps for vehicles and hydrogen stations in California. This consensus vision does not necessarily represent the organizational views or individual commitments of CaFCP members.

CaFCP Vision Document

Overview

Fuel cell vehicles and hydrogen fuel provide a sustainable transportation choice for the future. By offering zero tailpipe emissions as well as significantly reduced criteria pollutant and greenhouse gas emissions from fuel production, fuel cell vehicles powered by hydrogen can improve local air quality and reduce greenhouse gas emissions. Because hydrogen can be made from a diverse mix of traditional and renewable energy sources, it can dramatically increase our nation's energy security. Most importantly, fuel cell vehicles are family-friendly, full-function vehicles that will fit peoples' lifestyles.

California is the right place to begin a transition to a hydrogen fuel cell vehicle future. California has a long standing record of success in cleaning up local air pollution, and has established bold policies to reduce greenhouse gas emissions and increase the use of alternative fuels. California is home to approximately 10 percent of the United States' population, and the California economy compares to some of the world's largest nations. California's residents embrace technological and social innovation, and carry a strong environmental ethic. The State has made a commitment to hydrogen as a vehicle fuel through the California Hydrogen Highway Network program, which has authorized almost $20 million to date to support hydrogen vehicles and fuel stations.

In 1999, the California Fuel Cell Partnership embarked on a program to demonstrate the real-world feasibility of fuel cell vehicles. In the first phase from 1999-2003, industry members successfully proved the technical viability of the vehicles and stations through their own on-road operations. During the second phase from 2004-2007, automakers and energy companies launched demonstration programs to gain real-world driving and fueling experience with customers. Through 2007, CaFCP members have successfully operated more than 200 fuel cell vehicles and 25 hydrogen fuel stations in fleet and early customer demonstration programs. These demonstrations have proven that hydrogen fuel cell vehicles and transit buses have the potential to meet customer demands and provide significant environmental and energy diversity benefits to meet California's goals.

The first step to achieving significant benefits is to realize a commercial market for fuel cell vehicles and hydrogen fuel. This technology, along with other electric drive vehicles, will be essential for California to achieve its goal of 80% reduction of greenhouse gas emissions by 2050 and to make a significant reduction in petroleum use for transportation.[1, 2] As with any ambitious endeavor, achieving a commercial market will require careful planning and appropriate transition time. Similar to other vehicle technologies, it will take decades for fuel cell vehicles to become a majority in the vehicle fleet.

As the CaFCP enters its third phase, some CaFCP members are planning to begin the transition from demonstration projects to pilot commercial projects. This phase is characterized by larger numbers of vehicles, retail-like hydrogen fueling stations and individual customers who drive fuel cell vehicles as part of their daily lives. During this phase California must build new fuel stations and leverage existing infrastructure to support the early commercial market. Moving to pilot commercialization will require intense coordination to reach our common goals. This document lays out the CaFCP's vision for next steps in a transition to a commercial market for hydrogen fuel cell vehicles.

How many vehicles will be deployed in the next few years?

Automakers project thousands of vehicles will be available for consumers in the 2012 to 2015 timeframe. At least one automaker will start leasing fuel cell vehicles to early customers beginning in 2008. The California Air Resources Board (CARB) requires automakers and transit agencies to introduce zero-emission vehicles (ZEVs) and buses (ZeBus) in increasing numbers starting in 2009[3]. Many of these vehicles will be hydrogen fuel cell vehicles and buses.

The number of light-duty fuel cell vehicles to be deployed in California and other ZEV states can be estimated based on the CARB ZEV regulation. This regulation requires automakers to deploy certain volumes of "gold" zero-emission vehicles[4] (ZEVs), where gold ZEVs are fuel cell or battery electric vehicles. This document assumes that all "gold" ZEVs will be fuel cell vehicles and deployed in a concentrated region of California.

Under this regulation, from 2009 through 2011 the six major automakers will deploy between 250 and 2,500 (depending on credit use) "gold" ZEV in California or other ZEV states. From 2012 through 2014 automakers will be required to deploy up to 25,000 "gold" ZEVs, with an option to produce fewer (5,357 to 9,375, depending on vehicle driving range) with considerable numbers of other advanced technology vehicles (plug-in hybrids, extended range electric vehicles or hydrogen ICEVs). Starting in 2015, automakers are expected to produce significantly more gold ZEVs. The regulation requires at least 25,000 "gold" ZEVs between 2015 and 2017, although the CARB staff will propose an overhaul to the program in 2009 and these numbers may change.

Table 1: CARB "Gold" ZEV requirement[a]

2009-2011	2012-2014	2015-2017
2500	25,000	50,000
OR		
NA	5,357 to 9,375 plus 58,000 silver+[c]	at least 25,000[b]

[a] *large-volume automakers required to build their market share*
[b] *2015-2017 requirements to be considered in 2009*
[c] *Silver+ vehicles are plug-in hybrid or hydrogen internal combustion engine vehicles*

Under the CARB zero-emission bus (ZeBus) regulation, all transit agencies operating more than 200 buses will be required to make 15 percent of their new bus purchases zero-emission buses starting in 2011 to 2012. As a result of this regulation, transit agencies could purchase and operate more than 200 fuel cell buses by 2015.

Table 2: Estimated Number of Fuel Cell Buses in California

	2009-2011	2012-2014	2015-2017
Number of FCBs (per CARB ZeBus regulation)	Up to 15	Up to 220	15% of new bus purchases

Although it is difficult to predict an exact number of fuel cell vehicles, it is expected that the numbers of hydrogen fuel cell vehicles will grow significantly over the next six years, and even more rapidly thereafter. Customers will need a hydrogen fueling infrastructure to support full utilization of these new products and encourage further market growth.

How might vehicles and fuel stations grow to commercial volumes?

Based on experience and information gathered during fleet demonstrations, many auto manufacturers are confident fuel cell vehicles are ready or nearly ready to be introduced to individual customers. As vehicles are introduced to customers, fuel stations must also evolve from fleet applications to early retail-like stations. These retail-like stations should provide easy access and customer-friendly fueling to any hydrogen-fueled vehicle.

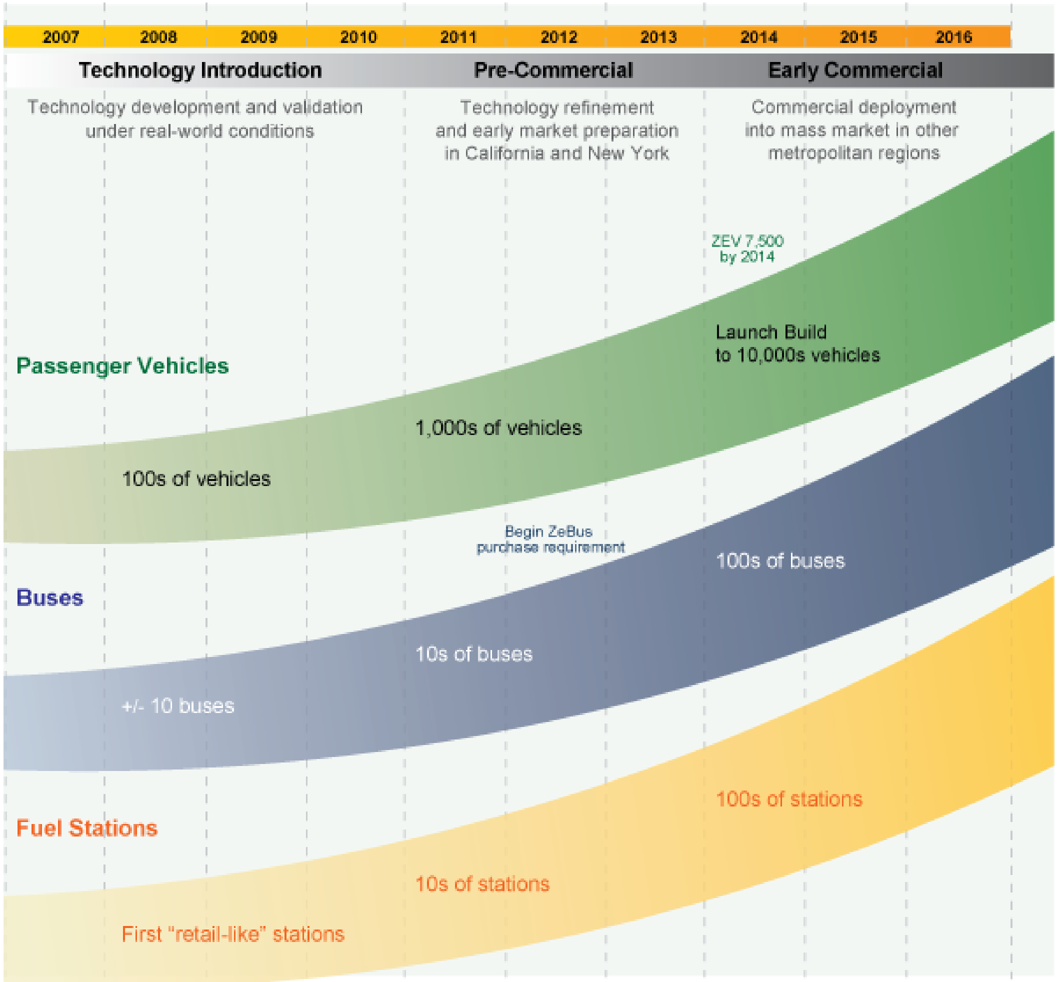
The Oak Ridge National Laboratory in conjunction with other national laboratories and industry conducted a scenario analysis[5] of three fuel cell vehicle penetration rates to assess costs and infrastructure needs to accommodate growth to two, five and ten million fuel cell vehicles in the U.S. fleet by 2025. These scenarios provide insight into transition and market issues as we move toward commercializing hydrogen fuel and fuel cell vehicles.

The transition to a commercial market is a process that will take years, and will be accomplished by moving from technology introduction to pre-commercial and early commercial phases. For light-duty fuel cell vehicles, the numbers of vehicles in each of these phases grows by a factor of 10 for each automaker. The amount of hydrogen and number of fuel stations in the early deployment regions must match growing vehicle numbers.

A conceptual roll out plan is illustrated in Figure 1. This concept applies to vehicle and station production and deployment in general, but because of the need to link vehicle and station deployment, it should be considered representative of what is needed in a given region. Considering such a concept for California, the pre-commercial phase correlates well with the CARB ZEV regulation for 2012–2014.

After 2014, the pace of increasing vehicle production volumes depends on technology readiness. An “early volume production” phase corresponding to 150,000 to 200,000 FCVs can occur once a technology review indicates readiness to lock-in vehicle designs for the early commercial market. Such a review should be conducted on state and national levels in 2009 to determine if hydrogen and fuel cell vehicle technology is ready to ramp up to early volume production and enter the early commercial market. A review in 2009 allows for appropriate adjustments to the California ZEV regulations as well as federal funding to support a second phase of the national learning demonstration starting in the 2010 budget year. A second phase of the national learning demonstration will be needed to support early volume production, providing a 50/50 cost share to support both vehicles and hydrogen stations. This is an important positive signal for industry to make the early capital investments required.

Figure 1: Fuel Cell Vehicle Commercialization Overview (Conceptual)



How much will it cost to achieve a sustained hydrogen fuel cell vehicle market?

New technologies are expensive when first introduced. Fuel cell vehicles and hydrogen stations require technology advancements and mass production economies of scale to be competitive with established technologies. The Oak Ridge National Laboratory's hydrogen scenario analysis found that "…with targeted deployment policies in place during 2012 to 2025, the fuel cell vehicle (FCV) market share could grow to 50% by 2030 and 90% by 2050."[6] The analysis considered both incremental vehicle costs and fuel infrastructure cost and concluded "the costs for the three policy cases analyzed were estimated to range from $10 to $45 billion cumulatively over the 2012-2025 timeframe (14 years), with peak annual costs of between $1 and $6 billion."[7] These costs were due to vehicles and fuel stations. The report also found that "in all three vehicle production scenarios, hydrogen FCVs are able to achieve and maintain market dominance without policy supports beyond 2025, such that by 2050 most new light-duty vehicles could be FCVs and the majority of fuel used by light-duty vehicles could be hydrogen."[8]

The cost to transition to hydrogen fuel cell vehicles is too high for industry to bear on its own, and given the public benefits, it is entirely appropriate and essential for government to support this transition. In fact, deployment of any new technology to reduce transportation greenhouse gases and petroleum use will require government support. Hydrogen and fuel cell vehicles can provide dramatic greenhouse gas emission reductions, energy security and improved local air quality, which will make investments in this technology well worth it.

Local, state and federal government agencies will need to coordinate and integrate funding and other support programs to target investments and achieve the maximum benefit for the public funds invested in hydrogen stations and fuel cell vehicles.

How much hydrogen will the early fuel cell vehicles need?

To calculate hydrogen demand for fuel cell passenger vehicles, one can assume that each vehicle will use approximately 0.7 kg of hydrogen each day[9]. For an average fuel cell vehicle with a fuel economy of 50 to 60 miles per kg, this would accommodate about 35 to 40 miles of driving on an average day.

To calculate hydrogen demand for fuel cell buses, one can assume that each bus will use approximately 30 kg of hydrogen each day. This provides enough fuel to drive 200-250 miles per day, which is typical of buses operated in California.[10]

Table 3 estimates the amount of hydrogen needed to support expected volumes of fuel cell vehicles and buses in California (based on ZEV and ZeBus regulations).

Table 3: Projected hydrogen demand based on CARB ZEV and ZeBus estimates

	2010	2011	2012	2013	2014	2015	2016	2017
ZEV estimated passenger vehicles	250 to 2,500 *(depending on credit use)*		5,357 to 9,375 *(depending on FCV range)*			25,000 [c] (*to be determined based on ZEV review in 2009)*		
ZeBus estimated FCBs [a]	Up to 15		Up to 220			15% of new bus purchases		
Projected H_2 demand (kg/day) [b] *for passenger vehicles and buses*	270 to 2,200		3,750 to 13,200			20,000+		

[a] *based on ZeBus regulation and numbers that will be bought by AC Transit and VTA, SF Muni, etc. (FTA funded projects). Note ZeBus technology will be reviewed in mid-2008.*

[b] *assuming 0.7 kg/day per passenger fuel cell vehicle, 350 and 700 bar delivery pressure, 30 kg/day per fuel cell bus, 350 bar delivery pressure.*

[c] *to be determined based on ZEV review in 2009.*

[d] *projected hydrogen demand assumes the estimated ZEVs and ZeBus targets are met within the stated timeframes using fuel cell vehicles.*

How might the early hydrogen stations roll out?

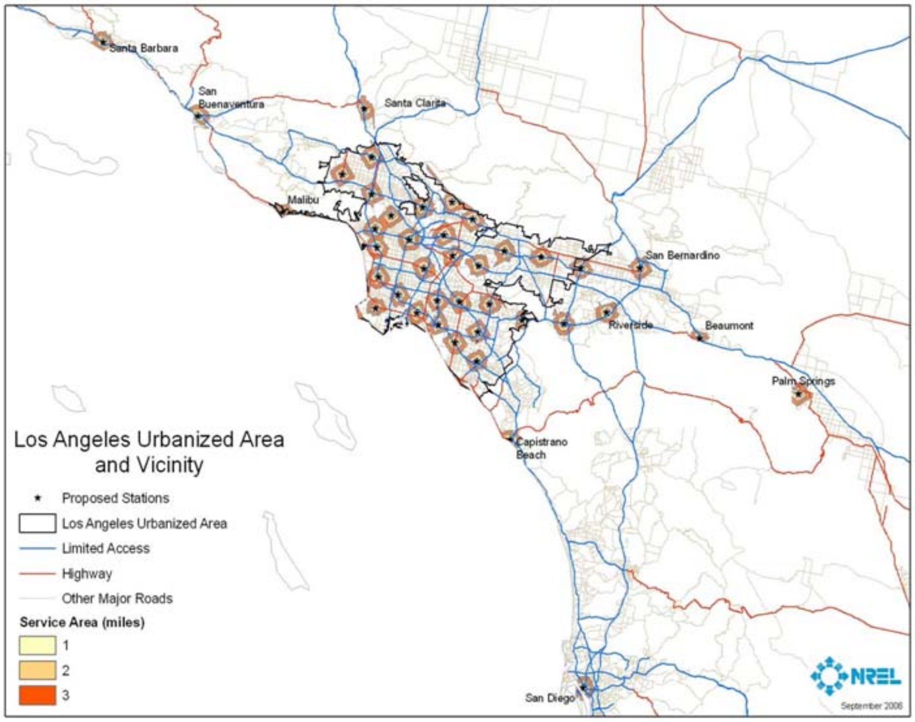
A significant challenge for implementing a hydrogen fuel station network is maximizing station availability for early customers while minimizing costs during the years when demand is still low due to fewer vehicle numbers. By the end of 2012-2014 fuel cell passenger vehicles in California are projected to require approximately 5,250 kg hydrogen per day.[11] This supply could be provided by twenty 400 kg/day stations or forty 200 kg/day stations, or some combination of stations with these or other supply capacities. This estimated number of stations assumes a 70% station utilization rate. This estimate is not intended to be definitive, but rather to frame the scale of hydrogen stations needed during this time period.

Focusing early vehicle deployments to be within close proximity of hydrogen stations will maximize utilization of the early stations. These stations will have a significantly lower demand for fuel when compared to conventional gasoline stations and should be sized accordingly. As technology advances and vehicle deployments increase the number and capacity of stations will likely increase as well.

Transit fleets will need large-volume fuel stations located on their property to provide up to 6,600 total kg/day. The dispensing capacity of each station will depend on the number of buses fueling at a given station. These hydrogen stations could also support light duty vehicles through customer-friendly, retail-like fuel dispensers located outside the transit yard fence. Of the 10 transit agencies that might deploy fuel cell buses to comply with the ZeBus regulations, three are located in the greater Los Angeles region and five are located in the San Francisco Bay Area. This presents an opportunity to leverage and coordinate transit and passenger car fueling.

Taking the Los Angeles region as an example, 40 hydrogen fuel stations would locate 23% of the Los Angeles-area population within three miles of a fuel station, and 51% within five miles of fuel station[12]. Figure 2 illustrates how approximately 40 stations might be located within the Los Angeles region. Although the illustration shows 40 stations, a different number of stations may be more optimal depending on station size, location and other factors. Similar hydrogen station build-out is needed in the San Francisco-Sacramento areas to support fuel cell vehicles deployed in the Northern California region.

Figure 2: Illustrative map of the first hydrogen fuel stations in the Los Angeles region



How much will the early hydrogen stations cost?

The cost to build and operate a hydrogen station depends upon many factors, including the type of station, location, equipment manufacturing volume and continuing technology advancements. As more stations are deployed, costs will likely decrease as a result of economies of scale and learning. Similarly, as more hydrogen fuel is dispensed, the cost per volume of hydrogen will be reduced. The first hydrogen stations, which will be few in number and dispense relatively low volumes of fuel, will be expensive and may never achieve profitability. Costs will come down as more hydrogen stations are built and fully utilized.

Several types of hydrogen stations can be feasible for near-term deployment: forecourt (on-site hydrogen generation from natural gas or electricity); liquid delivery by truck and on-site storage as a high pressure gas; gaseous delivery by truck and on-site storage as a high pressure gas; or liquid delivery by truck and on-site storage as a liquid with gaseous dispensing. Although early station costs can vary greatly depending upon the specific technology used, site conditions and experience, a rough estimate for capital costs is approximately $2-4 million. These costs do not include land or operating costs. Larger stations to support transit operations would cost more. A potentially less expensive option could be to deploy mobile fuel stations in the early years. These stations could provide flexibility to relocate hydrogen supply as vehicle demand evolves and changes over time.

The U.S. Department of Energy, in conjunction with national laboratories and industry has developed the H2A production and delivery models[13] to estimate the cost of hydrogen from various hydrogen pathways. For hydrogen produced at the forecourt, the H2A production model assumes the hydrogen production units are manufactured in quantities greater than 500 units per year, so economies of scale are realized. The H2A delivery model, however, can be used to estimate hydrogen costs for gaseous and liquid delivery stations in low volumes. A CaFCP analysis using the H2A delivery model yields a dispensed hydrogen cost of approximately $8-13/gasoline gallon equivalent, or gge (untaxed) for a network that includes approximately 20 stations delivering 400 kg/day using either gaseous or liquid delivery pathways[14]. A kilogram of hydrogen is equivalent to a gallon of gasoline on an energy basis, but given that a fuel cell vehicle is roughly twice as efficient as a conventional gasoline vehicle, $8-13/gge compares to gasoline at $4.00-6.50/gallon (untaxed) on a mileage basis.

The State of California has made it a priority to achieve low- to zero-carbon hydrogen from renewable sources. In 2007 the State Legislature passed Senate Bill 1505, which directs the California Air Resources Board to develop regulations that ensure state funds are used to support renewable hydrogen stations, and that as the hydrogen infrastructure matures, a significant percentage of the hydrogen used for transportation comes from renewable sources. In the early years, however, renewable hydrogen may be more expensive than hydrogen produced from natural gas. Even though hydrogen produced from natural gas creates some carbon emissions, the well-to-wheels emissions of a fuel cell vehicle using hydrogen from natural gas are much lower than those from a gasoline vehicle. As the market for hydrogen fuel and fuel cell vehicles matures, it will be important to achieve the goal of very low- to zero-carbon hydrogen to meet greenhouse gas reduction goals for transportation.

In the years before the fuel cell vehicle market is firmly established, demand for hydrogen will be uncertain and station utilization will be low. Station developers face a significant risk that stations will not operate at full capacity and they will likely face high capital costs without sufficient income stream from hydrogen sales in the early years. As well, fuel savings may be an essential requirement for the customer. If so, customers will most likely only switch to a hydrogen-powered vehicles if the fuel costs *less than* gasoline on a per mile basis over the life of the vehicle to offset the premium vehicle price. Government support for the first hydrogen stations, including ensuring that hydrogen is less expensive than gasoline, is needed to offset risks, both to the station owner and the vehicle owner.

How might the early hydrogen stations be funded?

The early hydrogen stations should be constructed using a combination of industry and government funding. These hydrogen stations will not be profitable until larger volumes of vehicles are in customer hands allowing maximum fuel station utilization. However, an integrated and coordinated fueling network is necessary in the early years to encourage broad application of fuel cell vehicles by creating an excellent customer experience. Several different approaches should be evaluated and specific funding models developed to optimize government investments.

Government funding could include one or more of the following approaches:

1. *Cost share hydrogen stations through one-time grants*
   The State could fund 50% of the capital costs of hydrogen stations in the Los Angeles and San Francisco-Sacramento areas. Additional funding could be provided for stations that use renewable energy to source the hydrogen. To maximize throughput, energy companies would need to work closely with automakers to ensure these stations are located in areas with the highest customer demand. These stations would also need to provide an excellent customer experience, allowing open access to vehicles from all different automakers, minimal training, no special equipment needed, and easy payment methods.
2. *Provide an ongoing incentives based on the volume of dispensed hydrogen ($/kg)*
   Rather than providing funding toward fuel station capital cost, the State of California could pay hydrogen providers based on the amount of hydrogen they dispense to vehicles. This approach rewards fuel station operators that provide a well-located station that is attractive to customers and easy to use (thereby maximizing fuel dispensed). It also gives the State volumes information for planning purposes. It may not, however, address the significant capital risk incurred by the first hydrogen station owners, especially during the early years when volume sales are low.
3. *Offer incentives to station owners*
   Government could offer incentives such as investment tax credits to offset a significant portion of capital equipment costs for the next hydrogen stations. The maximum number of stations eligible for this incentive or the maximum dollar amount over the life of the program should be established up front. This would provide similar benefits as option 1, although paperwork would be completed with annual tax filings rather than special grant applications.

   A detailed analysis should be conducted to more accurately determine the cost of the next hydrogen stations and the optimal funding strategy. As a rough estimate, the State of California should plan to spend $80-$90 million over four years (2010 through 2014) for hydrogen fuel stations to support the pre-commercial vehicle phase. *As an illustrative example only*, Table 4 describes annual and cumulative funding for two approaches: cost share through grants or per/kg incentives for dispensed hydrogen, keeping in mind that it might be a combination of the two.

Table 4: Illustrative example of State investment to achieve 5,250 kg/day hydrogen supply by 2014

	2010	2011	2012	2013
Number of new stations per year	4	4	12	20
Annual funding at $2 million per station[1]	$8 million	$8 million	$24 million	$40 million
Cumulative funding over 4 years	$8 million	$16 million	$40 million	$80 million
AND/OR				
Annual funding at $2/kg dispensed	$584,000	$1.2 million	$29 million	$58 million
Cumulative funding over 4 years	$584,000	$1.8 million	$31 million	$89 million

[1] assumes $3 million capital cost, $1 million operating costs over 4 years, State funding covers 50% of both. Note this assumes the State funding is not used for land costs.

What are some of the challenges to building the early hydrogen fuel stations?

Station Size

A conventional gasoline station can accommodate more than 300 vehicles a day. A hydrogen station capable of accommodating such demand would need to dispense approximately 1,500 kg/day. Current forecourt production technologies cannot deliver this daily volume, and scaling to commercial size is particularly challenging due to limited land availability. In the early years the limited number of vehicles accessing each station may result in supply exceeding demand in any given location, which is particularly problematic for on-site production from natural gas.

Land Availability

In urban areas, land is limited and expensive. The equipment used for current demonstration stations occupies approximately the same area as a conventional retail gasoline station, but serves only one-tenth the vehicles. Hydrogen storage occupies a majority of this space. As well, most existing fuel stations are not owned by the major energy companies. This further limits the locations available for hydrogen stations.

Infrastructure providers are working to identify novel approaches to hydrogen storage. The State should incentivize efforts by infrastructure providers to identify and deploy new ways of storing hydrogen.

Timing

There are a limited number of hydrogen production, storage and dispensing technology providers capable of deploying their technology without long lead times. This technology is still pre-commercial and is not an “off the shelf” offering by many technology companies. Further, there are a limited number of qualified design, engineering and construction firms capable of building out the infrastructure. This limited availability of qualified vendors has proven to be problematic even when building up to three stations in parallel. It will prove to be a major issue for larger-volume infrastructure deployment. State incentives should be consistent and long-term to allow for the development of the hydrogen industry vendor base to ensure that hydrogen stations are deployed and operated safely and reliably.

Timelines for planning, permitting and constructing a hydrogen station can be unpredictable and may vary from site to site, taking as long as two years. It is important to identify specific locations and build project teams early on. Engaging local communities early in the process can help expedite the permitting and construction process.

Renewable Requirement

Today most hydrogen is made from natural gas. Well-to-wheels studies show that hydrogen made from natural gas and used in a fuel cell vehicle has clear environmental and energy efficiency benefits compared to conventional vehicles and other advanced technology vehicles such as hybrids. In the early years, the technology for producing hydrogen from renewable sources is significantly more expensive. While it is important to develop low- and zero-carbon renewable hydrogen to achieve long-term goals, early hydrogen stations can provide benefits using current technology while renewable productions methods are further developed to reduce costs. Government should incentivize, but not require, renewable hydrogen for these early stations.

What else can government do to support hydrogen?

Insurance and Liability

Hydrogen has and continues to demonstrate an excellent safety record as an industrial gas. In limited use as a vehicle fuel there have been no significant safety incidents. But fueling vehicles with hydrogen is new, and there is insufficient data and experience with safety operations to clearly define risks and liability from a legal and insurance perspective. The U.S. Department of Energy collects safety incident information and maintains a database for learning. The State of California should consider establishing a risk pool of insurance for hydrogen technologies to include station and vehicle operators. To date, obtaining insurance quotes has proven very difficult with little to no interest from insurance carriers. The auto liability quotes alone suggest rates more than triple those for comparable internal combustion engine vehicles. A state-sponsored risk pool of insurance would help ease the burden of legal agreements for early customers and would more closely match the current retail fuel and vehicle experience

Permitting

The U.S. Department of Energy is working to develop national codes and standards for hydrogen fuel stations. Local communities will need assistance to understand and apply these new national codes and standards. The State of California should establish an ombudsman within the Office of the State Fire Marshal to assist local communities as they permit hydrogen stations in their areas. This will streamline the process for early hydrogen fuel station developers and give local communities a reliable resource as they deal with new and unfamiliar projects.

What is CaFCP's role in building the early hydrogen fuel station network?

CaFCP is a member-based organization that coordinates and enables its members as they develop hydrogen stations and fuel cell vehicles. From 2008 through 2012, the CaFCP will focus on building the foundations for a future hydrogen market.

Specifically, CaFCP will:

1. Establish and maintain a common vision for the market transition in California.
2. Identify hydrogen fuel needs based on projected vehicle demand.
3. Provide a forum to match partners to realize specific fuel station opportunities.
4. Facilitate an ongoing dialogue to coordinate hydrogen fuel stations and fuel cell vehicle deployments and identify and address challenges.
5. Maintain an accurate database of existing and planned stations in California.
6. Prepare California communities by educating local officials, including fire professionals, about hydrogen and fuel cell vehicles.

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[1] Schiller, Steven R. 2007, September 13. Implications of Defining and Achieving California's 80% Greenhouse Gas Reduction Goal

[2] Kromer, Matthew A. and John Heywood. 2007, Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet: Massachusetts Institute of Technology-Laboratory for Energy and the Environment, LFEE-2007-02 RP

[3] http://www.arb.ca.gov/msprog/zevprog/zevreview/summary.pdf

[4] "Gold" ZEVs are pure zero-emission vehicles—fuel cell vehicles or battery electric vehicles—that get varying amount of credit depending on driving range

[5] Greene, D.L., Leiby, P.N., James, B., Perez, J., Melendez, M., Milbrandt, A., Unnasch, S. and Hooks, M. 2008, March, Transition to Hydrogen Fuel Cell Vehicles & the Potential Hydrogen Energy Infrastructure Requirements, ORNL/TM-2008/30; http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf

[6] Green et. al., Executive Summary, p. x.

[7] Green et. al., Executive Summary, p. xi.

[8] Greene et. al., Executive Summary, p. xiv.

[9] one kilogram of hydrogen is approximately equal to one gallon of gasoline on an energy basis

[10] http://www.nrel.gov/hydrogen/pdfs/42665.pdf and http://www.nrel.gov/hydrogen/pdfs/42249.pdf (report about AC Transit has a table on page 8 and 17)

[11] 7,500 fuel cell vehicles (based on CARB ZEV regulation) using an average of 0.7 kg/day

[12] see reference 5, Melendez and Milbrandt, 2007

[13] Department of Energy Hydrogen Program, http://www.hydrogen.energy.gov/h2a_analysis.html

[14] Result of $8–13/kg for gaseous or liquid hydrogen delivery systems with gaseous dispensing assumes 300 psi hydrogen supplied at the plant gate at $2.34/kg, total volume of 6000 kg/day for all stations in the network, stations operated at an average utilization of 70%, 1.5 factor applied to storage, evaporator and compressor component costs to account for the increased capital requirements for 700 bar dispensing per industry recommendation, higher costs assumed for site preparation ($170,000) and engineering design ($120,000) per industry recommendation.