Chapter 3: Hydrogen Fuel Cell Vehicles and Infrastructure

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3.1. Introduction

Hydrogen Fuel Cell Vehicles and fueling infrastructure have been in development for well over two decades, promising zero emissions at the tailpipe, rapid refueling, and – if renewable energy is used to produce hydrogen fuel – the potential for significant reductions in greenhouse gas and air pollution impacts. To convert this potential into reality on the ground, the state of California and major automakers are investing substantial resources in new vehicle and fueling technology, as well as robust state incentives of up to $5000 per vehicle. Thanks to these investments, the years 2015-17 will see key milestones reached in the development of a viable Fuel Cell Electric Vehicle (FCEV) ecosystem in the state. These milestones include the development of a growing network of fueling stations sufficient to serve the first wave of FCEV early adopters. As of late 2015, an initial statewide network of nearly 100 fueling stations is in planning or under construction, timed to open progressively over the 2015-2023 period. The pace of station openings -- including one in Santa Barbara opening by the end of 2015 -- is designed to keep pace with the launch of several light-duty FCEVs from major manufacturers.

To assess the future potential of hydrogen vehicles in the Monterey Bay, and the actions that regional and local stakeholders can take to support FCEV readiness, this chapter covers these key issues:

- Overview of California’s Hydrogen Vehicle and Infrastructure Strategy
- Hydrogen Fuel Cell Vehicles (FCEVs) and related fueling infrastructure deployment in Northern and Central California and statewide
- Environmental and economic characteristics of FCEVs and potential contribution to air quality and GHG goals
- Operating attributes of FCEVs
- Sources of funding for FCEV infrastructure and vehicle incentives and potential market acceleration initiatives
- FCEV training needs, resources, and activities
- Recommendations on FCEV-related policies and programs for consideration by regional and local public agencies and other stakeholders

3.2. Overview of California’s Hydrogen Vehicle and Infrastructure Strategy

The California Hydrogen Highway Network was initiated in April of 2004 by Executive Order S-07-04 under then Governor Arnold Schwarzenegger. The intent of the Order and associated investments in FCEV technology by the California Energy Commission has been to ensure that hydrogen fueling stations will be in place to meet the needs of future FCEV drivers, and to provide an additional fuel pathway for the advancement of Zero Emission Vehicles (ZEVs). Over the medium-term (5-10 years), hydrogen technologies also have potential to be deployed in medium and heavy duty vehicle segments, as well as the light-duty sector. To provide an overall strategic framework for FCEV deployments across all vehicle types, the California Fuel Cell Partnership published A California Road Map: The Commercialization of Hydrogen Fuel Cell Electric Vehicle in 2012. This Road Map (and subsequent updates) has articulated the core policy and program framework for FCEV market development, including the all-important development of a new hydrogen fueling infrastructure.

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1 A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles, June 2012
http://cafcp.org/sites/files/A%20California%20Road%20Map%20June%202012%20%28CaFCP%20technical%20version%29_1.pdf
The *Road Map* in turn served as a basis for Governor Jerry Brown’s March 2012 executive order that directed California state agencies to support the accelerated deployment of the full range of zero-emission vehicles (ZEVs), including FCEVs. The state’s comprehensive 2013 *ZEV Action Plan* provided further guidance on bringing FCEVs to market. Most recently, the passage of Assembly Bill 8 (Perea, 2013) was another pivotal step in FCEV development, extending through 2023 the Air Resources Board’s Air Quality Incentive Program (AQIP) and the Energy Commission’s Alternative and Renewable Fuel & Vehicle Technology Program. AB 8 included a crucially important provision to fund at least 100 hydrogen stations via with up to $20 million a year in competitive grants and operating subsidies for fueling station developers, provided through the California (CEC). Since the passage of AB 8, three automakers (Honda, Toyota, and Hyundai) have announced plans to bring FCEVs to market in 2015-16, while several other automakers are ramping up new FCEV technology collaborations, and are expected to enter the market in the 2017-2022 timeframe. FCEVs have been embraced by key state policy makers because -- once an appropriate fueling infrastructure is in place -- they will combine the convenience and utility of conventional Internal Combustion Engine (ICE) vehicles, including diverse sizes, 300+ mile range and quick (gasoline-like) refill times, with some of the quiet and clean attributes of electric vehicles.

As discussed in depth later in this chapter, achieving some of the low-emissions attributes of EVs will require that sufficient quantities of renewable hydrogen fuel are economically available. Current state law mandates that 33% of hydrogen fueling supplies in state-supported stations be fueled by renewable hydrogen, but the majority of the balance of hydrogen fuel is derived from natural gas, limiting its environmental advantage relative to pure battery-electric vehicles (BEVs). With the potential to develop an even higher level of renewable and low-carbon hydrogen fuel supply chain, the state has produced another key policy document known as the Vision for Clean Air -- developed by several leading air quality management agencies -- to highlight strategies to accelerate the introduction of FCEVs as well as EVs in the context of air quality policy and goals.

Policies for FCEV promotion will of necessity be driven primarily at the state level, as most cities, regional agencies, and Air Districts do not have resources to offer a substantial quantity of vehicle incentives adequate for FCEV incremental cost buy-down, or sufficient grant funds to independently subsidize H2 fueling infrastructure. That said, local and regional stakeholders can work together with hydrogen fuel suppliers and the California Fuel Cell Partnership to support and accelerate existing plans for H2 fueling station deployment, or even to develop new plans and funding applications to the CEC for hydrogen stations. In 2015, the CEC announced funding for 28 new stations, resulting in an anticipated 51 operating hydrogen fuel stations by the end of 2015 (more than doubling the previous number of State-funded stations). There will be new opportunities in 2016 to site H2 fueling infrastructure in the Monterey Bay and Central Coast areas, beyond the first station in Santa Barbara.

### 3.3. The Statewide Hydrogen Station Network

The *Road Map* and *ZEV Action Plan* together prescribe a minimum network of hydrogen stations to establish the foundation for robust, commercial-scale FCEV adoption. Focused on “early adopter” areas in Southern California and the San Francisco Bay Area, the FCEV station network includes “connector” and “destination” stations intended to anchor the evolving statewide network and
enable north-south travel. As of mid-2015, eight stations are open to the public, with one in the San Francisco Bay Area, and the balance clustered in the greater Los Angeles/South Coast area. The only station currently being constructed between the San Francisco Bay Area and the Los Angeles/South Coast area is in the City of Santa Barbara, planned for South La Cumbre Road (discussed further below). There are no stations slated for construction in the tri-County Monterey Bay Area in 2015-16. The closest stations to the Monterey Bay region will be the San Jose station, slated to open in Q4 2015, and the Los Altos Station (Q2, 2016). The driving distance between Santa Barbara and San Jose stations is approximately 280 miles via Highway 101, which is within the range of a full tank of hydrogen fuel for currently available FCEVs. Of course, with no stations yet planned for opening in the tri-county Monterey area through 2016, most early adopter FCEV drivers will likely be commuters to the San Jose/ Silicon Valley area.

By the end of the 2016, the California Fuel Cell Partnership estimates that more than 50 stations will be open, with a total of 100 to be open by ~2020, per the schedule below. However, automakers such as Toyota, are indicating that approximately 40 will be open by the end of 2016. Thus, the dates provided on the Fuel Cell Partnership’s website below (current as of mid-2015) may be considered optimistic. (Hyperlinks provide additional information on each station.) The state’s rapidly growing infrastructure investment stands at $91 million since 2009, and nearly $200 million has been pledged by the state to help build out the planned 100 station network.7

<table>
<thead>
<tr>
<th>California Hydrogen Station Locations and Opening Dates</th>
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<tbody>
<tr>
<td>STATION LOCATION</td>
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<tr>
<td><strong>OPEN IN Q3 2015</strong></td>
</tr>
<tr>
<td>Burbank</td>
</tr>
<tr>
<td>Emeryville - AC Transit</td>
</tr>
<tr>
<td>Fountain Valley - OCSD</td>
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<tr>
<td>Irvine - UC Irvine</td>
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<tr>
<td>Los Angeles - Harbor City</td>
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<tr>
<td>Newport Beach</td>
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<tr>
<td>Thousand Palms - SunLine Transit</td>
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<tr>
<td>Torrance</td>
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<tr>
<td><strong>OPENING Q4 2015 – Q4 2016</strong></td>
</tr>
<tr>
<td>Anaheim</td>
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<tr>
<td>Burbank (Upgrade)</td>
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<tr>
<td>Campbell</td>
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<td>Chino</td>
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<td>Coalinga</td>
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<td>Costa Mesa</td>
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<tr>
<td>Diamond Bar</td>
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<tr>
<td>Foster City</td>
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<tr>
<td>Hayward</td>
</tr>
<tr>
<td>Irvine - UC Irvine (Upgrade)</td>
</tr>
<tr>
<td>Irvine - Walnut Ave</td>
</tr>
<tr>
<td>La Canada Flintridge</td>
</tr>
<tr>
<td>Laguna Niguel</td>
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<td>Lake Forest</td>
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<td>Lawndale</td>
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<tr>
<td>Long Beach</td>
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<tr>
<td>Los Altos</td>
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The most recent update to the state’s FCEV Road Map, known as the Hydrogen Progress, Priorities and Opportunities Report has further refined the locational strategies of the Fuel Cell Partnership and its Original Equipment Manufacturers (OEM) Advisory Group – which includes Honda, General Motors, Hyundai, Mercedes-Benz, Nissan, Toyota and Volkswagen. As of June 2015, the OEM Group produced a consensus list of recommended priority locations for the next 19 hydrogen stations to be built in the state, to ensure that customer travel-time to the nearest station is minimized within a regional market, inter-regional travel is facilitated, and there is at least some redundancy in the network. It should be noted that these recommendations are preliminary and will likely be further refined through further consultation with stakeholders. Monterey Bay stakeholders will note that there are no stations recommended as a Primary Priority for this region, whereas in the Central Coast, the Santa Barbara station will be opening by early 2016. One additional station – in Ventura/Oxnard – is proposed as a Secondary Priority. This locational strategy is based on market analysis that suggests
that early adoption will be strongly clustered in the Los Angeles and San Francisco Bay Areas, necessitating only a few connector stations in the rest of the state during the initial years of market development.

<table>
<thead>
<tr>
<th>Primary Priority*</th>
<th>Secondary Priority*</th>
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<tbody>
<tr>
<td>Berkeley/Richmond/Oakland</td>
<td>Culver City</td>
</tr>
<tr>
<td>Beverly Hills/Westwood</td>
<td>Dublin/Pleasanton</td>
</tr>
<tr>
<td>Fremont</td>
<td>Encino/Sherman Oaks/ Van Nuys</td>
</tr>
<tr>
<td>Lebec**</td>
<td>Granada Hills</td>
</tr>
<tr>
<td>Manhattan Beach Sacramento</td>
<td>Irvine South</td>
</tr>
<tr>
<td>San Diego #2</td>
<td>Los Banos**</td>
</tr>
<tr>
<td>San Diego #3</td>
<td>Palm Springs</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Ventura/Oxnard</td>
</tr>
<tr>
<td>Thousand Oaks/Agoura Hills Torrance/Palos Verdes</td>
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</tbody>
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*The locations are listed in alphabetical order and not ranked within the priority lists.
** These two locations will further strengthen the I-5 corridor

Source: California Fuel Cell Partnership.
3.4. H2 Fueling Station Cost and Regional Site Selection Process

Hydrogen fueling stations are estimated to cost between ~$1.2M and $2.4 million dollars on average. California’s stations are typically constructed with a combination of public and private funds, including significant grants from the California Energy Commission. While the state encourages siting and building of stations in alignment with the state’s cluster model, the complexities of siting are such that some stations may not be located within the designated clusters, and others will be difficult to site at locations that are otherwise considered optimum in terms of customer convenience. Stations are not expected to show a profit for up to 10 years or more, and therefore may require ongoing subsidy through both private and public sources.

The chart below illustrates California’s hydrogen fuel station rollout through 2020; including both existing and proposed stations – segmented according to the five key regional clusters identified by CARB to plan the hydrogen vehicle roll-out. These clusters include the San Francisco Bay Area, Sacramento Area, Los Angeles/Orange County/Ventura, San Diego, and “Other” (encompassing the rest of California). The successful roll out of the 51 stations expected by the end of 2015 is intended to support and align with near-term hydrogen vehicle sales.

As illustrated above, the Central Coast/South Orange County geographies are estimated to have only approximately five stations beginning in 2016, expanding through the 2020 period to locations yet to be determined. The “expanded network” plan has not yet identified specific Monterey Bay H2 fueling sites. To ensure ongoing functioning of the fueling network, the CEC has provided operations and maintenance costs for station operators to maintain their availability until sales revenue can cover costs and create a viable business case for private investment. The payback period for private investment in the stations is discussed in greater detail later in this chapter.
3.5. Current Status of Station Siting in Northern and Central California
The first hydrogen station planned for the entire Monterey Bay / Central Coast region will be located in Santa Barbara at 150 South La Cumbre Road. First Element Fuels won a $27.6 million dollar contract with the California Energy Commission to develop this station along with a network of 19 additional hydrogen fueling stations in California. The project is being constructed and managed by Black and Veatch, a large engineering firm that managed development of Tesla’s national Supercharger network. While the Santa Barbara project was initially planned for an October 2015 opening, it is now expected to be open by the end of the year. In its first two years of operation, fuel for the station will be provided by Air Products and Chemicals, with 33% of the hydrogen provided from renewable sources, per California state mandate. As in the case of most early H2 fueling stations, the California Energy Commission will also be providing Operations and Maintenance (O&M) funding during at least the first three years of operation, in order to enable sustained operation of the station while vehicle and fuel demand is still ramping up.

Santa Barbara Hydrogen Fueling Station Location: 150 South La Cumbre Road

3.6. Hydrogen Fueling and Vehicle Deployment in the National Policy Context
While California is an extraordinarily important market for FCEV infrastructure, as in the case of EVs, the full commercial scale-up of hydrogen vehicles will only occur as a full nationwide market is developed that complements state-level efforts. To that end, the U.S. Department of Energy (DOE), automakers, hydrogen producers, and allied organization launched H2USA in March 2013, a public-private partnership focused on advancing hydrogen infrastructure. The partners, which include the California Fuel Cell Partnership and the State of California, are encouraging early adoption of FCEVs with a focus on cost reductions and scale economies in both fuel production and FCEV manufacturing. As in California, long-term national energy policy is beginning to focus on the role that FCEVs could
play in diversifying fuel supplies, reducing GHGs in the transport sector, and in particular providing a
new low-carbon fuel for medium and heavy-duty trucks. In their 2013 report entitled *Transitions to
Alternative Vehicles and Fuels*, the National Research Council assessed the potential of the light-duty
fleet to enable an 80% reduction in petroleum consumption and GHGs by 2050, and indicated that
FCEVs ranked high among the various options. That said, it appears that the federal government is
some years away from investing the scale of dollars — variously estimated at $50 billion or more — that
could be required to extend a robust FCEV fueling infrastructure nationwide. In the meantime, more
modest R & D investments are being made in reducing fueling infrastructure costs and further
developing promising technologies for producing renewable and lower carbon H2 fuel supplies.

3.7. The Hydrogen Fueling Experience

Hydrogen fueling stations can be co-located with regular gasoline and diesel stations or they can be
operated in stand-alone locations. The hydrogen fueling experience is similar in appearance, function,
and timing with liquid fuels, although hydrogen fuel is delivered to vehicles in a gaseous state. FCEVs are
designed to accept hydrogen in gaseous form pressurized at two levels, either 350 bar (5,000 psi) --
known as H35 -- or 700 bar (10,000 psi) -- known as H70. Currently, 700 bar (H70) gaseous onboard
storage has been chosen for the first generation of commercial vehicles, while 350 bar (H35) is utilized
for buses, forklifts, and other lift trucks. A hydrogen dispenser looks similar to a gasoline fuel dispenser
and usually has one hose and nozzle for each pressure. Users cannot attach the high-pressure nozzle to a
lower pressure receptacle, so there is no chance of fueling at the wrong pressure level. When a driver
activates the dispenser, hydrogen flows from the storage tanks and through the nozzle into the vehicle in
a closed-loop system. If filling with H70 (the light-duty vehicle standard), the hydrogen passes through a
booster compressor and chiller before entering the dispenser. If the nozzle is not correctly attached, fuel
will not flow. A full tank of hydrogen—4–6 kilograms—provides range of approximately 300+ miles,
which is similar to a conventional ICE vehicle. Stations are designed for unattended operation.

While higher pressure fuel provides more energy density per kilogram of fuel and thus higher driving
range, it is also more expensive per kilogram due to the additional cost of higher pressurization. H70 is
currently in the range of $3.00-$3.50 per Gallon Gasoline Equivalent (GGE), although it is important
to note that these prices reflect the significant operational subsidies now provided by the California
Energy Commission to the initial generation of H2 station operators. Future H2 cost projections will
be discussed later in this chapter. In recent years, H2 fuel costs have proven more stable than
gasoline or diesel. As with conventional gas pumps, the dispensers are designed to accept credit
cards and display sales information conforming to state weights and measures requirements. Volume
is displayed in kilograms (kg). Fueling time is approximately 5 minutes for upwards of 300 miles of
range per tank for a typical light duty vehicle. Like a gasoline dispenser, a hydrogen dispenser typically
has two sides, each with a similar interface.

A hydrogen station has multiple safety systems to protect against fire, leakage, or explosion (described in
more detail in the safety training section of this chapter). If flame detectors or gas sensors detect a fire
or leak, safety measures turn on automatically, such as sealing the storage tanks, stopping hydrogen flow
or—in the case of an extreme fire—safely venting the hydrogen. Strategically placed emergency stops
will manually shut down hydrogen equipment. Retaining walls, equipment setbacks, and bollards are
designed into the site plan to maximize safety.

The following simplified chart from *Motor Trend* magazine describes the H2 fueling experience and
FCEV operational cost in the context of other alternative fuel types. The expectation of FCEV
automakers, notably Toyota (which is aggressively marketing hydrogen against pure Battery EVs), is that the more convenient fueling experience will be a decisive factor for consumers unwilling to deal with the inconvenience of slower-to-refuel BEVs. Thus, some market analysts hold that the principal consumer competition in Alternative Fuel Vehicles will be between PHEVs (Plug-in Hybrids), which combine some of the advantages of both EVs and ICEs, and FCEVs. Other analysts believe that if expected cost and performance improvements of batteries continue on their predicted course, there will be 200-300 mile range BEVs available in the early 2020s that will be price-competitive with ICEs and less costly than equivalent FCEVs. At that point, the need for BEVs to rely on slower public EV charging will be reduced, and the principal advantage of FCEVs will be perceived as relatively limited. However, it should be emphasized that at this early stage of market development — with near zero sales data and limited consumer awareness -- all estimates of FCEV potential by both policy makers and auto OEMs must be considered to be educated guesswork at best.

3.8. Hydrogen Fuel Production Pathways

Unlike fossil fuels, hydrogen fuel does not occur naturally on Earth and thus is not considered an energy source; rather it is an energy carrier. Like electricity, hydrogen can be produced from diverse resources by using primary resources — such as coal, oil, natural gas or biomass — to power a thermochemical hydrocarbon conversion that creates an intermediate product known as syngas (or
synthesis gas). In the United States, about 9 million metric tons of hydrogen are produced each year by this process, also known as steam reforming, mainly for industrial and refinery purposes. This is the equivalent amount of fuel required to power a fleet of about 35 million fuel cell cars. Steam reforming of natural gas is the most common method of hydrogen production today, accounting for about 95 percent of domestic production. However, as noted in the chart below, other primary energy resources, including renewable resources, can be used to produce hydrogen, with varying costs, environmental impacts, and technical complexity.

![Production pathways for hydrogen](image)

**Production pathways for hydrogen**  
*Source: NextSTEPS White Paper: The Hydrogen Transition, Institute of Transportation Studies, UC Davis, July 29, 2014, p. 15*

### 3.9. Hydrogen Production Using Electricity and Natural Gas

While current hydrogen production is dominated by natural gas feedstocks, hydrogen can be produced with electricity via a process known as electrolysis -- in which an electric current splits water into hydrogen and oxygen. If the electricity used in this process is itself produced from renewable sources, such as solar or wind, the resulting hydrogen gas is considered renewable as well, with a more favorable emissions profile. Because renewable electricity is increasingly available in surplus in California -- typically in the form of excess wind at night and excess solar in the early afternoon -- “power-to-gas” projects are beginning to emerge. These renewable projects have the potential to become more economical as the market for hydrogen grows through expansion of both the fuel cell vehicle market and stationary fuel cell energy production for the grid. The timing of EV charging to respond to these grid surpluses is also expected to be an important part of the state’s energy strategy going forward.

Notwithstanding the potential for surplus renewable energy to be dedicated to hydrogen fuel production, studies by the Institute for Transportation Studies at UC Davis indicate that natural gas rather than electricity will continue to be the least expensive and most energy-efficient resource from which to produce hydrogen through the 2020s. Although the full GHG impact of natural gas is still under study (due to new data emerging about methane leakages in the natural gas supply chain),

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4 Joan Ogden, Christopher Yang, Michael Nicholas, Lew Fulton, *NextSTEPS White Paper: The Hydrogen Transition*, Institute of Transportation Studies University of California, Davis, July 29, 2014, p. 15  
current estimates suggest that *natural gas based hydrogen fueled vehicles emit approximately half as much GHG as a comparable gasoline car on a well to wheels basis* (Nguyen et al. 2013). The domestic shale gas boom has been a significant factor in keeping gas prices low, and further boosting policy maker interest in hydrogen. Of course, natural gas is also used as a significant electricity feedstock in California (and thus is an important factor in the emissions profile of both EVs and FCEVs running on the standard California “grid mix”). However, FCEVs fueled by electricity-produced hydrogen (via electrolysis) as well as EVs using the standard grid mix will benefit from the progressive greening of California’s grid. The carbon intensity per kWh of electricity in California will steadily decline as Renewable Portfolio Standards ratchet up from the current 33% by 2020 to 50% or more in 2030 and beyond. That said, the full well-to-wheels calculation of the relative emissions of the two vehicle types must also take into account superior operating efficiencies in EVs, such that EVs will always environmentally outperform FCEVs on a well-to-wheels basis, when comparable feedstocks are assessed. These issues are further discussed in Section 3.26 below, *Assessing the Environmental Attributes of Hydrogen Fuels on a Life-Cycle Basis*. 

3.10. Onsite Production of Hydrogen Using Electrolysis

In addition to larger-scale “power to gas” projects located at renewable energy generation sites (such as wind or solar farms), hydrogen fueling companies can purchase renewably produced electricity for onsite hydrogen production from their local utility (if they have a renewable tariff) or via use of Renewable Energy Credits (RECs), which represent renewable power injected into the grid at another location. A compact production process can be installed at hydrogen fueling stations, consisting of an electrolyzer, a compressor, and a storage tank. A California company known as HyGen has opened a hydrogen fueling station in Orange County that features this relatively simple onsite hydrogen production process using renewable energy, illustrated in the diagram below. Renewable energy purchased from the utility is used to split water to obtain pure hydrogen, which is held in a buffer tank. Oxygen is the by-product of this process and is released to the atmosphere in the majority of on-site hydrogen stations. The next stage is to compress the hydrogen to pump the gas to storage vessels for delivery to the fuel pump.

Depending on production capacity requirements, the company claims a HyGen system can be installed for as little as $1.5 million, although a station of this size would have the capacity to fuel only up to 100 vehicles/week. Some experts maintain that onsite electrolysis is as much as twice as expensive per kilogram of hydrogen delivered as stations that procure hydrogen using natural gas.5 However, stations can potentially be upgraded to produce onsite hydrogen as the economics improve. For example, a larger station developed with the support of Hyundai Motors in Chino in early 2015 has been designed to add a fuel cell, but currently uses hydrogen produced by ChevronTexaco from natural gas feedstocks. Like most hydrogen stations open now, operational costs are supported by government funds, in this case a cost-sharing arrangement with the federal Department of Energy. The University of California at Davis recently estimated that production of hydrogen through electrolysis will continue to be significantly more expensive than natural gas (even accounting for future carbon sequestration costs) through 20206 and that subsidies will be required for at least the first 5 to 7 years of operation. The California Energy Commission is providing Operations and Maintenance (O&M) funding along with their capital grants in recognition of the reality that FCEV

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deployments will not be sufficient to support breakeven operation of the fueling stations until at least 2020 or later in most regions of the state.

3.11. The Potential to Utilize Excess Renewable Energy in Hydrogen Production

As noted above, a particularly promising way to make hydrogen from electrolysis both cleaner and more economically competitive is for companies to take advantage of surplus renewable energy production. In California, renewable energy currently makes up 20 percent of retail electricity sales and is mandated to reach 33%+ in future years. However, an overproduction of solar and wind during the middle of the day is already forcing the state to “dump” power, i.e., to pay out of state utilities to take power, when there is insufficient aggregate demand. The total amount of power dumped in 2014 was 19 gigawatt-hours of pre-purchased renewable energy, enough to refuel tens of thousands of cars with electrically produced hydrogen or via EV charging. For this reason, the California Public Utilities Commission has coupled their renewable energy mandates with a recent energy storage mandate that requires California utilities to provide 1.325 gigawatts of energy storage capacity. Additionally, utilities are mandated to develop much more robust “demand response” programs that would enable a variety of variable electric loads – including potentially both Electric Vehicle charging systems, and hydrogen production facilities – to take power from the grid when there is excess energy supply, much of which is likely to be generated by intermittent solar and wind.

As attractive tariffs are established to encourage distributed generation and storage resources to plug into these time of use rates and demand response programs, electrolyzers will become more economical as they utilize this excess generation to make renewable hydrogen. Like a battery storage device connected to the grid, electrolysis is considered a “dispatchable load”, which means the hydrogen fuel production system can rapidly adjust its power flow to stabilize electricity demand and supply. According to the National Renewable Energy Laboratory research, electrolyzers are also able to respond fast enough to offer frequency regulation or ancillary services to the grid, which can provide new sources of revenue for hydrogen fuel producers via payments from California utilities and/or the California Independent System Operator (CAISO). The revenue from energy market participation is not considered sufficient to recuperate all the original investment in a renewable hydrogen project. However, electrolysis systems that offer ancillary services and sell hydrogen fuel will be more economically competitive. Further hydrogen energy storage has one significant advantage over batteries in that it can provide megawatt-hours of energy storage – enough to operate buildings and production facilities for days or even weeks at a time – thank. This capability can effectively turn intermittent renewables into more reliable “base load” capacity. One leading company in this field is Proton Onsite, which will begin distributing a Proton Exchange Membrane (PEM) electrolyzer with the capacity to produce enough hydrogen to store multiple megawatts of renewable energy. The company plans to begin shipping in 2015.
Options for using hydrogen to integrate intermittent renewables on the grid.


3.12. Biogas, Biomass, and Coal to Hydrogen Production

Perhaps the most eco-friendly approach to hydrogen production is known as biogas to hydrogen. In this process, wastewater solids enter an anaerobic digester at a wastewater treatment plant. Microbes convert the waste into a biogas (CH4) similar in composition to natural gas, but with more impurities. A
scrubber removes many of the impurities, including carbon and sulfur. The purified biogas then enters a stationary fuel cell where heat and water vapor separate CH4 into hydrogen and carbon dioxide. Separating the gas creates heat and water vapor, which is used to power the reaction in the fuel cell. Excess heat goes back into the digester. The fuel cell also produces electricity that can be sent to the grid. Hydrogen enters additional cleaning processes and is then compressed and stored for distribution via underground pipelines to a public station.

From well to wheels, a biogas system creates net zero greenhouse gases, virtually zero criteria pollutant emissions, and makes commercial use of hazardous waste. Because of the many environmental virtues of biogas to hydrogen production, the California Energy Commission is particularly interested in supporting such projects, and has invested in several throughout the state. Of course, the total amount of H2 fuel that can be produced through this method is limited by the finite size of the waste stream, and hydrogen suppliers must compete with other productive uses of bio-waste, such as composting for use in agriculture and soil carbon sequestration.

**Source:** California Fuel Cell Partnership

A final method of creating hydrogen is known as syngas or synthesis gas. Syngas can be created by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier -- through a process called gasification. The resulting synthesis gas contains hydrogen and carbon monoxide, which is reacted with steam to produce more hydrogen. This approach is much less common than steam methane reforming with natural gas or other methods and is not yet viewed as cost competitive.
3.13. Distributing Hydrogen to Fueling Stations

Currently, most hydrogen is transported from the point of production to the point of use initially via pipeline, rail, or barge, with final over the road delivery by truck. As noted earlier, hydrogen can be delivered in either gaseous or liquid form before being converted to a gas and compressed to the appropriate pressure for final delivery to the car. Gaseous hydrogen is delivered by swapping storage trailers packed with fuel tubes, which are permanently mounted on the trailer. The driver opens the gate around the storage area, backs in a full trailer and connects it to the dispensing system. The driver then disconnects the empty tube trailer, hooks it to the tractor and drives away. Swapping trailers can take between 10 and 30 minutes. By contrast, liquid hydrogen is delivered by a tanker truck that looks much like a gasoline tanker. Because liquid hydrogen is at a cryogenic temperature, a vapor cloud often forms around the transfer point. Filling the storage tank typically takes around 30 minutes, depending on the size of the tank.

The location of hydrogen production has a significant impact on the cost of fuel, and on the choice of delivery methods to locally sited stations. A large, centrally located hydrogen production facility can produce H2 fuel at a lower cost, but a longer trip to final delivery can eliminate this cost savings. Local or on-site production facilities will typically reduce delivery costs while raising production costs.

Developing a ubiquitous hydrogen fueling infrastructure across the state (and ultimately, across the nation) poses significant challenges in the near-term. These include reducing delivery cost, increasing energy efficiency, maintaining hydrogen purity, and minimizing hydrogen leakage. Further research is underway to analyze the trade-offs between hydrogen production and delivery options when considered as a complete system. To address these challenges, the National Renewable Energy Laboratory and Sandia National Laboratories have announced the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project – which is designed to reduce the cost and time of fueling station construction, increase station availability, and improve reliability.

The California experience with deployment of H2 fueling stations at scale, along with ongoing R&D, will eventually produce an economically and environmentally optimized formula for hydrogen production, distribution, and delivery. However, this optimized system is some years away. The initial generation of station operators and H2 stakeholders must choose among many alternative production and distribution pathways now available, with a variety of economic and technology profiles. The chart below highlights key advantages of each production and distribution approach.

The first choice facing operators is on-site production vs. delivery of fuel produced at a distance. The second key choice is delivery of H2 in either liquid or gaseous form. If the fuel is delivered in liquid form, it must be converted to a gas using onsite equipment, and both liquid and gaseous storage facilities are required. On-site production can lower delivery costs, while using less environmentally friendly natural gas or the standard California “grid mix” of electricity. Use of on-site renewables (such as solar) to power the electrolysis process, potentially in combination with battery energy storage, is environmentally preferably but requires a larger station footprint and may not be economically feasible at the current time. (Pathways for increasing the production of renewable hydrogen are discussed in more detail later in this chapter). The chart below illustrates the tradeoffs involved in the range of production and delivery options currently available.
### Comparison of Hydrogen Fuel Delivery Methods: Advantages vs. Disadvantages

<table>
<thead>
<tr>
<th>Method</th>
<th>Equipment at Station</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Liquid Delivery</strong></td>
<td>▪ Liquid storage tank ▪ Heat exchanger ▪ Compressor ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser</td>
<td>▪ Can store more fuel</td>
<td>▪ Much larger footprint ▪ Potential for fuel to boil off ▪ Expense of two types of storage tanks (liquid &amp; gaseous)</td>
</tr>
<tr>
<td><strong>Gaseous Delivery</strong></td>
<td>▪ Gaseous storage ▪ Compressor ▪ Chiller ▪ Dispenser</td>
<td>▪ Smaller footprint than liquid ▪ Equipment can be in various locations</td>
<td>▪ Least amount of storage capacity without multiple trailers/ storage tubes</td>
</tr>
<tr>
<td><strong>On-site Electrolysis</strong></td>
<td>▪ PV or wind system (optional) ▪ Water purifier ▪ Electrolyzer ▪ Compressor ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser</td>
<td>▪ Make fuel on site ▪ Potential to sell carbon credits</td>
<td>▪ More equipment ▪ Larger footprint ▪ Can be more expensive</td>
</tr>
<tr>
<td><strong>H2 from Pipeline</strong></td>
<td>▪ Scrubber ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser</td>
<td>▪ Larger capacity ▪ Can require less storage</td>
<td>▪ Station must be near ▪ pipeline ▪ More equipment ▪ Larger footprint</td>
</tr>
<tr>
<td><strong>On-site Reforming</strong></td>
<td>▪ Natural gas or biogas supply ▪ Scrubber ▪ Water purifier ▪ Reformer ▪ Compressor ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser</td>
<td>▪ Make fuel on site ▪ Potential to sell carbon credits</td>
<td>▪ More equipment ▪ Larger footprint ▪ Can be more expensive</td>
</tr>
</tbody>
</table>

### Hydrogen Fuel and Station Companies and Suppliers:

Of course, final decisions regarding H2 fueling infrastructure will involve both private station developers, state funders, and relevant permitting authorities. Local planners and permitting authorities are encouraged to reach out both to the California Fuel Cell Partnership for more information on local options for H2 fueling production and delivery infrastructure, as well as directly to the companies in the field. Key market actors in California including industrial gas companies such as Air Liquide, Air Products, and Linde, which provide equipment, design and construction of stations. Proton OnSite makes electrolyzers and SunHydro branded stations. Hydrogenics and Powertech also provide equipment. Two new start-up companies, First Element and
Hydrogen Frontier, are designing stations and providing equipment, with Irvine-based First Element having recently won a very large contract with the CEC for installation of multiple stations, including the first station in City of Santa Barbara.


The long-term success of the hydrogen project will be based in significant measure on the development of a low-cost, low-carbon, high-capacity hydrogen fuel supply chain. The extraordinary versatility of both the production and distribution pathways for hydrogen provide many options for stakeholders to advance the availability of hydrogen where regional clusters of stations will be located. As in the case of electricity, it is likely that diverse primary sources will be used to make hydrogen in different regions of the state. The chart below indicates the relative costs of various production pathways, based on a definitive 2014 study by the UC Davis Institute for Transportation Studies. Note that the chart illustrates the delivered cost of hydrogen for a variety of future supply pathways, after large-scale deployments have enabled scale economies for all the fuel production approaches. It is important to note that these cost projections do not reflect current pricing available in 2015-2017. It is also important to note that biomass may not be scalable beyond the early years of FCEV deployment, due in part to competing uses.

![Delivered Cost of Hydrogen](chart)

**Delivered Cost of Hydrogen:** The grey shaded area indicates where the fuel cost per mile for hydrogen FCEVs would compete with a gasoline hybrid. Costs assume that hydrogen supply technologies are mature and mass-produced.

**Source:** NextSTEPS White Paper: The Hydrogen Transition, Institute of Transportation Studies, UC Davis, 2014.

3.15. The Business Case for Developing Hydrogen Fueling Stations

The California Energy Commission, CARB, and the California Fuel Cell Partnership have worked closely together to develop a “cluster strategy” for H2 stations, based on the idea of co-locating the first several thousand vehicles and tens of stations in likely early adopter areas within the state’s larger metro areas (especially the South Coast, Bay Area, and San Diego). In the Southern California region, it was found that average travels times to stations of less than 4 minutes could be achieved with a relatively sparse initial regional network, amounting to less than 1% of gasoline stations. Targeted clusters represent only a fraction of the California population but reflect specific areas where fuel cell
adoption is most likely. The table below illustrates a possible scenario for the 7-year FCEV rollout and hydrogen station development in Southern California, based on the state’s proposed cluster strategy. By year 7 the system serves 34,000 FCEVs with a network of 78 stations.

<table>
<thead>
<tr>
<th>Illustrative Regional Deployment of Hydrogen Stations Relative to FCEVs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td># FCEVs in fleet</td>
</tr>
<tr>
<td>H2 demand (kg/d)</td>
</tr>
</tbody>
</table>

| Mobile Refuelers (100kg/d) | 4 | 0 | 0 | 0 | 0 | 0 | 0 |

<table>
<thead>
<tr>
<th>Compressed Gas Truck Deliveries/Station Size</th>
<th>170 kg/d</th>
<th>250 kg/d</th>
<th>500 kg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Refuelers (100kg/d)</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Compressed Gas Truck Deliveries/Station Size</td>
<td>170 kg/d</td>
<td>250 kg/d</td>
<td>500 kg/d</td>
</tr>
<tr>
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<td>4</td>
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<td>0</td>
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<td>170 kg/d</td>
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</tr>
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<td>170 kg/d</td>
<td>250 kg/d</td>
<td>500 kg/d</td>
</tr>
<tr>
<td>Mobile Refuelers (100kg/d)</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| Total station capacity (kg/y) | 400 | 400 | 1,080 | 3,580 | 11,580 | 21,580 | 31,580 |
| Total number of stations | 4 | 4 | 8 | 18 | 38 | 58 | 78 |
| Average travel time home to station (minutes) | 4 | 4 | 3.5 | 3 | 2.8 | 2.6 | 2.6 |


In the scenario illustrated above, hydrogen is supplied via truck delivery, building on the current industrial gas supply system -- and the hydrogen is largely derived from natural gas or industry by-products. Initially, hydrogen is supplied via mobile refuelers, a small-scale portable station incorporating storage and dispensers that can be towed to any site. After several years, a network of small fixed stations (170 kg/day) is established to ensure coverage, and as demand rises, larger stations (250 kg/d and then 500 kg/d) are added to the network. To put these quantities in perspective, a mid-size FCEV consumes approximately 0.7 kg of hydrogen per day on average (if it is traveling 15,000 miles per year in a 60 mpg equivalent car). This would require a station capacity of perhaps 1 kg per day per FCEV served, accounting for 70% station utilization. So a 100 kg/d station might serve a fleet about 100 FCEVs, and a 500 kg/d stations about 500 FCEVs.

The charts below illustrate both the capital cost and the estimated levelized cost of hydrogen assuming the stations are operated at their rated capacities (e.g., 100 kg/d, 170 kg/d 250 kg/d or 500 kg/d). Note that hydrogen fuel costs become more competitive as station technology develops and larger stations are deployed.
### California Hydrogen Station Cost Model

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Capital Cost</th>
<th>Annual O&amp;M cost $/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1 (years 1-2)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 kg/d</td>
<td>$1 million + $1.5 million</td>
<td>$100 K (fixed O&amp;M) + 1 kWh/kgH2 x kg H2/yr x $/kWh (compression electricity cost) + H2 price $/kg x kg H2/y</td>
</tr>
<tr>
<td>250 kg/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phase 2 (years 3-4)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>170 kg/d</td>
<td>$0.9 million + $1.4 million</td>
<td></td>
</tr>
<tr>
<td>250 kg/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phase 3 (year 5+)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>170 kg/d</td>
<td>$0.5 million + $0.9 million</td>
<td></td>
</tr>
<tr>
<td>250 kg/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 kg/d</td>
<td>$1.5-2 million</td>
<td></td>
</tr>
</tbody>
</table>

**Assumptions:** Truck gas delivery. 700 bar dispensing. Stations built at least 12 months prior to FCEV deployment in significant numbers. **Source:** NextSTEPS White Paper: The Hydrogen Transition, ITS, UC Davis, July 2014, p. 26

In the UC Davis analysis, cash flow for station operators is negative initially, but after about year 7, it becomes positive. By year 9, the cumulative cash flow become positive as well, and the network can pay for itself, even though the initial years show a negative balance. The total capital investment for the proposed 78 station regional cluster in Southern California is about $113 million. H2 costs to enable station owners to earn a 12% rate of return are estimated below.

![Levelized Delivered H2 Cost](image)

**Source:** NextSTEPS White Paper: The Hydrogen Transition, ITS, UC Davis, July 2014, p. 26

The assumptions in the cost model above include the following:

- Compressed hydrogen costs $6/kg truck-delivered to the station
- Rate of return = 12%
- Station life is 10 years
The levelized cost is what the station would have to sell hydrogen for to make a 12% rate of return.

- Stations dispense a fuel amount equal to their full capacity
- H2 costs decline due to reductions in capital costs and increased output.

If the FCEV market accelerates rapidly, the UC Davis study indicates that larger (500 kg/d) station will have a business case that should attract investors. Whereas the earlier smaller stations (100 - 250 kg/d) involve more risk if FCEV deployment is slow. The scenario sketched below illustrates a potential relationship between FCEVs in the fleet, annual FCEV sales, the total number of hydrogen stations in the network, and the average size of new stations likely to be built each year. This assumes that the Southern California regional FCEV fleet grows rapidly from 34,000 in year 7 to 250,000 FCEVs in year 11. In year 11, the on-road FCEV fleet would be about 1% of all existing light duty vehicles in California, while new FCEV sales would be ~6% of the state’s annual light duty vehicle sales. (Ogden and Yang 2009). This is similar proportionately to the early growth rate for HEVs in the United States.

Deployment Scenario for regional FCEV sales (Year 1 = start of commercialization/2016).

Assumptions: After year 4, stations employ compressed gas truck delivery (500 kg/d) or onsite steam methane reformation (1000 kg/d). H2 costs at the pump are $5-8/kg -- competitive with gasoline vehicles on a cent per mile basis.


In the Southern California regional model developed above, in year 9, 100,000 FCEVs are on the road, served by 200 stations, hydrogen costs about $7.1/kg and the cumulative station capital investment is about $300 million. Approximately $150-300 million is needed to build the first 100-200 stations, serving 50,000-100,000 vehicles. According to this analysis, once this level of FCEV and station deployment is reached, there will be a self-sustaining (no subsidy needed) economic case for building larger stations, assuming the market for FCEVs continues to grow.

3.16. The Hydrogen Driving Experience

Fuel cell vehicles offer performance, range, and refill time similar to conventional gasoline vehicles, yet drivers also benefit from the quiet operation, zero tailpipe emissions, and power characteristics of battery electric vehicles. FCEV acceleration is generally adequate (from 9 to 12 seconds for 0-60 times among first generation vehicles), and they cruise readily at highway speeds. Their MPG equivalent
(MPGe) is approximately 50 to 70+ MPGe for a standard sedan. For example, the four-door Toyota Mirai sedan was recently EPA rated at 67MPGe, while the compact SUV Hyundai Tuscan has been rated at 50 MPGe. The more comprehensive measure of “well to wheels” energy efficiency is based on energy inputs across the entire fuel chain (from production, distribution, to end use) and depends on a variety of factors related to hydrogen feedstocks and production methods. The driving range of FCEVs is also similar to combustion vehicles, 230-400 miles is typical depending upon the vehicle’s tank capacity. On the interior, FCEVs are comparable to similarly sized EVs or ICEs. The controls are all familiar, although the dashboard gauge displays kilowatts instead of RPMs. Like EVs, the operation of FCEVs is noticeably quieter than many ICEs.

**Off-board Power Options:** Some FCEVs will provide outboard power for appliances or potentially to power an entire home for a limited time period. The Toyota Mirai has an optional “power takeoff” DC outlet that allows the owner to draw power off of the fuel cell via an adapter module. On a full charge, the car provides up to 60 kWh to a home in case of a grid outage, which can potentially provide up to six days’ worth of energy for a typical California residence.

**Safety:** Automakers and federal agencies have conducted extensive safety testing at the component, system and vehicle level. FCEVs have several safety systems designed for hydrogen and electric drive to protect passengers and first responders in case of an accident. FCEVs have been in real-world accidents and all performed as designed with safety rating equivalent to ICE vehicles. There have been no known catastrophic failures of hydrogen fueling equipment for vehicles.

**Basic Operation of a Fuel Cell Vehicle:** The California Fuel Cell Partnership has provided the following description of a typical FCEV operation, which utilizes a proton exchange membrane (PEM) fuel cell.

*Fuel cells create electricity from reactants stored externally. A proton exchange membrane (PEM) fuel cell uses hydrogen and oxygen as the reactants. In its simplest form, a PEM fuel cell is two electrodes— the anode and the cathode—separated by a catalyst-coated membrane. Hydrogen from the vehicle’s storage tank enters one side of the fuel cell stack and air on the other side. The hydrogen is naturally attracted to the oxygen in the air. As the hydrogen molecule moves through the stack to get to the oxygen, the catalyst forces the hydrogen to separate into electron and proton. The proton moves through the membrane and the electron moves to the anode. The electricity flows into a power module, which distributes electricity to the electric motor that turns the wheels of the car. The power module also distributes electricity to the air conditioning, sound system and other on-board devices. At the cathode, the electron recombines with the proton, and the hydrogen joins with the oxygen to create the vehicle’s only tailpipe emission—water. Fuel cells produce electricity as long as fuel is supplied. Credit: California Fuel Cell Partnership:*  
http://www.fuelcellpartnership.org/carsandbuses/howitworks

The following diagram describes the workings of the various key components of a Fuel Cell Vehicle.
3.17. Fuel Cell Vehicle Gallery

FCEVs are currently available in sizes ranging from compact to intermediate to SUV and transit buses. Several of the leading models are pictured below.
First Generation Fuel Cell Vehicles Available in California

Honda FCX Clarity
Mercedes-Benz B-Class F-CELL
Toyota Mirai (FCEV)
Hyundai Tucson Fuel Cell
AC FCEV Transit buses
SunLine Transit buses

3.18. FCEV Performance Relative to Electric Vehicles

From a technical standpoint, Fuel Cell Vehicles are considered to be a form of Electric Drive vehicle (and thus are often referred to as FCEVs or Fuel Cell Electric Vehicles.) However, consumers are likely to view FCEVs in their own category, given their unique performance characteristics (fast fill-up, limited fueling infrastructure, highly differentiated technology.) Thus, a key issue for consumer adoption is how consumer perspectives on FCEVs will compare to both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs.) EVs clearly have a head start in consumer awareness, cost competitiveness, and infrastructure deployment. The following table compares the attributes of these vehicle types from a consumer perspective.
Comparison of Key Consumer Attributes of Fuel Cells and Plug-in Vehicles

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen Fuel Cell Vehicles</th>
<th>Plug-in Hybrid and Battery Electric Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refueling time</td>
<td>Shorter (3-5 minutes)</td>
<td>Longer (20 min to many hours), PHEV can refuel gasoline quickly</td>
</tr>
<tr>
<td>Vehicle sizes</td>
<td>Small to large vehicles</td>
<td>Small to midsize vehicles</td>
</tr>
<tr>
<td>Vehicle range</td>
<td>300+ miles per refill</td>
<td>10-200 miles all electric range</td>
</tr>
<tr>
<td>Refueling paradigm</td>
<td>H2 stations similar to gas stations</td>
<td>Chargers (home and public)</td>
</tr>
<tr>
<td>Fuel cost per mile</td>
<td>$0.13/mile at $8/kg H2</td>
<td>$0.04/mile at $0.12/kWh</td>
</tr>
<tr>
<td></td>
<td>$0.08/mile at $5/kg H2</td>
<td></td>
</tr>
</tbody>
</table>

Given the current market position of electric vehicles, under which circumstances might a consumer choose an FCEV relative to a BEV? Given current battery costs, BEVs may be best suited for smaller commuter vehicles with localized driving patterns that fit within the vehicle’s range, especially in a multi-car household. As more diverse FCEV models are introduced, these could be particularly advantageous for drivers needing larger cars, light trucks, and SUVs, whose driving range is greater, and for whom fast refueling is critical. FCEVs might also appeal to those who cannot charge an electric vehicle at home.

As noted in the UC Davis study, FCEV sales are dependent on these diverse market factors and market actors:

- **Vehicle costs** – purchase prices, fuel prices, and incentives (set by automakers, fuel providers, and government)
- **Consumer utility and convenience** – vehicle characteristics, performance, range and availability of refueling locations (determined by automakers and fuel providers)
- **Infrastructure availability** – expansion of hydrogen station deployment to additional regions (supported by automakers, fuel providers, and government)
- **Technology & environmental factors** – future FCEV technology, performance vs. other vehicle types, and environmental benefits (automakers and government.)

### 3.19. Future Fuel Cell Vehicle Product Diversity and Availability

Light duty fuel cell vehicles are becoming commercially available in 2015-16. FCEVs will grow in product diversity and decline in costs in the period through 2020 as more manufacturers bring vehicles to market, in part to fulfill the Zero Emissions Vehicle (ZEV) mandates of CARB, which provide significant additional “compliance vehicle” credits for FCEVs relative to Plug-in Electric Hybrid and Battery Electric Vehicles. While it is difficult to accurately predict specific manufacturer introductions, it is expected that Toyota, Hyundai, and Honda will all be putting vehicles into the market in the next two years. Toyota is expected to have its Murai in eight dealerships statewide (including Santa Barbara) by late 2015. Hyundai is providing a small number of vehicles into Southern California dealerships late in 2015, while Honda plans to
release an FCEV in Japan in March 2016 and in America later that year. Mercedes is operating a limited pilot program in 2015-16 with their B-Class FCEV. BMW and Audi have demonstrated FCEVs and plan to enter the market in future years, with BMW announcing plans for commercializing their FCEV after 2020. A total of eight automakers have announced plans for FCEVs, including Toyota, Hyundai, Honda, BMW, Daimler, Ford, GM, and VW Group.

Introductory FCEV Pricing: Initially, most FCEVs are being leased rather than sold. A typical scenario is the new Hyundai Tuscan, which is currently being offered via a three-year closed end lease at $499/month after a $4,000 signing deposit (including incentives). The Toyota Mirai is priced at nearly identical levels. Both include free fueling for three years. The purchase pricing for the Mirai has been set at $58,325; before incentives. However, Toyota projects that about 90% of Mirai customers will choose the $499-per-month lease with approximately $3700 due at signing as of mid-2015. The current Mirai package deal includes roadside assistance, three years of vehicle maintenance, eight years or 100,000 miles of warranty coverage for fuel-cell components, as well as the complimentary fuel for three years. Still unanswered are questions regarding longer-term maintenance and replacement costs for the fuel-cell powertrain and supporting hardware, and how much hydrogen will cost in future years.

FCEV Technology and Cost Outlook: Hydrogen fuel cell vehicles have already met the 2015 performance goals set by the U.S. Department of Energy (DOE) for fuel economy and range (see the table below). However, further development is ongoing to reduce costs and enhance performance and durability on key component technologies such as the core proton exchange membrane (PEM) fuel cell technology, hydrogen storage on vehicles, and technologies for renewable and low-carbon hydrogen production. Given the pace of previous advances in H2 technologies, it is anticipated that FCEVs will meet the additional DOE goals outlined below, and significantly enhance the performance of FCEV products.

### Department of Energy Performance Goals for Fuel Cell Vehicles

<table>
<thead>
<tr>
<th>Goals</th>
<th>2013 Status</th>
<th>DOE Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell In-Use Durability (hours)</td>
<td>2500 (on-road)</td>
<td>5000</td>
</tr>
<tr>
<td></td>
<td>4000 (in lab)</td>
<td></td>
</tr>
<tr>
<td>Vehicle range (miles/tank)</td>
<td>280-400</td>
<td>300</td>
</tr>
<tr>
<td>Fuel Economy (miles/kg H2)</td>
<td>72</td>
<td>60</td>
</tr>
<tr>
<td>Fuel Cell Efficiency</td>
<td>53-58%</td>
<td>60%</td>
</tr>
<tr>
<td>Fuel Cell System Cost2 ($/kW) in large scale mass production</td>
<td>$55</td>
<td>$40 (2020 goal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$30 (long term goal)</td>
</tr>
<tr>
<td>H2 Storage Cost ($/kWh)</td>
<td>$15-23</td>
<td>$10-$15 (NRC 2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2-$4 (USDOE)</td>
</tr>
</tbody>
</table>


The projected mass-produced cost of FCEV fuel cell systems has dropped more than 50% since 2006. However, the actual costs to manufacture FCEVs in the early years of deployment are likely to continue exceeding the selling price, depending on internal accounting for the costs of development and
production ramp-up. This is typical for many new vehicle technologies, including conventional hybrids and EVs. However, manufacturers have made an effort to price FCEVs within range of an equivalent conventional vehicle after incentives, and these pricing policies are likely to continue while mass market volumes ramp up.

Most studies project that future mass-produced fuel cell cars will be somewhat more expensive than an advanced gasoline car (reflecting the light-weighting and other strategies that OEMs must pursue to meet federal fuel mileage standards). For example, in a 2008 National Academies study, mass-produced, mature technology FCEVs were estimated to have a retail price equivalent (RPE) $3,600 to $6,000 higher than a comparable gasoline internal combustion engine vehicle. (Retail Price Equivalent reflects actual production costs, whereas showroom pricing may vary if manufacturers choose to subsidize the price to build market awareness and volume for a new technology.) Similar numbers were estimated by MIT, UC Davis, the National Renewable Energy Laboratory, Argonne National Laboratory, and the Electric Power Research Institute.

3.20. Future Pricing of FCEVs vs. EVs and Conventional Vehicles

Of course, FCEVs and EVs are not the only advanced vehicles that will be in the market in coming years. Conventional gasoline-powered vehicles will also be incorporating higher-cost new technologies to meet stringent mileage and emissions standards. Plug-in hybrid technologies will proliferate across all model lines. Among others, VW and BMW have indicated that PHEVs will likely be offered across all model types, and most other automakers will be forced in this direction to comply with U.S. and European fuel economy and environmental regulations.

In 2013, a new National Research Council report provided updated estimates for future vehicles that will incorporate advanced light-weighting and efficiency strategies. The reference gasoline car achieves a fuel economy of about 50 mpg by 2030 and 75 mpg by 2050, albeit at higher cost than today's vehicles. As a consequence of these trends, in the 2030 – 2045 timeframe, both fuel cell and battery vehicles are projected to have lower retail prices than these advanced gasoline vehicles. This finding underscores the importance of building adequate infrastructure for both EVs and FCEVs.

The table below illustrates projected pricing for battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs) and hydrogen fuel cell vehicles (FCEVs) between 2010 and 2030, as compared to a highly efficient gasoline internal combustion engine vehicle (NRC 2013). A “base case” projection shows cost parity in 2045, while the more optimistic projection suggests 2030 for all three vehicle types. However, this study was criticized by many EV advocates and independent analysts as exhibiting an overly optimistic assessment of future FCEV pricing and an overly pessimistic assessment of EV pricing and performance. As of 2015, the NRC model is showing some of these alleged flaws -- insofar as the NRC projected a 100 mile BEV in 2015 would be priced almost $10K higher than FCEVs, whereas actual pricing in 2015 is in the mid $30K range for 100 mile BEVs vs. the mid $50K range for equivalent FCEVs. Likewise, in the NRC projection, PHEVs were expected to be at price parity with FCEVs in 2015, whereas in fact a Chevy Volt PHEV is ~$20K less than a comparable FCEV. That said, the NRC report gives insight into the strongly pro-hydrogen orientation of many federal and state policy makers.
Retail Price Equivalent Projections for FCEVs, EVs, PHEVs, and Gasoline Cars: 2010-2030

Assumptions: All cars will be at mass production levels. The BEV is assumed to have a 100 mile range. The PHEV is assumed to have a 30 mile all electric range.


Given the novelty of FCEV technology, and the nascent state of fueling infrastructure, California sales estimates have been low for the 2015-2020 period, and difficult to assess thereafter. For example, Toyota expects only about 200 early adopters in the first year of sales (2015-2016), ramping up to approximately 3000 total on the roads by the end of 2017. While a variety of automakers have announced that they will be ready to produce thousands or even tens of thousands of vehicles beginning over the next few years if demand warrants, none have publicly projected how many cars will produced or where they will be deployed.

One of the most recent public estimates for regional FCEV introduction was developed based on a 2014 OEM survey conducted by the California Air Resources Board (see table below). The Air Board distributed mandatory surveys to 16 auto manufacturers requesting information on planned deployment of FCEVs in the five geographic “clusters” used by CARB and CEC to plan FCEV infrastructure. As noted earlier, these clusters include the San Francisco Bay Area, Sacramento Area, Los Angeles/Orange County/Ventura, San Diego, and “Other” (encompassing the rest of California). Auto OEMs forecast a rapid acceleration in the number of vehicles coming to California beginning in 2015 and sustaining growth at least to 2020 (the last year included in the survey). According to the OEMs, by 2017 the state’s fleet is expected to grow to more than 6,600 vehicles and, by 2020, to nearly 18,500 vehicles. For the Central Coast and South Orange County areas, the vehicle projections are approximately 1,000 FCEVs in 2017, and ~3,000 by 2020. Given the lack of announced H2 stations or dealerships planning to carry FCEVs in the Monterey Bay area in 2015-2016, it is likely that FCEV registrations in the region will be in the low hundreds at most by 2017. Of course, this estimate could be revised upward if a regional H2 station were to be established and local dealers were to begin carrying FCEV models.
Current and Projected Cumulative FCEV Deployment in California

![Bar chart showing FCEV deployment in California from 2013/2014 to 2020.]


Because there is very little sales history for FCEVs, estimates of future sales in general, and sales beyond 2020 in particular, are exceedingly difficult to project. Many of the goals set forth by both manufacturers and policy makers may be considered aspirational. For example, the California Zero Emission Vehicle (ZEV) regulation initially suggested that 50,000 FCEVs may be on California roads by 2017-8. Given the slow deployment of fueling infrastructure, this is likely to prove highly optimistic. That said, the CARB ZEV credit system will help sustain the ongoing production of at least at trickle of “compliance car” FCEVs in the face of potentially persistent low demand – as these credits provide manufacturers with a substantial economic incentive for manufacturing H2 vehicles. Additionally, it is expected that CARB will continue to provide consumers with a larger incremental state rebate for H2 vehicles ($5000 for FCEVs vs. $2500 for EVs) to further incentivize sales through the 2023 period authorized by Assembly Bill 8.

### 3.22. Nationwide FCEV Sales Projections

At the national level, the National Research Council data on price parity for FCEVs in turn informed a UC Davis Institute of Transportation Studies scenario illustrated below, which shows modest penetration by 2020, and a substantial uptake -- to approximately 300,000 new car sales per year nationally by 2030 vs. 700,000/year for Electric Vehicles, including both BEVs (indicated as EVs below) and PHEVs.

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8 The California Vehicle Rebate Program (CVRP) process is essentially the same for both EVs and FCEVs, and is administered by the Center for Sustainable Energy on behalf of the state. The rebate application of the Honda Clarity (one of the initial FCEVs for sale in California) is shown on this site: [https://energycenter.org/clean-vehicle-rebate-project/requirements/919](https://energycenter.org/clean-vehicle-rebate-project/requirements/919)
Projected National FCEV vs. Electric Vehicle Annual Sales (2010 – 2030)

New Car Sales are in 1000s Per Year

Source: UC Davis Institute for Transportation Studies - (Ogden, Fulton and Sperling, 2014), p. 15.

For both EVs and FCEVs, many analysts look at the conventional hybrid vehicle market as an illustrative case for new vehicle technology adoption. In the case of regular hybrids (technically known as Hybrid Electric Vehicles or HEVs), annual sales grew very slowly in the early years, reaching the 500,000/year threshold after 14 years. In the case of EVs (counting BEVs plus PHEVs), it is likely that at current adoption rate growth, EVs will likely achieve this level in just ten years or less. Given the many variables in FCEV adoption, the federal DOE has also produced a variety of different scenarios for FCEVs in the 2015 – 2025 period. Two out of the three scenarios show a gradually progressive upslope after 2017, toward 500,000 by 2020 and 700,000 by 2025. The final more aspirational scenario, suggesting 2.5M in annual sales by 2025, would likely require significant price reductions, large-scale infrastructure roll-out, new incentives, and potentially a significant increase in gasoline prices to enhance the relative economies of hydrogen operation.

Alternative Scenarios for National FCEV Sales Growth (U.S. Department of Energy)

Source: Greene, Leiby and Bowman 2007, as shown in NRC 2008, cited in UC Davis Institute for Transportation Studies - (Ogden, Fulton and Sperling, 2014), p. 21.

Implications of FCEV Sales Projections for Regional FCEV Readiness and Market Development:
As with the introduction of any new technology, consumer acceptance and future price/performance characteristics are exceedingly difficult to predict with accuracy. Despite the uncertainties involved, state policy makers have already chosen a pro-active stance in building the market for FCEVs by providing a combination of generous incentives and a significant investment in H2 station rollout. This will enable California consumers to “vote with their feet” with regard to the FCEV value proposition — and provide further signals to both automakers and policy makers regarding the outlook for further investment in the FCEV ecosystem in the 2020 – 2035 timeframe. For local policy-makers that wish to support FCEV adoption, the two most important opportunities are: 1) To work with FCEV fueling station developers and the California Fuel Cell Partnership to ensure that projected FCEV station siting proceeds without undue delays; and 2) To assess whether FCEVs can meet local fleet needs not otherwise achievable by plug-in vehicles or sustainable biofuels. One of the most promising near-term opportunities for FCEV deployment in fleets is in the public transit segment, as the first generation of hydrogen buses have been demonstrated in revenue service for several years (including at AC Transit in the Bay Area). Fuel cell buses and available incentives are described in further detail below.

### 3.23. Fuel Cell Buses and Procurement Incentives

Several companies are conducting hydrogen fuel cell bus trials. These include Daimler AG, Thor Industries (the largest maker of buses in the U.S.) based on UTC Power fuel cell technology, Toyota, Ford (based on the E-350 shuttle bus platform), and others. In California, buses are currently being operated in ongoing revenue testing and revenue service by SunLine Transit Agency in the Coachella Valley and AC Transit in Alameda and Contra Costa Counties. While capital costs are currently higher than diesel or electric, the zero tailpipe emissions, fast refueling, and flexible fuel supply chain hold promise for FCEV transit applications. Additionally, future hydrogen drayage trucks for port applications may help reduce port emissions, along with the battery electric drayage trucks now in operation.

As hydrogen fuel cell buses become available commercially, they will be eligible for the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). This program was established in 2007 as part of the California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (AB 118). AB 118 in turn created the Air Quality Improvement Program (AQIP), a voluntary incentive program administered by the Air Resources Board to fund clean vehicle and equipment projects, research, and workforce training. HVIP funding helps to buy down the high incremental cost of advanced clean vehicles while production volumes are still low. Both public and private fleets are eligible for the incentives. See the HVIP "For Fleets" page for additional details.

The HVIP offsets about half of the incremental additional cost of eligible vehicles using a purchase voucher, and thus far has enabled procurement of ~1,700 clean vehicles. The HVIP base vouchers normally range from $8,000 to $45,000 on a first-come, first-served basis for the purchase of each eligible new truck or bus. However, with the program’s additional funding, the first three vehicles purchased can receive vouchers of as much as $65,000 per vehicle. And electric transit buses currently receive a voucher of $95,000. The complete rules and conditions of the program are available in the Year 4 HVIP Implementation Manual.

The environmental characteristics of hydrogen fuels depend on the well-to-wheels carbon emissions associated with the full hydrogen fuel supply chain, including production, delivery, and refueling. As noted earlier, hydrogen is similar to electricity in that it is an energy carrier, and can be produced from diverse primary energy resources. Just as electricity on the power grid is a mix of generation sources, a number of diverse hydrogen feedstocks and production methods are represented in California’s hydrogen fuel supply chain. Therefore, to assess the environmental attributes of hydrogen fuel, it is important to consider the source, supply, and carbon intensity of hydrogen fuel stocks compared to other alternative fuel sources -- including gasoline, natural gas, electricity, and various biofuels.

In recent years, natural gas prices have been relatively low due to a glut of gas produced from shale formations through hydraulic fracturing, commonly known as fracking. Low natural gas prices have in turn helped support low hydrogen prices, and natural gas is thus considered the “feedstock to beat” in a cost-driven market for hydrogen fuels. However, natural gas fueled hydrogen production does not have significant advantages over regular gasoline from a greenhouse gas (carbon) perspective, although it will provide important local air emissions benefits (notably a significant reduction in particulate matter if it is replacing diesel trucks or buses). To address the limitations of natural gas as the principal H2 fuel feedstock -- and to encourage the integration of cleaner renewable feedstocks in the hydrogen supply chain -- the state of California has advanced these four key strategies.

1. The 33% renewable hydrogen standards: The state has mandated that 33% of hydrogen fuel be renewably produced, per Senate Bill (SB) 1505. The 33% standard is based on the energy content of the fuel and can be averaged over multiple stations within the state. The statute also requires that hydrogen fuel blends shall provide a 50% reduction of Nitrous Oxides (NOx) and Reactive Organic Gases (ROG), and a 30% reduction of greenhouse gas on a well-to-wheels basis compared with gasoline, along with zero increase in toxic air contaminants. The regulation applies to state co-funded hydrogen stations currently, and it will apply to all hydrogen stations once a volume of 3.5M kg/year is reached state-wide (equivalent to a statewide FCEV fleet of ~10,000 cars.)\(^9\) For purposes of assessing the 33% renewable standard for hydrogen production (as well as electricity) renewable fuels are defined by CARB to include:

- **Biomass**, which is any organic material not derived from fossil fuels, including agricultural crops, agricultural wastes and residues, waste pallets, crates, dunnage, manufacturing, and construction wood wastes, landscape and right-of-way tree trimmings, mill residues that result from milling lumber, rangeland maintenance residues, sludge derived from organic matter, and wood and wood waste.
- **Digester gas** - gas from the anaerobic digestion of organic wastes.
- **Geothermal**, landfill gas, municipal solid waste
- **Ocean wave**, ocean thermal, or tidal current technologies
- **Solar Photovoltaic** or solar thermal technologies
- **Small hydroelectric** (30 megawatts or less)
- **Wind energy**

2. **Renewable Portfolio standard for electricity**: The state has also mandated that electricity be produced from 33% renewable sources by 2020. Further, Governor Brown has proposed increasing the RPS to 50% by 2030. Thus, as California’s grid becomes less carbon intensive, hydrogen produced by electrolysis will become cleaner (as will EVs driven by the California grid power mix).

3. **The Low Carbon Fuel Standard** benefits lowest-carbon fuel producers with economically advantageous tradable credits. Hydrogen fuel producers are eligible to achieve LCFS credits if the hydrogen fuel meets LCFS standards for carbon content.

4. **Preferential Support of Renewable Hydrogen Fueling Infrastructure**: The state is preferentially supporting the development of renewable hydrogen projects vs. non-renewable production in an effort to increase the available supply and reduce the cost of renewable hydrogen.

Given the strategies described above, the hydrogen fuel supply chain in California will likely become lower carbon over time, although fuel costs may increase as the proportion of renewable supply increases.

3.25. **Assessing the Environmental Attributes of Hydrogen Fuels on a Life Cycle Basis**

The methodology used by the California Energy Commission to assess hydrogen fuel attributes is based on the GREET assessment model, which stands for *Greenhouse gases, Regulated Emissions, and Energy Use in Transportation*. GREET is the authoritative model developed by the Argonne National Laboratory to assess the energy and emission impacts of fuels for the full fuel cycle from well to wheels (or “seed to wheels” in the case of biofuels), as well as (via a separate but related protocol) to assess the vehicle’s use cycle from manufacturing through material recovery and vehicle disposal. **The GREET model demonstrates that the current “California mix” of hydrogen in a Fuel Cell Vehicle reduces GHG by slightly more than half compared to a current average ICE.**

As noted above, the California H2 fuel mix includes at least 33% renewable sources. However, it should be noted that this is a statewide average. In local practice, the carbon intensity of hydrogen (as well as electricity) varies by territory, season, and other factors. As illustrated in the chart below by the California Fuel Cell Partnership, the California average mix of hydrogen produces a total environmental impact of 150 grams of CO2 equivalent (CO2e) per mile (Co2e/ml) on a well-to-wheels basis. **By contrast, the well to wheels impact of gasoline is nearly 400 grams of CO2e per mile, while electricity is 100 grams of CO2e per mile,** given the California average grid mix as of 2013.

It is important to note that the carbon impact of both EVs and FCEVs powered by hydrogen produced through electrolysis will be declining significantly in time as the California grid power mix becomes lower carbon. However, the relative well-to-wheels advantage of EVs will remain due to higher efficiencies in the EV powertrain, and avoided inefficiencies resulting from producing hydrogen fuel from electricity (vs. using electricity directly via on-board battery storage and delivery to the electric motor.)
The relative environmental impact of hydrogen fuel will also be subject to future changes in both actual feedstock carbon intensity and potentially in the measurement methodologies used to assess key feedstocks. On the environmentally positive scale, the electricity used to manufacture hydrogen will steadily be reduced in carbon intensity, making some H2 feedstocks cleaner. On the environmentally negative scale, the assessment of well-to-wheels CO2e intensity of natural gas is likely to be adjusted upward (toward higher carbon intensity) based on emerging research that suggests that methane leakage in the fuel supply chain may be much higher than previously assumed (potentially in the range of 3% leakage rather than slightly above 1.3%, which was the previous EPA estimate.) These refinements in the understanding of well-to-wheels impacts of natural gas could degrade the absolute and relative rated environmental performance of both FCEVs and Natural Gas Vehicles (NGVs) vs. EVs. A comprehensive review of the issue of methane leakage in the natural gas supply chain is underway by the Environmental Protection Agency (EPA) and is expected to be completed in the 2016-17 timeframe.

3.26. The Transition to Green Hydrogen

To realize the full climate benefits of hydrogen and fuel cells, hydrogen must be produced via low carbon production pathways. However, each low-carbon pathway faces challenges. Cost is the major issue for hydrogen produced via electrolysis fueled by solar or wind energy, or biomass gasification. In theory, hydrogen produced by fossil fuels with CO2 sequestration could produce very low emissions, but decades of research have yet to produce cost-efficient methods of sequestration of coal or natural gas emissions at scale. The UC Davis Institute for Transportation Studies (Chris Yang and Joan Ogden) analyzed alternative strategies for achieving a near zero carbon H2 fuel supply system in California by 2050 and produced a scenario that envisioned future breakthroughs in carbon capture and sequestration (CCS), along with biomass derived hydrogen, and hydrogen produced with renewable electricity. Of course, the existence of cost-efficient CCS in the future must be considered speculative. The scenario without CCS demonstrates that either emissions will rise (due to continued use of fossil resources without CCS) or costs will rise due to reliance on more expensive renewables. According to the UC Davis projections illustrate below, to develop a sufficiently large, low-carbon H2 infrastructure to meet the 80% carbon reduction in the transportation sector called for under AB 32 will require a $50 billion dollar capital investment.
In the UC Davis “base case” scenario, hydrogen is made primarily from distributed Steam Methane Reformation (the most common method in use today) in the first several years of H2 station operations, through 2020. As demand grows in the 2020 to 2030 timeframe, medium-scale biomass gasification systems are also deployed. Beyond 2030, large scale fossil fuels with CCS (in this case coal) is envisioned to provide H2 at low cost and low emissions, if such technologies are available and effective. Also envisioned in 2045 to 2050 is the emergence of larger-scale distributed renewable electrolysis to ensure the 33% renewable hydrogen mandate is met. In this scenario, average H2 costs decline from over $10/kg in 2012 to $4.20/kg H2 in 2050. Average H2 carbon intensity, declines from an efficiency-adjusted value of 4350 gCO2/kgH2 to 1630 gCO2/kgH2 in 2050 – which represents an 85\% reduction from current gasoline carbon intensity on a well-to-wheels basis, taking into account higher FCEV efficiency. The UC Davis analysis suggests that the development of a low-carbon hydrogen supply pathway could become economically competitive with gasoline on a cost-per-mile basis with just 50,000 FCEVs in a region with 100 stations, at an initial capital investment of $100-200 million.

3.27. Best Practices in Local Readiness for Hydrogen Fueling Station Development

Overview of Local Readiness Roles and Activities: Auto makers, policy makers, and the general public are well aware that convenient and ubiquitous refueling is essential to the success of any new Alternative Fuel Vehicle, whether they be EVs, Fuel Cell Vehicles, Natural Gas Vehicles, or biofuel-powered. Regional agencies, counties, and municipalities have an important role to play in scaling up the AFV fueling infrastructure in general – and hydrogen stations in particular – by:
- Participating in public/private consortia to obtain grant funding for stations
- Assisting in the siting and permitting process
- Ensuring that planning, permitting, and emergency responders receive appropriate training in the many facets of the FCEV transition.

Of course, the widespread availability of FCEV stations is only part of the overall market deployment challenge. Vehicle manufacturers and consumers will ultimately determine whether adoption levels are sufficient to enable station operators to sustain and expand a retail H2 fueling infrastructure beyond the early years of state subsidy. As discussed earlier, overall station placement across the state is being guided by the collaborative efforts of the California Fuel Cell Partnership, the California Energy Commission, FCEV manufacturers, and fueling providers. The first stages of the siting process begin with the targeting of localities for stations based on the statewide market analysis. Specifically, the automakers, Fuel Cell Partnership, and the CEC have assessed the coverage needed to enable intra-regional and (ultimately) inter-regional driving between the identified early-adopter market “clusters.” This mapping process is balanced with the expected capacity utilization that will be required for each station to achieve breakeven operations. Thus, the over-arching strategy for early station deployment is to create a network that meets the needs of early adopters, while ensuring that operators are able to build a business case for selling hydrogen over the long term. This may require that market actors build fewer stations initially to support higher utilization rates and an earlier breakeven point.

Local vs. State Station Development Roles: Broadly speaking, there are two levels of approach to FCEV station development – the first is “top down” and involves pro-active outreach by state-level FCEV stakeholders to local Authorities Having Jurisdiction (AHJs). State level actors include fueling station operators, the Fuel Cell Partnership, FCEV manufacturers, the Energy Commission, and GoBiz, the state’s economic development organization now assisting with the siting process. The second approach is “bottom up” and involves potential public, private, and NGO sector allies forming local partnerships to accelerate the establishment of FCEV infrastructure in a particular city or region. Such initiatives may or may not require state grant support in the longer-term, although in the early years of market development most FCEV stations will require both state funding and matching private investment.

In the context of the Central Coast, both “top-down” and “bottom-up” processes are already in motion. As noted earlier, First Element Fuels is expected to open a station in Santa Barbara by the end of 2015, and other stations are on the 100 station “drawing board” for opening in the 2015-2020 timeframe, per the state’s ZEV Action Plan and the Fuel Cell Partnership siting strategy. To advance Central Coast hydrogen readiness and fueling infrastructure in particular, the County of Santa Barbara was awarded a planning grant from the Energy Commission, which provides resources to develop guidelines and plans to site potential hydrogen fueling stations, and to educate local planning staff and policy-makers on FCEV related issues. This planning process will extend from mid-2015 through 2017, and result in a comprehensive FCEV infrastructure plan for the region. Monterey stakeholders (such as the Monterey Bay Unified APCD or the City or County of Santa Cruz) could likewise apply for a future H2 planning grant – if there is strong interest in advancing FCEVs and related fueling infrastructure in the region.

Although much of the action in FCEV readiness occurs at the state and regional level, there are a number of critically important roles to be played by municipalities, notably in the area of FCEV station site planning, permitting, zoning, and safety. Local leaders can begin the H2 readiness process by considering these opportunities for advancing FCEV readiness, and packaging those elements that are aligned with local priorities into a municipal AFV or FCEV readiness action plan.
<table>
<thead>
<tr>
<th>Summary of Potential Local Government Actions to Support Hydrogen Readiness</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FCEV Site Identification</strong></td>
</tr>
<tr>
<td>1. <strong>Determine if your locality is in or near a designated FCEV cluster, connector route, or destination areas (see the Fuel Cell Partnership website at <a href="http://www.calfcp.org">www.calfcp.org</a> for information).</strong></td>
</tr>
<tr>
<td>2. <strong>Reach out to companies with grants for fuel station installation</strong> to coordinate on future siting, permitting, and construction issues.</td>
</tr>
<tr>
<td>3. <strong>Participate in the Monterey Bay AFV Coordinating Council</strong> to maximize local opportunities to access grant funds and expertise on FCEV deployment. (The local contact for the AFV Council is Ecology Action and the Monterey Bay Unified Air Pollution Control District, which is helping coordinate AFV activities in the region.)</td>
</tr>
<tr>
<td>4. <strong>If no sites have been identified, assess available locations</strong> by determining if any existing gasoline or natural gas station has a vacant area of at least 20 by 40 feet, which could house an FCEV installation.</td>
</tr>
<tr>
<td><strong>H2 Station Zoning</strong></td>
</tr>
<tr>
<td>5. <strong>Determine which zoning classifications, if any, should provide explicit permission for hydrogen stations,</strong> based on the current land use mix.</td>
</tr>
<tr>
<td>6. <strong>Consider including hydrogen fueling as an option for obtaining a density bonus</strong> when negotiating with developers who want to build more densely on a site than the zoning code normally allow.</td>
</tr>
<tr>
<td><strong>Hydrogen Fueling Station Permitting</strong></td>
</tr>
<tr>
<td>7. <strong>Document existing municipal permitting and inspection processes for gasoline or compressed natural gas (CNG) stations</strong> and for completing the inspection process, including contact information for key staff.</td>
</tr>
<tr>
<td>8. <strong>Create an expedited permitting process for hydrogen stations,</strong> which could include pre-permit meetings and negative CEQA declarations where feasible and appropriate.</td>
</tr>
<tr>
<td>9. <strong>Create instruction sheets to guide installers and inspectors</strong> through local requirements for hydrogen stations.</td>
</tr>
<tr>
<td>10. <strong>Provide a pre-submittal review</strong> to address issues at the proposed site that the applicant is not aware of or that were not assessed in the draft evaluation. **</td>
</tr>
<tr>
<td>11. <strong>Communicate plans to the public:</strong> Station developers and key partners (such as FCEV automakers and the California Fuel Cell Partnership) can prepare high-level presentations about FCEVs and fueling, safety, and emergency response. Plan for intensive and ongoing outreach to the public—including local elected officials, businesses, and residents.</td>
</tr>
</tbody>
</table>
12. **Participate in training on hydrogen vehicle and fueling safety, codes, and standards** -- utilizing best practice resources such as the U.S. DOE online training: *Introduction to Hydrogen for Code Officials*; resources available at H2BestPractices.org; the *Regulations, Codes and Standards Template for California Hydrogen Dispensing Stations*; and other resources at the California Fuel Cell Partnership website.

13. **Assess potential of Fuel Cell Vehicles to meet GHG reduction, air emissions, green fleet, ZEV adoption, or other sustainability goals** -- taking into account the most authoritative research on GHG and air quality impacts of hydrogen vehicles.

14. **Integrate FCEVs in local plans** addressing climate action, air quality, AFV readiness, transportation, and fleet operations.

15. **Integrate the principle of ZEV readiness in the General Plan.** At a minimum, including ZEV readiness as a high-level policy objective can be added in just one sentence in the circulation element of a General Plan — stating that the community intends to work toward ZEV readiness. See the state’s *Office of Planning and Research General Plan Guidelines Update* for more information about incorporating ZEVs into general plans, available at www.opr.ca.gov.


### 3.28. Hydrogen Station Construction and Zoning

As noted above, H2 fueling equipment is most often co-located with existing gasoline or CNG fueling stations. From a safety perspective, H2 dispensers can physically be placed under an existing fueling station canopy, but some station brands do not allow other fuels to be under the brand canopy. At some stations, H2 dispensers are on the same island as other dispensers. At other stations the H2 dispenser is on its own island either under the canopy, just outside, or on a separate section of property. Since local jurisdictions are responsible for writing or adopting their own zoning codes, rules governing the specific layout of hydrogen stations may differ from one jurisdiction to another. A typical station map featuring locally specific setbacks and layout decisions and a setback diagram are indicated below. In the single-line drawing below, the scenario illustrated is that of an integrated gasoline and hydrogen station that does not have on-site fuel production, and includes a convenience store and two “liquid fuel dispensing islands” as well as one hydrogen-only dispensing island. Note that the distances separating the hydrogen fuel storage canisters from other station elements are per National Fire Protection Association (NFPA) code.
Hydrogen Station Installation Showing Protective Bollard

Source: H2 Readiness: Best Practices for Hydrogen Stations in Early Adopter Communities, p. 11.

Hydrogen Station Elements and Typical Setbacks
3.29. Hydrogen Station Permitting and Signage

Hydrogen station development and permitting typically involves these seven stages:

1. Preliminary project scoping
2. Station design
3. Approval process
4. Station/dispenser construction
5. Station/dispenser startup (Commissioning)
6. Station/dispenser operation
7. Station/dispenser maintenance

The required permits typically address all of these stages – from project scoping and design through operations and maintenance, as noted below in this generic example.

<table>
<thead>
<tr>
<th>Range of Permits Potentially Required for Hydrogen Station Development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permit</strong></td>
</tr>
<tr>
<td>-----------</td>
</tr>
</tbody>
</table>
| **Construction** | Building Department | - Permit to Construct General/  
| | | - Address safety construction issues |
| **Drainage** | Engineering Department | - Permit to Construct Drainage/  
| | | - Modification to sewer drainage |

### Site grading
- Engineering Department
  - Permit to Construct Grading/
  - Modification to site elevation

### Electrical
- Building/Electrical Department
  - Electrical Permit
  - Modification to electrical service

### Demolition
- Building Department
  - Construction Permit/Demolish structures required for dispenser construction

### Food services
- Health Department
  - Food sales

### Air emission impacts
- Air Quality Management District
  - Air Quality Permit or No impact declaration

### Fire safety
- Fire Department Plans Review Office
  - Fire Safety Permit/General fire code compliance

## Approvals Required for Hydrogen Station Construction and Operation

<table>
<thead>
<tr>
<th>Approval</th>
<th>Agency</th>
<th>Approval Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>California Environmental Quality Act (CEQA)</td>
<td>Local Agency Having Jurisdiction (typically a city or county)</td>
<td>CEQA approval or finding of no significant impact</td>
</tr>
<tr>
<td>Zoning</td>
<td>Local zoning board</td>
<td>Zoning approval allowing construction and operation at specified location</td>
</tr>
<tr>
<td>California Accidental Release Prevention Program (CAL–ARP)</td>
<td>Local administering agency (for example county health or fire department) and U.S. EPA</td>
<td>Approved submission or finding of non-applicability -- requires an evaluation of the impact of the release of regulated materials and a plan in the event of release</td>
</tr>
</tbody>
</table>

The administrative process for reviewing and approving projects varies by jurisdiction, but a typical process involves:

- Pre-submittal review and feedback (optional but highly recommended)
- Review and feedback to applicant
- Formal submission of application
- Public meeting (on an as needed basis)
- Adjustments in the permit application (as needed) based on public input
- Review of modified application and feedback to application
- Resubmittal of modified application
- Issuance of permit
- Project construction
- Site inspection to determine that project built as shown in final design plans
- Periodic inspections to determine ongoing compliance

Of the steps above, the pre-submittal review and consultation with other jurisdictions on their permitting process are particularly important. The pre-submittal review provides an opportunity to avert potential issues that may delay the permitting process or lead to application denial, such as right-of-way issues, or other requirements the applicant had not evaluated in the draft application. Consultation with other local jurisdictions that have already permitted hydrogen stations can alert local officials to issues,
work-arounds, and document templates that can be invaluable in developing and managing an efficient and streamlined process.

**Permit Template for Hydrogen Dispenser Added to an Existing Fueling Station**

*Source: H2 Readiness: Best Practices for Hydrogen Stations in Early Adopter Communities, p. 43.*

For this template a single dispenser is added to an existing fueling station. In all California jurisdictions, the California Fire Code is the enforced fire code. The addition of a single dispenser will trigger construction requirements. The dispenser will require at least the following elements:

- A dispensing platform
- Vehicle crash protection
- Electrical service
- Hydrogen storage or generation equipment or both for dispenser that has hydrogen generating and storage capability
- Lighting
- Compressors to compress the hydrogen to vehicle storage pressure
- Dispenser with fueling hose and nozzle
- Piping from the gaseous hydrogen storage system to the dispenser
- Fire protection system
- Maintenance system
- Unique construction requirements such as handicapped parking requirements

**Additional permit templates** are available at [www.nrel.gov/docs/fy13osti/56223.pdf](http://www.nrel.gov/docs/fy13osti/56223.pdf)

**Sample Permit**

*Jurisdiction of ____________________, California*

Building/ Fire Permit For Hydrogen Dispensing Installation

**Section 1: Basic Identifying Information**

Compliance with the following permit will allow the construction and operation of a hydrogen dispensing installation in the ________ jurisdiction. This permit addresses the following situations:

- The addition of a hydrogen dispensing and storage system to an existing fueling station
- Other station elements TBD

This permit contains a general reference to the California Fire and Building Codes or equivalent codes used in the jurisdiction. All work and installed equipment will comply with the requirements of XXXX code used in the jurisdiction. The jurisdiction maintains the authority/responsibility to conduct any inspections deemed necessary to protect public safety.
Section 2: Code Requirements

[This section identifies code requirements (see listing below of specific relevant fire/safety codes) and addresses specific elements of station safety:
  ▪ Approval/listing and labeling requirements
  ▪ Piping code compliance
  ▪ Storage vessel stamps/approval]

<table>
<thead>
<tr>
<th>Issue</th>
<th>Sample Permit Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siting</td>
<td>Do storage and dispenser systems meet separation distance requirements?</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Is equipment listed or approved? Valves, Pressure Relief Devices (PRDs), Piping, Containers, Hoses, Nozzles</td>
</tr>
<tr>
<td>Electrical</td>
<td>Is equipment proximate to dispenser classified?</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Have maintenance requirements been defined in the permit application? Is documentation required?</td>
</tr>
<tr>
<td>Emergency response</td>
<td>Are E-stops accessible? Do they have a plan? Are personnel trained? Is communication with the fire department and other emergency responders clearly defined?</td>
</tr>
<tr>
<td>Sensors</td>
<td>Do sensors detect releases or upset conditions? Is the information from sensors conveyed to the process equipment, operators, and fire department?</td>
</tr>
</tbody>
</table>

Section 3: Standard Certification Statement

By signing the certification statement the applicant agrees to comply with the standard permit conditions and other applicable requirements. This consent would give the jurisdiction the option of allowing the applicant to proceed with installation and operation of the dispensing equipment.

Example

I hereby certify that the electrical work described on this permit application shall be/ has been installed in compliance with the conditions in this permit, NFPA 70, National Electric Code, and the Fire Code currently adopted and enforced within the jurisdiction of installation. By agreeing to the above requirements, the licensee or owner shall be permitted to construct and operate the hydrogen station.

Signature of Owner ________________________________ Date __________________

Section 4: Jurisdiction Checklist

Below is a sample checklist the jurisdiction could develop to track key information on the application. A few of the many items that could be tracked include:

1. Unique requirements in the jurisdiction such as seismic requirements
2. Summary of California Risk Management Plan (RMP) analysis if subject to RMP
3. Summary of California Environmental Quality Act Compliance (CEQA) analysis
Section 5: Schematic (optional)
A schematic drawing should show the arrangement of the equipment in conformance with relevant Fire Code and other codes and standards (see below).

**Relevant California Fire Code Citations** (2012 edition) are available at [http://cafcp.org/sites/files/H2-Best-Practices_Final-Single-Page.pdf](http://cafcp.org/sites/files/H2-Best-Practices_Final-Single-Page.pdf), pp. 44-48. The relevant citations (using the International Fire Code numbering system) include: General Requirements (2309.3.1.1.), Dispensing platform (2309.4.1.), Vehicle crash protection and fueling area (2309.5.1.), Electrical Service (2309.2.3.), Lighting (must meet NEC requirements), Hydrogen storage or generation equipment or both for dispenser that has H2 generating and storage capability (2309.2.0 – 2309.2.3 and 2309.3.1.3 – 2309.3.1.4), Compressors to compress the hydrogen to vehicle storage pressure (2309.2.0 – 2309..2.2.), Dispenser with fueling hose nozzle (2309.2.1 – 2309.2.2), Piping from the gaseous hydrogen storage system (shall be in accord with ASME B31.12 hydrogen pipelines and piping), and Sections 704.1.2 through 704.1.2.5.1, Chapter 27 of the International Fire Code and ASME B31.3), Fire protection system (2309.3.1.5.2. and 2309.3.1.5.3. and 2309.3.1.5.4. addressing emergency discharge and shutdown control), Maintenance system (2309.3.1.2.1.), Ignition control (2309.3.1.2.2 – 2309.3.1.2.4., Emergency shutoff (2309.5.0 – 2309.5.3.1.) Unique construction requirements – Canopy tops (2309.3.1.5.1.- 2309.3.1.5.5, Chapters 53 and 58 and the International Fuel Gas Code), Construction of canopies (2309.3.1.5.1.), Signage (2309.3.1.5.5), Canopy separation (2309.3.2.)

**Hydrogen Fueling Stations and the California Environmental Quality Act:** The California Environmental Quality Act (CEQA) applies to projects undertaken by state and local agencies or a private entity for which some discretionary approval is required. Installing a hydrogen station generally fits the definition of a project under CEQA. Local governments have taken a range of actions under CEQA to install hydrogen fueling stations, including filing categorical exemption or preparing a negative declaration. According to the Governor’s Office of Planning and Research, most of the recently built hydrogen stations have used categorical exemptions. Commonly filed exemptions for hydrogen stations are:

- 15301 (Class 1) for Existing Facilities
- 15303 (Class 3) for Small Structures

It is recommended that agencies enforcing the CEQA statue refer to exemptions granted by other authorities having jurisdiction. An up-to-date map of currently opened hydrogen fueling stations is available at [www.cfcp.org](http://www.cfcp.org) to determine which localities have issued permits and filed CEQA documentation.

**Hydrogen Fueling Station Signage:** As in the case of Electric Vehicles, signage is an important “force multiplier” to drive enhanced consumer awareness and confidence in the availability of fueling stations. Accordingly, local authorities and station operators are strongly encouraged to deploy signage in the most expansive way feasible in the early stages of commercial station deployment. Signs should conform to the Caltrans standards for ZEV signage, including the FCEV sign protocol which was issued in its Traffic Operations Policy Directive 13-01 released in March 2013 ([www.dot.ca.gov/hq/traffops/signsht/signdel/policy/13-01.pdf](http://www.dot.ca.gov/hq/traffops/signsht/signdel/policy/13-01.pdf)). The directive incorporates new ZEV-related signs and pavement markings into the California Manual on Uniform Traffic Control Devices (MUTCD). State law and federal regulations require signs, markings and signals placed on California’s public roads to comply with the requirements of the MUTCD. Also, signs installed on private roadways and parking must be consistent with the MUTCD to be legally enforceable. Specifically, the MUTCD defines the
allowable hydrogen sign illustrated below and indicates (in Section 21.03 of the General Service Signs for Expressways and Freeways, Paragraph 41, Subpart 13) it states: “Where hydrogen (HYD) fuel is available, the Hydrogen (G66-22G(CA)) symbol sign and Hydrogen (G66-22H(CA)) supplemental plaque may be used within 3 miles of a State highway and be available to the public at least 16 hours a day, in addition to the other appropriate signs.”

In addition, Guidance 34 indicates that “To avoid misleading the road user, those services that are more than 0.5 mile from the access point on the major route to the service, should have a Distance with Arrow (G66-21A(CA)) plaque installed below the service sign.” Given the importance of signage to raise consumer awareness, local authorities could consider placing hydrogen station signs on all major public thoroughfares in a substantial radius of the facility and on nearby freeways (with Caltrans concurrence). The cost of such installations could potentially be provided in whole or in part by the station developers and relevant funding agencies.

**The California Approved Hydrogen Fueling Sign**

![Hydrogen Fueling Sign](image)

**Fueling Technology Codes, Standards, and Certification:** A variety of organizations have developed codes and standards that address H2 distribution, storage, and dispensing. These include the National Fire Protection Association (www.nfpa.org), and the International Code Council (www.iccsafe.org). Nationally recognized testing laboratories are also beginning to publish design and performance standards for hydrogen station components. However, these are emerging only gradually during the early commercialization stage of FCEVs. For the latest information, local officials are encouraged to consult the National Renewable Energy Laboratory website, which provides continuously updated information about evolving codes and standards that can assist in H2 station design, construction, and regulatory approval. See [www.nrel.gov](http://www.nrel.gov) for the most up-to-date information.
3.30. Hydrogen Safety and Training for First Responders

Hydrogen has been produced in significant quantities for many decades – for use in oil refineries, as an industrial chemical, and for a variety of transportation applications from forklifts to space rockets. Consequently, methods to safely produce, store, transport and use hydrogen have been well developed – such that hydrogen is generally considered to be no more or less dangerous than other flammable fuels. Like gasoline and natural gas, hydrogen is flammable and can behave dangerously under specific conditions, but some of its properties provide safety benefits compared to liquid fuels such as gasoline. Because hydrogen is a lighter-than-air gas that diffuses quickly, it is difficult to concentrate the fuel enough to make it catch fire, let alone explode. To further reduce the chance of accidents, hydrogen stations are mandated to implement the following safety systems:

- **If required flame detectors or gas sensors detect a fire or leak, safety measures turn on automatically**, such as sealing the storage tanks, stopping hydrogen flow or—in the case of an extreme fire—safely venting the hydrogen.
- **Strategically placed emergency stops will manually shut down hydrogen equipment.**
- **Retaining walls, equipment setbacks and bolsters** are designed into the site plan to maximize safety.
- **Above ground fuel storage is required** for ease of inspection and maintenance. (Note that codes and standards organizations are looking at below-ground storage, but this change is not likely for some years).

**Other Safety-Related Attributes of Hydrogen:** Hydrogen also has a variety of natural properties that provide some relative safety benefits in comparison to gasoline or natural gas.

- **Hydrogen flames have low radiant heat:** When hydrogen does ignite, it burns with an invisible or near-invisible flame and produces heat and water. Because a hydrogen fire radiates significantly less heat compared to a hydrocarbon fire, the flame is more easily contained and the risk of secondary fires is usually lower.
- **The energy required to ignite hydrogen (0.02 megajoule) is low compared to gasoline and natural gas.** Further, it is more difficult to reach a combustible mix of hydrogen and oxygen in the air than with other fuels.
- **Hydrogen is non-toxic and non-poisonous:** It will not contaminate groundwater, because it is a gas under normal atmospheric conditions, nor will a release of hydrogen directly contribute to atmospheric pollution. Hydrogen does not create harmful fumes, and does not have the drips and spills associated with liquid fuels.
- **Hydrogen has a low risk of asphyxiation:** While any gas can cause asphyxiation hydrogen’s buoyancy and diffusivity make it unlikely to be confined where asphyxiation might occur.

To minimize risks associated with hydrogen fuel, it is critical that first responders gain training in the unique challenges associated with both FCEVs and hydrogen fueling stations. Rather than summarize key elements of the training, which could result in a limited understanding of risks and mitigation strategies, we recommend that emergency responders consult *The Emergency Response Guide to Alternative Fuel Vehicles*, available at: [http://osfm.fire.ca.gov/training/pdf/alternativefuelvehicles/Altfuelintroduction.pdf](http://osfm.fire.ca.gov/training/pdf/alternativefuelvehicles/Altfuelintroduction.pdf)
This comprehensive manual prepares emergency medical, law enforcement, and fire service personnel for an emergency response involving FCEVs and the full spectrum of alternative fuel vehicles. Other hydrogen-specific resources are listed below:

- **California Fire Code Text**: [www.osfm.fire.ca.gov](http://www.osfm.fire.ca.gov/)
- **California Risk Management Plan regulations**: [www.calarp.com/CalARP%20Regs.pdf](http://www.calarp.com/CalARP%20Regs.pdf)
- **Governor’s ZEV Executive Order**: [gov.ca.gov/news.php?id=17472](http://gov.ca.gov/news.php?id=17472)
- **ZEV Guidebook**: [www.opr.ca.gov/docs/ZEV_Guidebook.pdf](http://www.opr.ca.gov/docs/ZEV_Guidebook.pdf)

### 3.31. Recommended Regional and Local Actions to Support Hydrogen Vehicle Readiness

Hydrogen fuel vehicles have overcome significant technical and economic obstacles to provide a potentially viable alternative fuel and vehicle choice for California consumers and fleet operators. To fully develop the potential of the hydrogen vehicle ecosystem, however, auto manufacturers, fuel producers, and state policy makers must achieve these challenge goals:

1. **Product manufacturing costs and retail pricing must achieve parity** with both ICEs and other EVs
2. **Fueling infrastructure must become ubiquitous**
3. **The hydrogen fuel supply chain must continuously improve its “well-to-wheels” emissions while remaining economically competitive** with gasoline -- by developing cost-efficient renewable and low-carbon feedstocks and production methods at scale
4. **The FCEV product range must diversify** to fully leverage hydrogen’s refueling advantages over EVs – notably in the medium and heavy-duty segments
5. **State policy-makers must maintain support for both vehicle incentives and fueling infrastructure** to bridge the “chasm of death” between early adopter and mass markets.

While these challenges are significant, the California Governor’s Office, the California Air Resources Board, the California Energy Commission, and their supporters in the state legislature have reaffirmed their steadfast support of the hydrogen vehicle market for nearly two decades – most recently reaffirmed by the passage of AB 8 and the commitment to build out the initial 100+ hydrogen fueling station network over the 2015 - 2023 period. Further, there are a host of technological advances in both fuel cell vehicles and fueling infrastructure that promise to lower costs and improve the environmental attributes of hydrogen over time. While the energy efficiency of EVs (and thus the potential well-to-wheel emissions profile) will always be superior to hydrogen (even accounting for 100% renewable energy inputs for both vehicle types), there is a legitimate policy case for continued public development and support of the hydrogen vehicle infrastructure and ecosystem, especially given its advantage in fueling convenience – and its potential for replacing diesel powered heavy-duty trucks and transit buses.

As of 2015-16, California has begun establishing the necessary “virtuous circle” of policies and programs to enable a viable Fuel Cell Vehicle market – including both vehicle incentives and fueling infrastructure investments and operating subsidies. California’s station funding program is establishing the necessary “cluster” and “corridor” fueling network to provide assurance to drivers and automakers that they will
be able to refuel FCEVs as they travel within and between major population centers throughout the state. Soon, auto manufacturers must respond in kind by committing to increased development and promotion of FCEV models so that station builders will reach breakeven operations and a sustainable ROI for their stations.

As in the case of the Electric Vehicle ecosystem, the most important role of local governments, regional agencies, public and private fleet operators, and relevant NGOs, are:

1. **To pro-actively assist interested fueling station developers** to move expeditiously through the planning, permitting, and construction process
2. **To participate in training on FCEV infrastructure and vehicles** from a station planning, fleet operations, and safety/emergency response perspective
3. **To partner with the Monterey Bay AFV Coordinating Council and other agencies to access available funds** for fueling stations, vehicle incentives, and H2 related planning, outreach and education.

**H2 Readiness Tasks Currently Underway at the Regional Level:** Some key hydrogen infrastructure development tasks are underway at a regional level on the Central Coast, but not yet in the Monterey Bay area (beyond the current high-level AFV readiness planning activities). Most importantly, as noted above, a comprehensive hydrogen plan for the tri-County Central Coast is being developed under the auspices of the County of Santa Barbara Planning Department, which will go into much more depth on specific fuel station siting issues than is possible in a higher-level AFV Readiness Plan that spans multiple fuel types. Through that intensive planning process, additional training of local stakeholders in code and permit issues will also be addressed. In addition, the broader AFV Readiness initiative in the Monterey Bay, of which this AFV Readiness Plan itself is just one component part, will be actively building stakeholder awareness and knowledge across the AFV spectrum, including the hydrogen Fuel Cell Vehicle ecosystem. The key tasks that are central to both FCEV readiness and the broader AFV work include the development of pro-active consumer and fleet outreach via local sponsorship of multiple Green Car Shows (Recommendation 3.1), and AFV Training seminars (Recommendation 3.2.) described further in the chart of Recommended Actions below. Additional recommendations for local government action (not yet underway in most Monterey Bay jurisdictions) are indicated below.

**H2 Readiness Tasks Recommended for Local Government Action:** In addition to the regional actions noted above, recommended local government FCEV readiness activities involve three domains:

- **Assessment and potential integration of FCEVs into public fleets** (Recommendations 2.1. - 2.2)
- **Integration of FCEVs and fueling infrastructure into General Plans, Climate Action Plans, and other sustainability-related plans** (Recommendation 2.6.1)
- **Assessment of local hydrogen fueling infrastructure needs & siting options** (Recommendation 2.6.2) as appropriate relative to the California Fuel Cell Partnership map of planned station locations;
- **Participation in available training on hydrogen fuel vehicle and infrastructure planning and safety issues** (Recommendation 2.6.3).
### Recommended Regional and Local Actions to Support Hydrogen Vehicle Readiness

<table>
<thead>
<tr>
<th>LOCAL ACTION</th>
<th>2.1. AFV Fleet Procurement Policies and Planning</th>
<th>2.2. AFV Fleet Management</th>
<th>2.6. Fuel Cell Vehicles and Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.1. Develop goals for public fleets to be powered by the most sustainable alternative fuels,</strong> taking into account CO2e (grams per mile or per megajoule of energy) and air quality impacts, economy of operation on a life-cycle basis, and operational requirements. Include specific targets and timelines for penetration of AFVs meeting sustainability benchmarks.</td>
<td><strong>2.2.1. Create a Green Fleet Spreadsheet</strong> for the 2015-2020+ period that lists the actions, AFV investments, fuel and operating cost savings anticipated for each of the years of the plan -- including vehicle and fueling infrastructure costs, efficiency improvements, fuel price projections, etc. (Note that CalStart has relevant assumptions to populate this spreadsheet, along with online resources referenced in the Monterey Bay AFV Readiness Plan)</td>
<td><strong>2.6.1. Assess potential of Fuel Cell Vehicles (FCEVs) to meet local GHG reduction, cost, and sustainability goals</strong> -- taking into account the most authoritative research on GHG and air quality impacts (see Recommendation #2.1.1.) and integration of FCEV readiness into General Plans, Climate Action Plans, and other sustainability related plans as appropriate.</td>
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<tr>
<td></td>
<td><strong>2.2.2. Revise and update green fleet plans on an annual basis</strong> to assess the economic and environmental benefits of AFV fleet procurement.</td>
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<tr>
<td></td>
<td><strong>2.2.3. Collect fleet baseline data and analyze specific opportunities for optimization</strong> related to vehicle specifications, route characteristics, etc.</td>
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<td></td>
<td><strong>2.2.4. Deploy best Green Fleet management policies relative to each alternative fuel type,</strong> including but not limited to: a) idle reduction and elimination; b) downsized vehicle engines and platforms tailored to specific duty cycles; c) utilization of state-of-the-art fleet pooling/sharing tools employing advanced telematics; and d) combined routes and missions to reduce fleet vehicle redundancy.</td>
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</tr>
<tr>
<td></td>
<td>City Councils Public Works &amp; Fleet Managers</td>
<td>Fleet Managers</td>
<td>Planning Departments Fleet Departments</td>
</tr>
<tr>
<td></td>
<td>8/1/15 - 12/30/16</td>
<td>1/1/16 - ongoing (individual milestones to be established by each city)</td>
<td>ongoing</td>
</tr>
</tbody>
</table>
2.6.2. Assess local hydrogen fueling infrastructure needs & siting options in cooperation with the AFV Council and the California Fuel Cell Partnership (where relevant based on planned station locations)

| Planning Departments | ongoing |

2.6.3. Participate in local government staff training on hydrogen vehicle and fueling safety, code, and standards utilizing best practices such as: a) the DOE online training: *Introduction to Hydrogen for Code Officials*; b) H2BestPractices.org; c) the *Regulations, Codes and Standards Template for California Hydrogen Dispensing Stations*; and, d) CA Fuel Cell Partnership resources.

| Planning Departments with AFV Coordinating Council and CA Fuel Cell Partnership | Ongoing as needed based on local H2 siting plans |

### REGIONAL ACTION

#### 3.1. Consumer Outreach and Education

3.1.1. Produce six Green Car Shows and five “Ride and Drive” events to introduce consumers to the full spectrum of AFV types. With CEC grant resources obtained by the Monterey Bay AFV Council (administered by the Monterey Bay Unified Air Pollution Control District), six Green Car Shows are being scheduled in the tri-County area in 2015-16 that will provide diverse AFV displays. Five events will include Ride & Drive opportunities enabling consumers to test drive a wide variety of AFV models, especially Plug-in Electric Vehicles (which have the largest number of model choices). Green Car Shows and Ride & Drive events will be produced by Ecology Action with Reach Strategies and the Monterey Bay AFV Council.

| Community Environmental Council of Santa Barbara Monterey Bay AFV Coordinating Council | 4/1/15 - 6/30/16 |

3.1.2. Produce three “AFV 101” seminars for consumers that address all key AFV types. With CEC grant resources, three AFV 101 events will be produced by Ecology Action in 2015-16, featuring information on vehicles, fueling infrastructure, incentives, and the economic and environmental benefits of AFV ownership.

| Ecology Action | 4/1/15 - 6/30/16 |

#### 3.2. Education of Key Decision-Makers and Stakeholders

3.2.1. Deliver four AFV training workshops targeting fleet operators, first responders, planners, and decision-makers. Seminars will introduce key stakeholders to the most recent authoritative information on the full spectrum of AFVs, fueling infrastructure, incentives, and their economic and environmental benefits and operating characteristics.

| Center for Sustainable Energy | 10/1/15 - 6/30/16 |
3.32. Information Resources on Hydrogen Fueling Stations, Funding, and Local Readiness:
The following organizations and resources can be helpful in preparing for the arrival of hydrogen vehicles and fueling infrastructure.

<table>
<thead>
<tr>
<th>Focus</th>
<th>Organization</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>• California H2 information, resources, training</td>
<td>California Fuel Cell Partnership</td>
<td><a href="http://www.cafcp.org">www.cafcp.org</a></td>
</tr>
<tr>
<td>• H2 station developers, business connections, &amp; education</td>
<td>California Hydrogen Business Council</td>
<td><a href="http://www.californiahydrogen.org">www.californiahydrogen.org</a></td>
</tr>
<tr>
<td>• H2 buses, medium and heavy duty vehicles, and stations</td>
<td>CALSTART</td>
<td><a href="http://www.calstart.org">www.calstart.org</a></td>
</tr>
<tr>
<td></td>
<td>Center for Transportation and the Environment</td>
<td><a href="http://www.cte.tv">www.cte.tv</a></td>
</tr>
<tr>
<td>• AFV and H2 workforce development</td>
<td>Rio Hondo College</td>
<td><a href="http://www.riohondo.edu">www.riohondo.edu</a></td>
</tr>
<tr>
<td>• Regional AFV information, training, resources</td>
<td>Clean Cities coordinators</td>
<td>www1.eere.energy.gov/cleanCities/coalitions.html</td>
</tr>
</tbody>
</table>

**Funding Resources for Fuel Cell Vehicle Readiness**

The California Fuel Cell Partnership - [http://cafcp.org](http://cafcp.org)

The California Governor’s Office of Policy and Research – see the 2013 ZEV Action Plan and companion documents at– [http://opr.ca.gov/docs](http://opr.ca.gov/docs)

California Energy Commission – [http://www.energy.ca.gov/contracts/transportation.html](http://www.energy.ca.gov/contracts/transportation.html)

Sign up for Energy Commission mailing lists at [http://www.energy.ca.gov/listservers/index.html](http://www.energy.ca.gov/listservers/index.html)

California Air Resources Board – [http://www.arb.ca.gov/ba/fininfo.htm](http://www.arb.ca.gov/ba/fininfo.htm)

Air Quality Improvement Program – [http://www.arb.ca.gov/msprog/aqip/aqip.htm](http://www.arb.ca.gov/msprog/aqip/aqip.htm)


FundingWizard – [http://www.coolcalifornia.org/funding-wizard-home](http://www.coolcalifornia.org/funding-wizard-home)


Clean Vehicle Rebate Project – [http://www.arb.ca.gov/msprog/aqip/cvrp.htm](http://www.arb.ca.gov/msprog/aqip/cvrp.htm)
California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project – [Link]

Enhanced Fleet Modernization Program – [Link]

Carl Moyer Program: On-Road Heavy-Duty Voucher Incentive Program – [Link]

Bibliographical References


California Fuel Cell Partnership, “A California Road Map: Bringing Hydrogen Fuel Cell Vehicles to the Golden State,” describing the infrastructure necessary to successfully launch commercial FCEVs. [Link]


Electric Drive Transportation Association,


NESCAUM, 2014 Multi- State ZEV Action Plan, [Link].


3.33. Glossary of Frequently Used Hydrogen-Related Terms

- **Fuel Cell**: A device that uses hydrogen and oxygen to create electricity through an electrochemical process
- **Fuel Cell Stack**: Individual fuel cells connected in series (or stacked) to increase electrical current
- **Fuel Cell Electric Vehicle (FCEV)**: A vehicle that uses electricity produced by an onboard fuel cell (typically powered by hydrogen) to run motors located near the vehicle’s wheels
- **Fuel Processor**: Device used to extract the hydrogen from fuels, such as natural gas, propane, gasoline, methanol and ethanol, for use in fuel cells
- **Liquefied Hydrogen (LH2)**: Hydrogen can exist in a liquid state, but only at extremely cold temperatures, and typically has to be stored at -253°C (-423°F)
- **Proton Exchange Membrane (PEM) Fuel Cell**: A fuel cell that uses a solid catalyst-coated membrane, similar in consistency to thick plastic wrap, to allow positively charged ions to pass through it, but block electrons
- **Reformer**: Device used to extract the hydrogen from fuels, such as natural gas, propane, gasoline, methanol and ethanol, for use in fuel cells
- **Reforming**: A chemical process that reacts hydrogen-containing fuels in the presence of steam, oxygen or both into a hydrogen-rich gas stream