

# A California Road Map

*Bringing Hydrogen Fuel Cell Electric Vehicles  
to the Golden State*



Zero-emission vehicles, including those powered by fuel cells, will play an important role in improving California's air quality, reducing greenhouse gases that contribute to climate change, and increasing energy security while promoting a green economy. To get there, we need to invest in infrastructure, including an early network of hydrogen stations that will provide convenient and reliable fueling for the first customers that purchase fuel cell electric vehicles.

July 2012

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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.



## Overview

Fuel cell electric vehicles (FCEVs) are poised to enter the commercial market, helping California reach its goals for reducing greenhouse gas emissions, improving air quality and diversifying our transportation fuel to improve the quality of life and wellbeing of Golden State residents. FCEVs will provide customers with a no-compromise electric-drive vehicle with the range, refill time, performance and comfort they have come to expect, along with zero emissions and a low-carbon and potentially renewable fuel.

Automakers are preparing to bring fuel cell electric vehicles to market in California in 2015 as an integral part of their electric-drive portfolio. But the biggest obstacle to introducing FCEVs to the market is the lack of fueling stations. The first FCEV purchasers will need to have confidence that sufficient fueling is available wherever they may be, whether it's their home, work or favorite destination. As the number of vehicles increases, the station network must grow in number and capacity to keep up with the fuel demand.



Stakeholders representing industry, academia, non-governmental organizations and government came together to discuss, contribute and write *A California Road Map*.<sup>1</sup> Their collaboration created a report to guide the placement of hydrogen fueling stations and launch the early commercial market, paving the way for tens of thousands of fuel cell electric vehicles.

Based on a variety of information, input and technical analysis from CaFCP members, including projections of fuel cell vehicle numbers and extensive marketing assessments by automakers, the road map identifies 68 strategically placed stations required to be operational by the beginning of 2016. Most of the stations are in five geographic clusters where a majority of early adopters are expected: Santa Monica/West Los Angeles, coastal Southern Orange County, and Torrance with nearby coastal cities, Berkeley, and San Francisco South Bay. Additional stations will connect these clusters into a regional network.

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<sup>1</sup> <http://www.cafcp.org/roadmap>

The first stations will not be fully utilized and profitable in the early years, even as vehicle sales increase. To estimate the funding needed to support early stations, stakeholders considered two models. Under the cash flow support model, the total funding needed to expand to 68 stations, and support operations and maintenance for all stations is estimated at \$65 million. The traditional capital buy-down model identified a similar overall funding need of \$67 million. These models take into account a mix of existing and new stations, varying station sizes and a cumulative capacity to support approximately 20,000 vehicles. The California Air Resources Board's Clean Fuels Outlet regulation supports the next phase of fuel station development.

This document provides an overview to the *A California Road Map* report along with background information. The road map report, available on CaFCP's web site, puts forth the details of hydrogen station deployment that will seed the emerging fuel cell vehicle market. It is part of a continuous plan to reach full-market potential.





## A Vision for a Greener California

With 96% of the vehicles in the state using petroleum-based fuels, gasoline and diesel-powered vehicles produce about 50% of the criteria pollutants and 38% of greenhouse gas emissions. California's strong commitment to low- and zero-emission vehicles reflects the understanding that advanced vehicle technology is necessary to achieve energy and environment goals, including reductions in criteria pollutants and greenhouse gas emissions.

Since the mid-twentieth century, California has been a leader in improving air quality, including the creation of the first air pollution control district in the United States. Over time, the agenda for clean air has evolved to meet the challenges of the twenty-first century to address air quality, energy security and climate change. In the 1990s California began setting more advanced vehicle emission standards, such as the Zero Emission Vehicle regulation that is now part of the Advanced Clean Cars regulation.

In 2006, the California Global Warming Solutions Act (AB 32) established the goal of reducing greenhouse gases to 1990 levels by 2020. An Executive Order issued by Gov. Schwarzenegger and reinforced by Gov. Brown called for reducing GHGs a total of 80% by 2050. The California Air Resources Board projects that meeting the 2050 goal will require nearly 100% of passenger vehicles sold by 2040 to be ZEVs.

Dependence on fossil fuels has become a national issue. 71% of all petroleum used in the United States goes to the transportation sector.<sup>2</sup> The California Energy Commission's State Alternative Fuels Plan calls for accelerating the growth of all alternative fuels, including hydrogen. The Plan estimates that alternative fuels can displace the equivalent of 4 billion gasoline gallon equivalents by 2020 and, as electric vehicles play a bigger role, by 2050 alternative fuels could provide more than half the energy needed to power California's transportation system.<sup>3</sup>

Automakers and fuel providers believe that achieving air quality, greenhouse gas and energy security goals will require a portfolio approach, an "all-of-the-above" strategy. In the short term, they are working on lower-carbon fuels and more efficient combustion. CaFCP members and other stakeholders believe fuel cell electric vehicles are vital to transforming California's transportation sector to clean, zero-emission vehicles.

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<sup>2</sup> National Academies <http://needtoknow.nas.edu/energy/energy-use/>

<sup>3</sup> <http://www.energy.ca.gov/2007publications/CEC-600-2007-011/CEC-600-2007-011-CMF.PDF>

## Benefits of FCEVs

In June 2012, eight major automakers had fuel cell electric vehicles on the road in California and three transit agencies were operating fuel cell electric buses. Most of the passenger vehicles were in the hands of consumers and the buses in revenue service. Through years of demonstration and technology validation programs, automakers and bus builders have developed vehicles that are ready for the commercial market. The vehicles meet or exceed the Department of Energy's goals for range, durability, performance and refill time.<sup>4</sup>



Fuel cell vehicles are electric vehicles that make their electricity from hydrogen and oxygen. To “recharge” an FCEV, a driver fills the tank at a hydrogen dispenser. Filling a tank with compressed, gaseous hydrogen takes about the same amount of time as filling with gasoline: less than five minutes for passenger vehicles and about 10 minutes for a bus.

With a full tank, FCEVs have range similar to gasoline vehicles, between 250 and 400 miles, and buses can operate continuously for about 16 hours, similar to a diesel or CNG bus. Because FCEVs are electric-drive vehicles, they are two-to-three times as efficient as a combustion engine. They have fewer moving parts, substantially reducing maintenance.

FCEVs are zero-emission vehicles. The tailpipe produces only a small amount of water vapor. From well-to-wheels (source to tailpipe), pollutants and greenhouse gas emissions from FCEVs are greatly reduced compared to combustion vehicles and hybrids.<sup>5</sup> Hydrogen made from natural gas has nearly zero criteria pollutants and reduces greenhouse gases by about half. In California, 33% of the hydrogen for transportation must come from renewable sources, such as solar or wind electrolysis of water, or conversion of waste or biogas. With renewable hydrogen, the well-to-wheels GHG emissions for an FCEV are nearly zero.

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<sup>4</sup> Department of Energy <http://www1.eere.energy.gov/hydrogenandfuelcells/accomplishments.html>

<sup>5</sup> Well to Wheels: A Guide to Understanding Energy Efficiency and Greenhouse Gas Emissions <http://www.cafcp.org/sites/files/20091026wells2wheels.pdf>

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. Fuel cells can scale up to support larger vehicles, from sport utility vehicles to heavy-duty platforms like transit buses.

Automakers consider FCEVs complementary to their other advanced vehicle technologies such as plug-in electric vehicles (PEVs), although FCEVs are seen as being the most capable of replacing their gasoline counterparts as a household’s primary vehicle as Figure 1 represents. Unlike PEVs, however, fuel cell electric vehicles are reliant on hydrogen refueling outside the home. For this reason, the first FCEV customers need to see stations before they will consider buying an FCEV instead of a gasoline vehicle.

Figure 1 – Vision of Vehicle Market

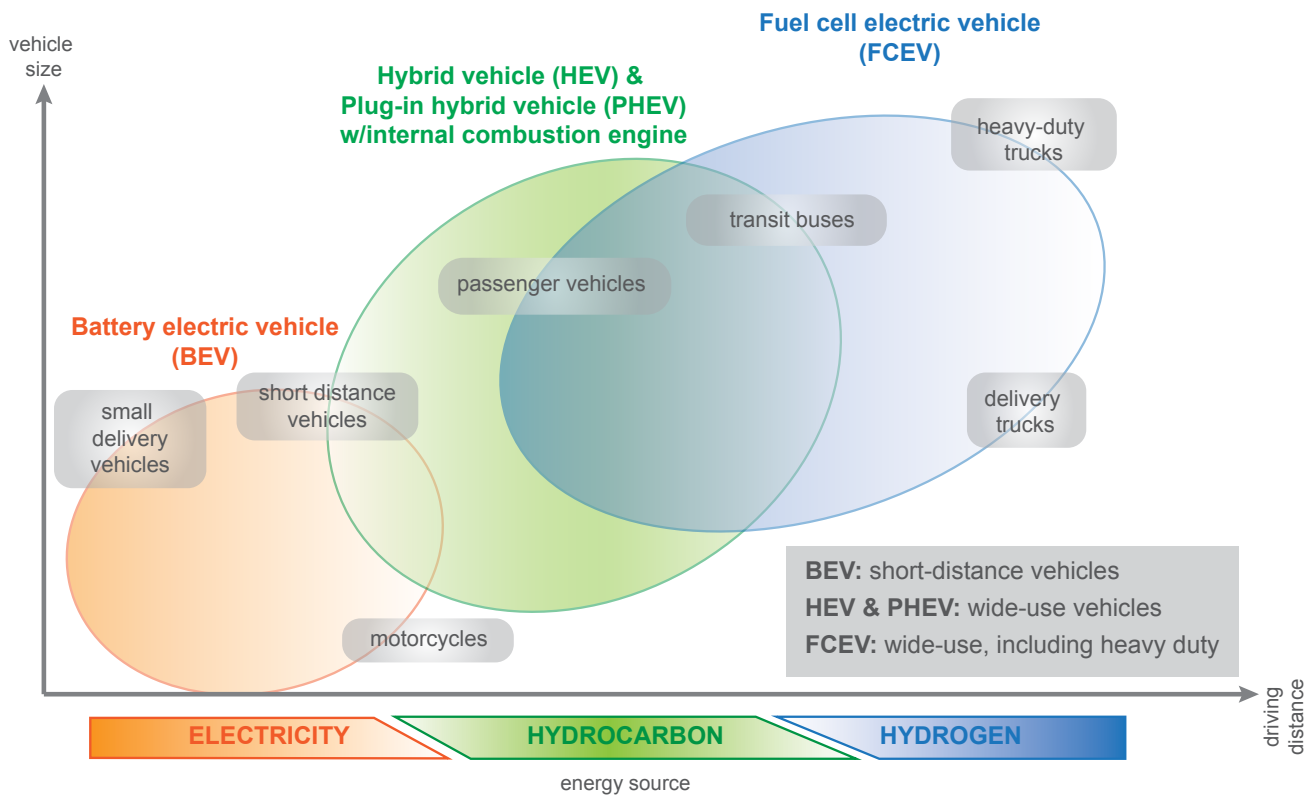


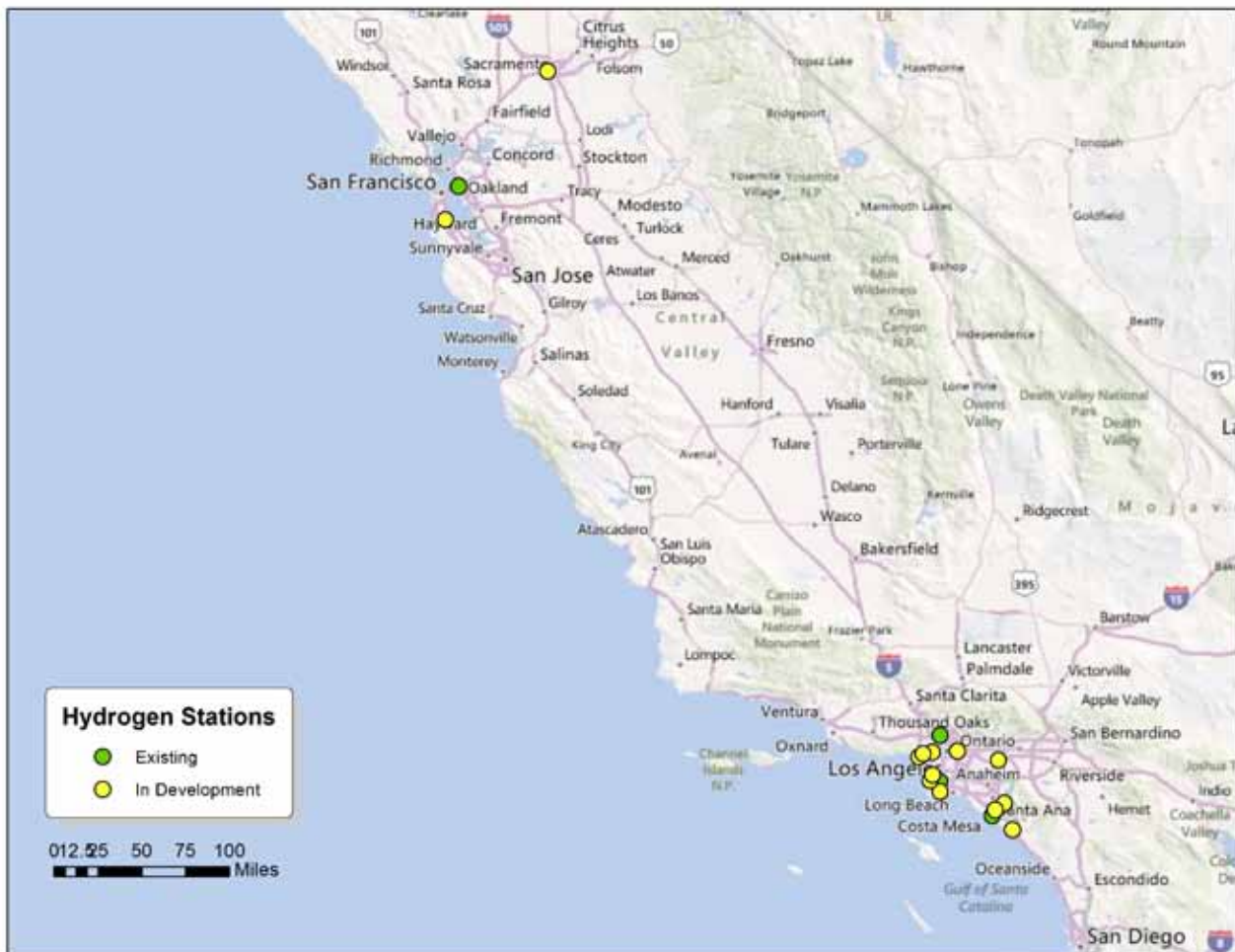
Figure 1 visually describes the driving range, vehicle size and energy source of various electric vehicles. Fuel cell electric vehicles, for example, occupy the top right of the chart, offering the greatest vehicle range and vehicle size, from passenger to transit buses and heavy-duty trucks. This figure is a modified version of a Toyota graphic used in the technical version of *A California Road Map*.



## Hydrogen Stations in California

By mid-year 2012, California had eight publicly accessible hydrogen stations. Some of these stations will close in the next few years because they were designed to prove technology, not to serve increasing numbers of customers. An additional 14 new or upgraded stations are in development; a few are ready to open within months and others have yet to break ground.

Figure 2 – Hydrogen Stations in California, Existing or in Development



Currently, most stations in California are supported through funding from the California Energy Commission and its Alternative and Renewable Fuel and Vehicle Technology Program (AB 118). This program, funded by vehicle licensing fees, provides approximately \$100 million annually to develop fueling infrastructure for alternative and low-carbon fuels, including biofuels, natural gas, propane, electricity and hydrogen. In the first years of the investment program, CEC provided funding for 11 of the hydrogen stations in development. (Before AB 118 was enacted, the California Air Resources Board provided co-funding to five stations in development and three that are currently operating.) Industry

co-funded development and construction, and supports operating and maintenance expenses. In July 2012, CEC was conducting workshops in preparation for releasing the next program opportunity notice (PON) which is expected to provide \$29.7 million of incentive funding for hydrogen stations.



CEC has also provided funding to the California Department of Food and Agriculture Division of Measurement Standards to perform the work necessary to sell hydrogen by the unit in California, including testing for hydrogen quality and certifying dispensers.

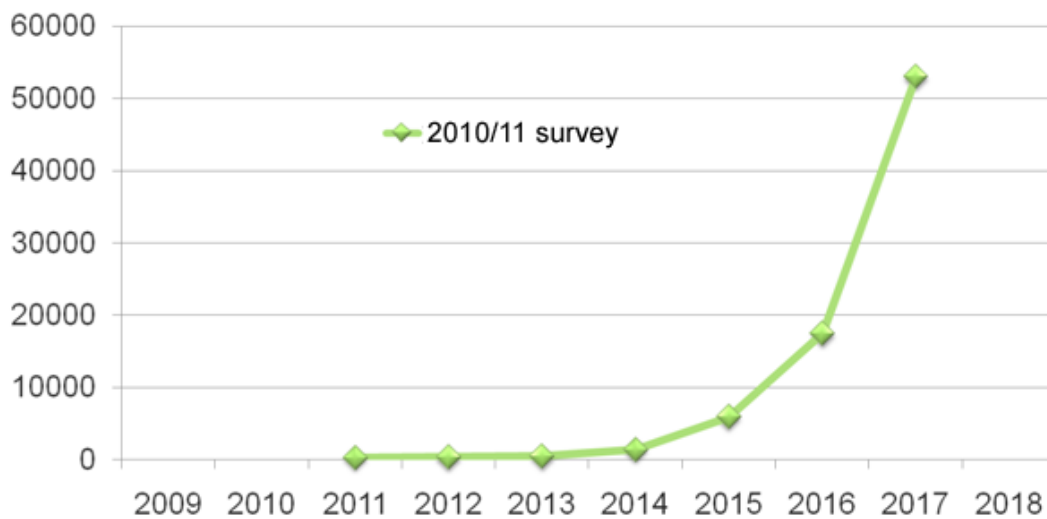
If all stations are developed as planned from currently available funding California will have about 37 public hydrogen stations in 2015. These represent roughly half the stations needed for the initial commercial rollout.



## Countdown to 2015

Several automakers plan to introduce FCEVs to the California commercial market around 2015. Figure 3 shows the results of the most recent vehicle survey that CaFCP issued in conjunction with the California Air Resources Board and California Energy Commission. Automakers completed this confidential survey each year for three consecutive years, and CaFCP compiled the data in a manner where no automaker, nor any entity outside the participating government agencies, can discern an individual automaker's response.

Figure 3 – Anticipated FCEVs on the Road, 2011-2017<sup>6</sup>



Launching FCEVs and the supporting hydrogen fueling infrastructure is a significant undertaking and requires considerable planning and coordination. Automakers must begin engineering development three-to-five years in advance of vehicle deployment 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.

<sup>6</sup> Based on automaker aggregate survey; 2015-2016 is not defined, but notional estimate provided for illustrative purposes only.

Recognizing the need to spur progress with zero emission vehicles, Governor Brown recently issued an Executive Order<sup>7</sup> directing state agencies to support and facilitate the rapid commercialization of zero-emission vehicles with three specific milestones:

**2015** – Communities will be ready for plug-in and hydrogen vehicles and infrastructure

**2020** – California will have established adequate infrastructure to support one million zero-emission vehicles

**2025** – More than 1.5 million zero-emission vehicles will be on the road and the market continues to expand

Governor Brown's 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 to meet these and other milestones. As he was issuing the order in March of 2012, CaFCP members were already well into the work of preparing communities and defining an infrastructure plan.

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<sup>7</sup> Executive Order B-16-2012, Governor Jerry Brown, State of California, 2012



## Defining the Hydrogen Fueling Network

Consumers must have confidence that they can fill up near home, work and other key locations before they will consider purchasing or leasing a hydrogen fuel cell electric vehicle.

Through a collaborative process substantiated by research, data and modeling, CaFCP members determined that a network of 68 stations operating statewide by 2015 will enable the launch of the early commercial market of 10,000-30,000 fuel cell electric vehicles.

Before FCEVs are sold or leased on a larger scale, consumers must have confidence that they can fill up near their homes, close to their jobs or at key locations and destinations throughout California. At the same time, hydrogen stations must have an adequate supply on a daily basis and during peak hours to supply the growing number of vehicles. Providing customers with sufficient locations will initially result in more available hydrogen supply than needed, but location and minimum station coverage are keys to customer adoption that will launch the early commercial market.



Moving from the pre-commercial phase of FCEVs (2012-2014) to the early-commercial phase (2015-2017) relies on balancing customers' needs for as much station coverage as possible with station operators' requirements, including high station-utilization factors. Automakers will focus the early vehicle deployments on identified target areas, enabling the stations in those areas to realize increased utilization and grow into a successful fueling network.



## Clusters of Stations, Connectors and Destinations

Initial station deployments will focus on geographic clusters in key markets with additional stations connecting these clusters into a regional network.

In February 2009, CaFCP published an action plan that described the early rollout of hydrogen stations and vehicles in geographic clusters to encourage customer confidence, optimize resources and lay the foundation for expansion. Following the plan, the first public stations were co-funded in Santa Monica/West Los Angeles, Torrance, Irvine and Newport Beach, and the San Francisco Bay Area. These stations, as listed in Table 1, form “pre-commercial clusters” that optimize resources and create the foundation for further network expansion.

As of July 2012, California has 19 hydrogen stations currently open or in planning (either new construction or expansion of existing stations). Two of these stations are technology validation stations and not designed to serve more than a few vehicles a day. They are expected to close by 2015.

*Table 1 – Current and Planned Stations*

Station	Current Status
Beverly Hills	Planned – 2013
Burbank	Operational
Diamond Bar	Upgrade (2013)
Emeryville	Operational
Fountain Valley	Operational
Harbor City	Planned – 2012
Hawthorne	Planned – 2013
Hermosa Beach	Planned – 2013
Irvine #2	Planned – 2013
Irvine #1	Upgrade (2012)

Station	Current Status
Laguna Niguel	Planned – 2013
Los Angeles	Planned – 2012
Newport Beach	Operational
San Francisco	Planned – 2012
Santa Monica	Planned – 2013
Torrance	Operational
West Los Angeles #2	Planned – 2013
West Los Angeles #1	Operational
West Sacramento	Planned – 2013

Through individual and joint meetings over more than a year, automakers identified the areas where they expect to find their first customers in a manner that would not divulge competitive information. To determine the most likely locations for FCEV customers, participants considered:

- Demographic information, such as household income, cars per household, population and land use considerations
- Individual automaker market assessments, including FCEV hand-raiser data
- 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
- 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
- Geographic distribution of the Air Resources Board’s Clean Vehicle Rebate Program

Stations fell into geographic areas that stakeholders defined as cluster,<sup>8</sup> connector and destination. These definitions serve as broad geographic descriptions of early market communities in which hydrogen stations are currently or will likely be located. Some of these areas may have more than one existing, forthcoming or recommended station. The goal is to increase the number of stations and geographic coverage to ensure a sufficient number of early adopters believes the infrastructure is adequate to consider purchasing a fuel cell electric vehicle.

## Terms

**Cluster** – A small geographic area with a high percentage of potential early FCEV adopters.

**Connector** – A city or community that links clusters and seeds new communities.

**Destination** – A city or community that is a popular destination and seeds new communities.

**Market** – An area that can include two or more clusters. Examples: Los Angeles County, San Francisco Bay Area.

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<sup>8</sup> UC Davis’ paper, “Analysis of a ‘Cluster’ Strategy for Introducing Hydrogen Vehicles in Southern California,” defined clustering as coordinated introduction of hydrogen vehicles and refueling infrastructure in a few focused geographic areas such as smaller cities (e.g. Santa Monica, Irvine) within a larger region (e.g. Los Angeles Basin).

## Clusters

Much of the data pointed to the clusters CaFCP previously identified and where stations are either operating or under development. The data indicated that some clusters needed to be geographically widened and that new clusters in Northern California should be added. The participants identified the cluster communities as:

- Santa Monica/West Los Angeles , including Beverly Hills and West Hollywood
- Torrance and nearby coastal cities
- Irvine and southern coastal Orange County
- Berkeley
- San Francisco South Bay Area

To determine the number and locations of stations in the clusters, the National Fuel Cell Research Center, a CaFCP member, analyzed the clusters with their Spatially & Temporally Resolved Energy & Environment Tool (STREET) model. STREET considers variables, including automaker market data, travel time, travel routes, existing gas stations and vehicle ownership density to determine the optimal locations for stations. STREET has the ability to analyze how customers will use the stations as well as how stations obtain the hydrogen, taking delivery routes and times into consideration.

STREET helped target communities where the first FCEV customers are expected, and then assess the existing gas stations in each of those communities with respect to the expected drive times to those gas stations. From that, STREET determined the minimum number and location of hydrogen stations needed for FCEV customers to reach a hydrogen station in six minutes or less. A six-minute maximum travel time is based on optimization research, driver behavior surveys and a need to balance network coverage with network cost.

The optimal result was 45 stations in the five clusters, as displayed in Figure 4 and Figure 5 on the following page. This equates to having hydrogen available at five-to-seven percent of existing gasoline stations in a cluster. In comparison, the current gasoline fueling 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 early adopter consumers.

The first FCEV customers will expect high-performing hydrogen stations that mirror their gasoline counterparts and offer no compromises with respect to availability, the ability to serve adequate numbers of customers and ease of use. Customers will also expect to fill and pay for hydrogen in a similar manner as a retail gasoline or natural gas station.

Stations must be safe and open to all automaker vehicles, be retail oriented and provide a customer experience similar to today's conventional fuel stations: 24/7 operating hours, no requirements for signed "use" agreements or classroom training requirements, and conventional payment methods.

Figure 4: Cluster Stations in Southern California

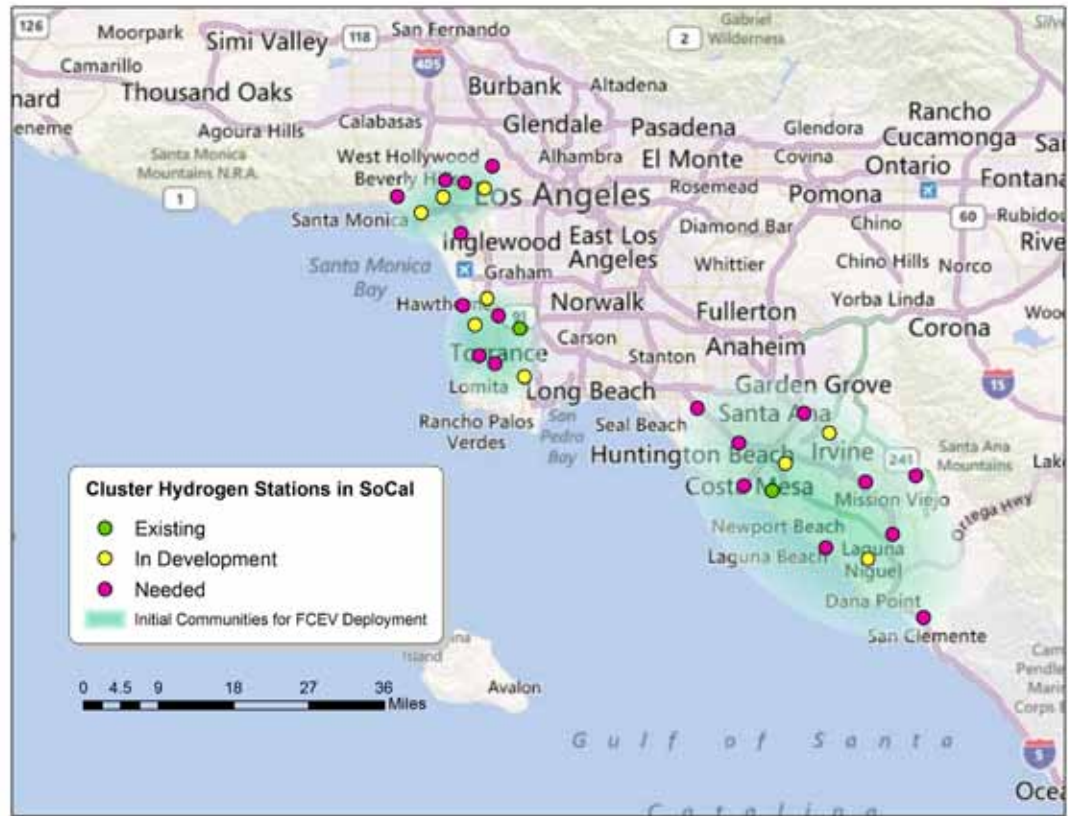
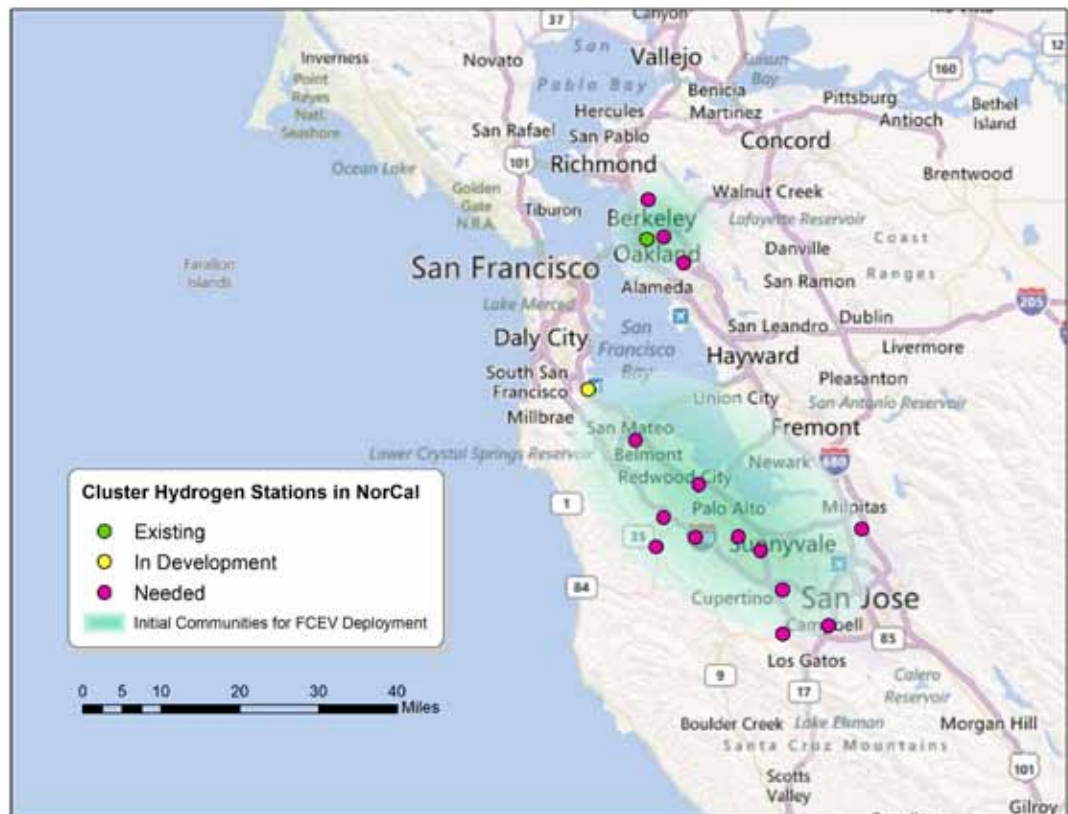


Figure 5: Cluster Stations in Northern California



## Connectors and Destinations

Connector and destination stations are an important element of the early commercial hydrogen network. Research indicates that people typically drive 40 miles or less in a day,<sup>9</sup> and FCEVs have range of 250-400 miles on a tank of fuel. Before replacing a gasoline vehicle with an FCEV, the first customers will want to know that they can go beyond their daily commute or, for purposes of the road map, travel outside their cluster.

Providing fuel for long-distance trips is essential to meet customer expectations. With a broad fueling network, FCEVs provide the same utility as gasoline vehicles. The stations maximize full use of the vehicles throughout the state and help FCEVs appeal to a broader audience by providing redundancy and consumer confidence. At the same time, these stations will seed the next clusters.

Stakeholders, using the aforementioned data, identified the following cities as emerging markets and 23 stations in these areas will support the hydrogen station network.

- Anaheim
- Central Valley
- Diamond Bar
- Hayward
- Lake Tahoe
- Long Beach
- Napa
- Palm Springs
- Pasadena
- Pleasanton
- Riverside
- Sacramento
- San Diego
- San Fernando Valley
- San Francisco
- Santa Barbara
- Sonoma



<sup>9</sup> DOT National Household Travel Survey [http://www.bts.gov/publications/highlights\\_of\\_the\\_2001\\_national\\_household\\_travel\\_survey/html/executive\\_summary.html](http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/html/executive_summary.html)



## The Network

With 45 stations in the cluster communities and 23 additional stations seeding other early markets as well as promoting wider travel, California will have a small network of 68 hydrogen stations that give customers the freedom to drive almost anywhere in the state, as suggested in Figure 6.

Once hydrogen fueling opportunities are available to the first FCEV customers, hydrogen fuel demand should then closely follow vehicle sales growth. Slower growth may require fewer or no additional stations, and faster growth may encourage a quicker and broader rollout of hydrogen stations. In other words, if the current projections transpire, 68 stations will be serving thousands of vehicles in the 2016 timeframe, estimated between 10,000-30,000 vehicles. Table 2 is one scenario for the number of stations added each year.

Figure 6: Map of 68 Hydrogen Fueling Stations: Existing, In Development and Needed



**Table 2 – Station Deployment Based on Market Development and Vehicle Roll out**

Year	Start of Year (Station Total) <sup>10</sup>	Added Stations <sup>11</sup>	Number of FCEVs in CA <sup>12</sup>
2012	4	4	312
2013	8	9	430
2014	17	20	1,389
2015	37	31	5,000-15,000
2016	68	<i>Market Needs</i>	<i>10,000-30,000</i>
2017	>84	<i>Market Needs</i>	53,000
2018	>100	<i>Market Needs</i>	>53,000

Note: The automaker survey only requested years 2015-2017 as a single entry. 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.

Automakers plan commercialization of fuel cell vehicles beginning around 2015. While vehicle sales are projected in this document, it should be noted that actual vehicle sales will be based on numerous market-based factors, especially 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 will be ready to accommodate accelerated FCEV sales. The number of stations operating in 2015-2017 is crucial to increasing FCEV sales.



<sup>10</sup> The number represents only those stations expected to be available.

<sup>11</sup> The 68 station numbers should be characterized as the anchor for this analysis (provided by the 2011 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.

<sup>12</sup> Based on automaker 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>

## Growing the Network

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

The Clean Fuels Outlet (CFO) regulation,<sup>13</sup> adopted by the California Air Resources Board in January 2012, will be activated once automakers project 10,000 fuel cell electric vehicles in an air basin or 20,000 across the state. Once these projected volumes are verified, major producers and importers of gasoline must ensure that sufficient hydrogen fueling capacity—defined as the amount of fuel available at the station—is available to meet expected FCEV demand. If supply and demand are expected to strictly match, 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 the stations added by the CFO capacity-based approach.



Given the investments required to bring FCEVs to market, along with the infrastructure to adequately support these vehicles, it is important to minimize the risks to all stakeholders to manageable levels. Vehicle roll out and station implementation will be a dynamic process and will require flexibility, such as specific station locations. Implementing the road map in a manner that enables industry to adapt to new information or changes in market dynamics will ensure that California can build a robust early-adopter market that is prepared and confident of purchasing fuel cell electric vehicles. This will require leadership and commitment from all stakeholders through each stage of execution.

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<sup>13</sup> <http://www.arb.ca.gov/fuels/altfuels/cf-outlets/cf-outlets.htm>



## Hydrogen Stations: Funding the Gap

Stakeholders estimate 37 stations will be funded and operating in 2015, leaving a gap of 31 needed stations. Bridging this gap is essential to creating, building and maintaining confidence that California will be ready for the early commercial FCEV market.

Current funding from the California Energy Commission through AB 118 has focused on driving down equipment cost with cost-share grants to hydrogen station equipment developers. This program has resulted in making stations less expensive, but does not address operation and maintenance costs incurred by station owners, nor does it leverage the potential private financing from station developers who are not equipment manufacturers.

Compared to gasoline stations, hydrogen stations require higher up-front capital costs and have greater operating and maintenance expenses. These costs can ultimately be offset by potentially high margins on every kilogram of hydrogen sold (compared to gasoline margins). For the early hydrogen stations, however, when vehicle numbers are still low, fuel revenues will not likely offset the 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, CaFCP members worked with Energy Independence Now as they developed a model to analyze station costs. Results are published in EIN's *Incentivizing Hydrogen Infrastructure Investment*. EIN's analysis includes a detailed breakdown of capital and operating costs for different sized stations in various years under utilization growth scenarios. It then evaluated the costs of 68 stations under two possible incentive approaches, capital buy-down and cash-flow support.



The *capital buy-down* approach is the funding mechanism used today. To determine government and private funding necessary to reach the 68 station target, the report's analysis adds operation and maintenance (O&M) costs to the total capital cost for all new stations and includes O&M for existing stations until the net retail margin for a station exceeds its O&M costs.



The *cash-flow support* approach is an alternative incentive structure aimed at

attracting a broader set of investors to hydrogen station investment. Investors pay for and finance hydrogen station development in full, but receive an incentive payment when the station begins



operating. These payments are intended to cover cash flow shortfall (e.g. due to operating expenses as well as financing payments), and continue until cash flow is positive and the net retail margin can cover 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, support 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.

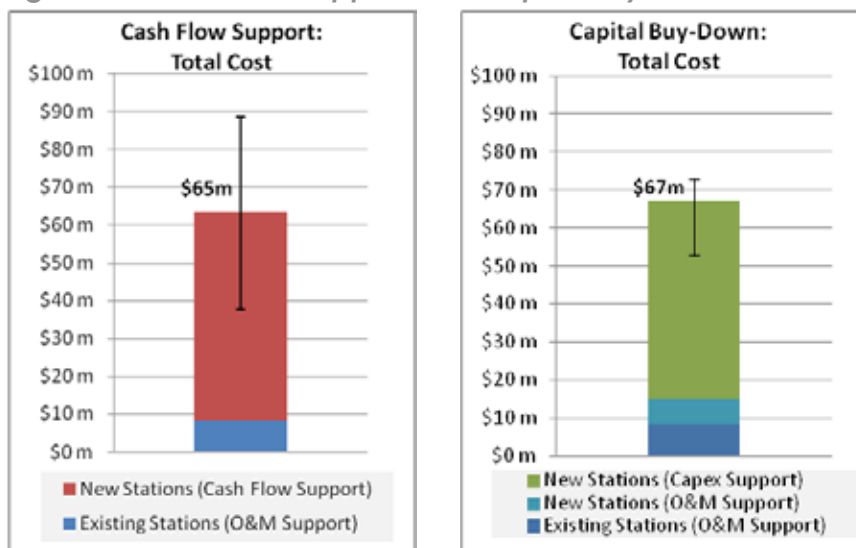


# The Cost of the Hydrogen Station Network

The *Incentivizing Hydrogen Infrastructure Investment*<sup>14</sup> modeling used a range of capital cost, utilization and retail-margin assumptions. 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, as shown in Table 3.

The model estimated the total cost to build and support a network of 68 stations using conservative, medium and slow-growth curves, 70 percent utilization and a \$3.00/kilogram retail margin. With the current funding approach—capital buy-down—the total funding needed for 68 stations is approximately \$67 million. Using the cash-flow model, the funding needed is \$65 million. Figure 7 provides a comparison of the two.

Figure 7 – Cash Flow Support and Capital Buy-Down



Given the baseline assumptions, the cash-flow and capital 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 buy-down approach is likely to be better in a market where slower growth may be expected. A hybrid between the two approaches will most likely be required to complete the network of 68 stations.

Table 3 – Hydrogen Station Baseline Cost Assumptions

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 <sup>[15]</sup>	\$112k
400-500 kg/day	\$1.5M-\$2.0M	\$81k	\$167k

14 [http://www.einow.org/images/stories/factsheets/ein\\_california\\_h2\\_infrastructure\\_cost.pdf](http://www.einow.org/images/stories/factsheets/ein_california_h2_infrastructure_cost.pdf)

15 Property tax (1% of capital cost) accounts for the slight cost difference between the 250kg and 400-500kg stations with no-load.

## Conclusion

Commercialization of fuel cell electric vehicles is expected to begin around 2015. If customers believe FCEV technology is mature and fits their needs, the station network is adequate and station performance meets their expectations, then the market is ready to support accelerating FCEV sales. For that reason, the number of stations operating by the beginning of 2016 will be crucial to building market confidence and growing FCEV sales.

An efficient development of the hydrogen fueling infrastructure relies on two primary factors: coverage and capacity. In the early years of the FCEV market, coverage is the vital component, as vehicles can only be successfully marketed if fueling stations are available and convenient to potential owners. Analysis shows that a network of 68 stations in key locations is expected to provide



enough coverage to offer FCEV owners a fueling experience similar to gasoline. The additional funding required to complete this nascent network of stations is approximately \$65 million.



To successfully navigate and address these challenges, 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 also have an immediate impact on high-tech, green jobs and air quality in California. 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.

Lastly and, most importantly, stakeholders must address the question of how to fund the additional \$65 million and how incentives will be provided to station developers. The road map lays the foundation for developing the early fueling network of the FCEV market and offers stakeholders the data and ideas they will need for a substantive conversation about implementing it.

The emerging market for fuel cell electric vehicles and the hydrogen infrastructure will only be realized through continued collaboration with a broad set of dedicated stakeholders.



Download *A California Road Map* at  
[www.cafcp.org/roadmap](http://www.cafcp.org/roadmap)

## Resources

- Governor’s Executive Order B-16-2012 regarding zero-emission vehicles, Governor Jerry Brown, State of California, 2012 <http://gov.ca.gov/news.php?id=17472>
- February 2009 Action Plan, California Fuel Cell Partnership, February 2009. <http://www.cafcp.org/sites/files/Action%20Plan%20FINAL.pdf>
- 2012-2013 Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program, California Energy Commission, 2012 [www.energy.ca.gov/2012publications/CEC-600-2012-001/CEC-600-2012-001-SD-REV.pdf](http://www.energy.ca.gov/2012publications/CEC-600-2012-001/CEC-600-2012-001-SD-REV.pdf)
- Clean Fuels Outlet Regulation, Air Resources Board. [www.arb.ca.gov/fuels/altfuels/cf-outlets/cf-outlets.htm](http://www.arb.ca.gov/fuels/altfuels/cf-outlets/cf-outlets.htm) and [www.arb.ca.gov/regact/2012/cfo2012/cfo2012.htm](http://www.arb.ca.gov/regact/2012/cfo2012/cfo2012.htm)
- Incentivizing Hydrogen Infrastructure Investment, Energy Independence Now, 2012. [http://www.einow.org/images/stories/factsheets/ein\\_california\\_h2\\_infrastructure\\_cost.pdf](http://www.einow.org/images/stories/factsheets/ein_california_h2_infrastructure_cost.pdf)
- Progress and 2011 Actions for Bringing Fuel Cell Vehicles to Market in California, California Fuel Cell Partnership, 2011. [http://cafcp.org/sites/files/CaFCPPProgressand2011Actions\\_0.pdf](http://cafcp.org/sites/files/CaFCPPProgressand2011Actions_0.pdf)
- California’s Advanced Clean Cars Program, Air Resources Board [http://www.arb.ca.gov/msprog/consumer\\_info/advanced\\_clean\\_cars/consumer\\_acc.htm](http://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/consumer_acc.htm)
- How We Use Energy, The National Academies <http://needtoknow.nas.edu/energy/energy-use/>
- Petroleum & Other Liquids, U.S. Energy Information Administration <http://www.eia.gov/petroleum/>
- Fuel Cell Technologies Program, U.S. Department of Energy <http://www1.eere.energy.gov/hydrogenandfuelcells/accomplishments.html>
- Selling Hydrogen Fuel in a Pre-Commercial Environment within California. California Department of Food and Agriculture, Division of Measurement Standards, 2011. [www.cdfa.ca.gov/dms/](http://www.cdfa.ca.gov/dms/)
- Ryuichi Kitamura and Daniel Sperling, “Refueling Behavior of Automobile Drivers,” Transportation Research Part A: General, vol. 21, no. 3, pp 235-245, 1987
- Systematic planning to optimize investments in hydrogen infrastructure deployment, *International Journal of Hydrogen Energy*, Volume 35, Issue 10, May 2010, Pages 4652-4667, Shane D. Stephens-Romero, Tim M. Brown, Jee E. Kang, Wilfred W. Recker, G. Scott Samuelson
- Ogden, Joan M. and Michael A. Nicholas (2011) *Analysis of a “Cluster” Strategy for Introducing Hydrogen Vehicles in Southern California*. Energy Policy 39 (4), 1923 – 1938. [http://pubs.its.ucdavis.edu/publication\\_detail.php?id=1534](http://pubs.its.ucdavis.edu/publication_detail.php?id=1534)

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.

For a complete list of members, please visit us at [www.cafcp.org](http://www.cafcp.org).

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