CALIFORNIA HYDROGEN
BUSINESS COUNCIL

# CHBC Hydrogen FAQ

January 15, 2018

This document provides answers to commonly asked questions that people who are not very involved in the hydrogen and fuel cell industry have.

## What is Hydrogen?

Hydrogen is the most abundant element in the universe. However, naturally occurring atomic hydrogen is rare on earth since it readily combines with other elements to form molecules such as water, methane (natural gas) and methanol. Hydrogen is "produced" by breaking the chemical bonds in the molecules that form these substances. Today, most hydrogen is made from natural gas, some from electrolysis of water and some from bio-methane. Since Hydrogen can be made from many different sources, every region of the world has the potential to produce its own fuel, which ultimately benefits the environment and the local economy.

Historically, NASA has been the primary user of hydrogen resources for its space program—it fueled the shuttles using liquid hydrogen and employs backup hydrogen fuel cells for electricity. In recent years, the focus has turned to Fuel Cell Electric Vehicles (FCEVs), which have lower green house gas emissions than their gasoline counterparts. Hydrogen also has the potential to be used as stationary power (for buildings), backup power, storage of energy harvested through wind and solar processes, and as battery-like portable power (most commonly used in forklifts today).

## Why Hydrogen?

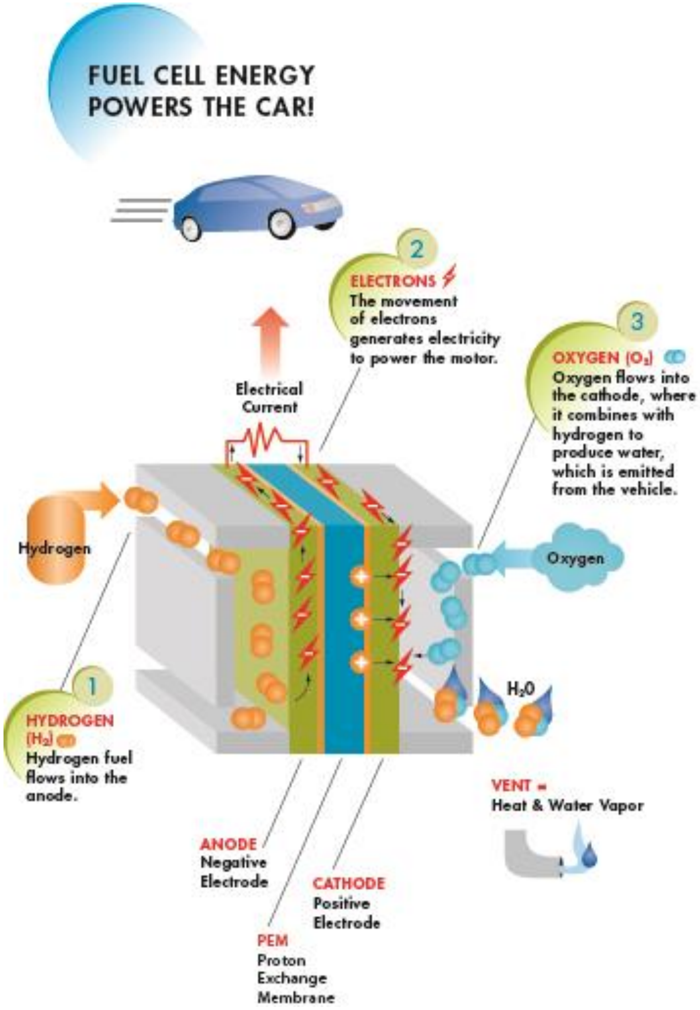
Hydrogen is a very versatile and unique fuel that has many properties that would make it a perfect fuel for any advanced energy society. It is a zero-emission fuel, which means that using hydrogen does not create any emissions, greatly benefiting local health near roads, interstates and areas of high emissions like industrial centers or ports. Hydrogen is an energy carrier like electricity, and can be produced from nearly any energy resource, including renewable resources like wind, solar, biomass, etc. and thus help create an energy economy that does not contribute to climate change. Hydrogen fuel cells are silent operating, decreasing noise pollution in traffic and increasing the livability of communities. Hydrogen is scalable, and can power any vehicle in any size, from bikes to heavy-duty long haul trucks, buses, ships and planes. Refueling with hydrogen is fast, similarly to gasoline vehicles, and thus does not require a change in behavior by adopters of the technology.

Hydrogen fuel cells can be used safely indoors, e.g. large warehouses, and do not lose performance like batteries when they run near empty. Hydrogen can
be stored for long periods of time, unlike batteries which lose charge. Fuel cells do not degrade as fast when utilized over longer periods of time and different use-cycles, allowing them to be

used for more than 10 years without requiring replacement. Hydrogen fuel cells are also fairly light on maintenance as they include very few moving parts.

## What is a Fuel Cell?

A fuel cell is an electrochemical device that converts hydrogen and oxygen into electricity. Fuel cell electric vehicles use a PEM fuel cell—proton exchange membrane. In its simplest form, a PEM fuel cell is two electrodes—the anode and the cathode—separated by a catalyst-coated membrane. The catalyst separates hydrogen into its components—a proton and an electron. The proton moves through the membrane to reach the anode, whereas the electron is forced to follow an alternate path which creates usable electricity for the vehicle's motor and other applications. Once the proton and electron reach the anode, they combine with oxygen and eventually create water—the only emission from these vehicles.



A single fuel cell cannot provide enough electricity to power a car, so a fuel cell stack is used. A fuel cell stack is made up of many PEM fuel cells that are stacked together, like slices in a loaf of bread. The stack generates electricity that powers the vehicle as long as fuel is supplied. When the fuel tank runs low, you stop at a hydrogen station and refill it in a few minutes. Then you're back on the road and ready to go!

## What are the Benefits of Hydrogen and Fuel Cells?

The key benefits of hydrogen and fuel cells include:

- Potential to be more than two times more efficient than traditional combustion technologies
- Lower green house gas emissions during vehicle operation
- Operate quietly
- Fewer moving parts and so lower chance of malfunction
- Well-suited to a variety of applications (building power, vehicle power, etc)

- Can be used in conjunction with solar and wind energy technologies for energy storage
- Reduces dependence on petroleum imports as hydrogen can be domestically produced from various sources
- Lower emissions of particulate pollutants from vehicle exhaust
- No NOx emissions
- Essentially a limitless supply of hydrogen from combination of sources (water, natural gas, etc)
- Using renewable energy such as solar or wind with electrolysis of water to produce hydrogen eliminates carbon dioxide emmissions over the entire production and usage cycle, meaning no net carbon dioxide emission

What does this all really mean?

This means that hydrogen fuel cells as an energy source are more sustainable than its gasoline and fossil-fueled counterparts. An overall reduction in carbon and other harmful and unwanted emissions nation and world-wide; leading to a healthier environment and population. Additionally, the use of fuel cells for energy storage allows for the seamless transition of energy within the power grid in the event of a power station failure or a black-out situation. An overall reduction of dependence on foreign energy imports which will boost the domestic economy in the long term.

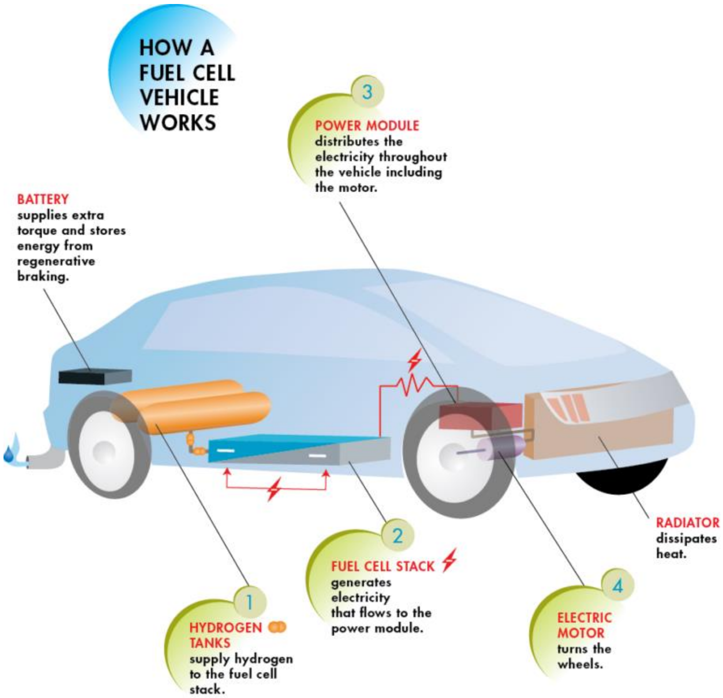
# Fuel Cell Electric Vehicles (FCEV)

## What are fuel cell electric vehicles (FCEVs)?

FCEVs and BEVs are “electric drive vehicles,” that is, propulsion is provided entirely by electric motors. A FCEV generates electricity from hydrogen stored onboard the vehicle to power electric motors. BEVs use electricity stored in batteries. Fuel cells power both on- and off-road vehicles, including cars, buses, trucks, and industrial vehicles, such as forklifts and airport ground support equipment. Both fuel cells and batteries provide electricity through chemical reactions. Using stored chemical reactants, a battery needs to be recharged or replaced when the reactants are depleted. In fuel cells, the reactants (hydrogen and oxygen) are stored externally (hydrogen on board the vehicle and oxygen in the atmosphere). As long as the fuel cell has a fuel supply and an oxygen supply, a fuel cell will produce electricity.

## How is a fuel cell different than a battery?

An old term for a fuel cell is “gas battery”, and in essence, both systems are very similar. A fuel cell has an anode, a cathode and a membrane coated with a catalyst. The membrane is the electrolyte. The reactants (hydrogen and oxygen) are stored externally. Hydrogen enters the anode side of the fuel cell and oxygen enters from the cathode side. When the hydrogen molecules come into contact with the catalyst, a chemical reaction converts the energy stored in the hydrogen into an electric current. A fuel cell will create a current as long as it has fuel. When the fuel supply is shut off, the reaction stops and therefore, so does the current. A battery has an anode, a cathode and an electrolyte that allows a chemical reaction to occur. The reactants are inside the battery. When the battery operates, a chemical reaction releases electrons through an external circuit, providing a current. Some types of batteries can be recharged, which reverses the chemical reaction and allows energy to be stored again in the battery.



## How common are fuel cells?

Fuel cells were first developed in the 19th century, but received greater attention when they became an integral part of the Space Program in the 1960s. Since then, technological advances have allowed fuel cells to become smaller and cheaper, and making them ripe for mass commercialization. Today, fuel cells are used in a variety of applications, including industrial vehicles, such as forklifts and airport ground support equipment, back-up generators for telecommunication towers, cars, buses, trucks, energy generators, drones, trains, etc.

## What happens when a fuel cell wears out?

Fuel cells are being designed to last the lifetime of the vehicle, about 150,000-200,000 miles. Demonstration fuel cell vehicles have already accumulated more than 100,000 miles in real-world driving. Automakers assume that, like today, when the vehicle reaches 150,000 miles most people will trade in their fuel cell vehicle for a newer model. Some people may choose to replace the fuel cell, however, just as some people choose to replace the engine in a conventional car. At the end of its lifespan, the fuel cell will be disassembled and the materials recycled, similar to what happens with vehicle components today.

## Do fuel cells work in cold and hot weather?

Fuel cells perform equally under most weather, temperature and altitude conditions, though small changes in performance are possible. However, these are considerably smaller than, e.g. battery

degradation under cold climate conditions.

## Is refueling a FCEV more difficult than a gasoline car?

No, it is actually very similar to fueling a gasoline or diesel vehicle, with slight differences. This video explains it all in 45 seconds.

## When will fuel cell electric vehicles be available to U.S. car buyers?

Thousands of commercially available FCEVs are on the road in California today. Honda, Toyota and Hyundai all sell or lease FCEVs. Numerous auto manufacturers, including Nissan, Renault, Daimler, BMW, Ford, and General Motors have announced or work collaboratively on fuel cell electric vehicles to be released in the 2020 time frame. Medium and heavy duty vehicles have also been announced and are being tested or sold by Toyota, U.S. Hybrid, Loop Energy, Nikola Motors, and Kenworth.

# Hydrogen Production

## How is hydrogen produced?

Hydrogen is one of the most versatile produced fuels. Technologies exist to produce hydrogen from every primary energy feedstock, including solar, wind, fossil fuels, coal, biomass, electricity. Currently, between 37% and 44% of hydrogen used for transportation in California is renewable. However, much hydrogen is produced via fossil fuels, especially for the oil refining, chemicals and fertilizer sectors.

**Long Answer:**

This is one of the wonderful things about hydrogen – it can be produced from every energy resource we have available to us. Currently and in the future, we will be producing hydrogen from environmentally benign renewable energy resources. Also, what is remarkable about a hydrogen energy system is that we do not "use" hydrogen but only "borrow" it. Consider water electrolysis where the electricity comes from solar or wind energy. We use that energy to split the water molecule ($H_2O$) into Hydrogen and Oxygen. Transport the Hydrogen where we want to use it, like the fuel tank of a car and release the Oxygen into the atmosphere. Then in the fuel cell electric vehicle (FCEV), the Hydrogen with the Oxygen from the air are combined to produce water, heat and electricity to power your car. In principal this water can be captured and used again to produce hydrogen. The chemistry looks like this ($e^-$ represents electricity, q represents heat):

$2H_2O + e^- > 2H_2 + O_2 + q$: put the $H_2$ in the tank of your car and release the $O_2$ into the air:

Then take the $H_2$ in the tank and $O_2$ from the air

$2H_2 + O_2 > 2H_2O + q + e^-$: the energy released ($e^-$) is used to power your electric hydrogen car and q
(heat) can be used to heat the car or …
Nothing is consumed.

## How is hydrogen produced today and where is it used?

Hydrogen, like electricity, is an energy carrier rather than an energy resource. Both electricity and hydrogen can be produced from all energy resources available (including, natural gas, petroleum products, coal, solar, wind, biomass, and others). Hydrogen and electricity can be made from GHG-neutral sources, addressing climate change and urban air quality problems. Also as with electricity, hydrogen can be made from sustainable domestic and renewable energy resources, which enhances our long term energy security.
Due to Hydrogen being an energy carrier, it is not consumed; it is only used. For example, hydrogen can be produced by splitting water ($H_2O$) into two atoms of hydrogen and one atom of oxygen. The oxygen produced in this reaction is released into the atmosphere and the hydrogen is stored in a tank. This stored hydrogen can then be used to fill up a FCEV. When the FCEV is in operation, its fuel cell takes the hydrogen stored on board, as well as oxygen from the atmosphere, and produces electric power (to power the vehicle's electric motors), water and heat. None of the oxygen, hydrogen and water is consumed in this process. The same amount of hydrogen, oxygen and water exist at the end of the process as at the beginning.

Today, 37%-44% of hydrogen used in transportation is renewable, but 95% of all hydrogen produced in the United States is made by industrial-scale natural gas reformation. This process is called fossil fuel reforming or steam methane reformation (SMR). The process takes natural gas (NG) and steam to generate a product stream of carbon dioxide ($CO_2$) and hydrogen ($H_2$). Large-scale SMR is an efficient process at more than 70% thermal efficiency. Most hydrogen is produced for chemicals and oil refining processes, in which more expensive renewable hydrogen is not desired.

Greenhouse gas emissions can be avoided completely if the $CO_2$ produced in SMR is captured and stored, in a process known as carbon capture and storage (CCS). As sustainable renewable energy generation advances in the United States, it is anticipated low to zero carbon hydrogen production will become more commonplace.

More than 10 million metric tons of hydrogen are produced annually in the United States, which is enough to fuel tens of millions of FCEVs. The current primary uses for hydrogen, however, are for the petroleum, ammonia for fertilizer, chemical and food industries.

## Where can I get hydrogen?

California is aggressively building Hydrogen Fueling Stations (HFS) clusters strategically located to make fueling a FCEV convenient. These clusters are located in Los Angeles metropolitan area, San Francisco Bay Area, and Sacramento. Several connector stations on Interstate 5, Santa Barbara, and on I15 to Las Vegas have also been deployed. The Northeastern U.S. will also be building HFSs strategically located with connector stations in a similar way that California has adopted.

**Long Answer:**
There are three leaders that aggressively deploy hydrogen fueling infrastructure: Japan, Germany, and California. Some states in the Northeastern U.S. are also aggressively rolling out hydrogen fueling stations – however, they are just getting started. In California, there are currently 31 strategically located commercial stations. The owner of a FCEV can drive up and, in a very similar fashion to fueling a gasoline vehicle, fuel his/her car. In California, there are grant contracts in place for 65 stations, with committed funding $20 million per year for a total of 100 stations. These stations are clustered in strategic locations in regions where Automobile manufacturers are offering vehicles for purchase. These stations provide fueling capability that is convenient and in sufficient numbers to support the vehicle rollout. There are also strategically placed "connector" stations up and down California. This same strategy is being discussed for placement of stations in the Northeast. California Fuel Cell Partnership maintains a map of Fueling Stations in California and their status. http://cafcp.org/stationmap.

# Economics

## Is hydrogen more expensive (or cheaper) than gasoline?

Right now the price for commercial hydrogen is more expensive than conventional fuels for example; gasoline on a price per mile basis. But as the commercial industry grows that price will decline.

**Long Answer:**
Prices for hydrogen vary depending on the quantity purchased, method of production, etc. For example: one can make a case for the production of very inexpensive hydrogen if one uses electricity
generated from excess electricity generated from renewable solar energy. The cost of this hydrogen can be arguably $0.00/kg. Commercial pricing in 2017 is about $10-$17 per kg, but this cost is not really the correct metric. For transportation applications, Fuel Cell Electric Vehicles (FCEV) are about twice as efficient as a conventional gasoline fueled vehicle – an FCEV will go about twice as far on a kg of hydrogen (the energy equivalent of a gallon of gasoline). So on a per mile basis, $10/kg is the same as $5/gallon compared to a gasoline fueled internal combustion vehicle. As the commercial market grows, it is expected this number will come down. The DOE FCTO has a cost per kg goal of $3-$5 per kg for commercial hydrogen. If these numbers can be achieved the cost per mile for FCEV will be less than a contemporary gasoline fueled vehicle.

## How will the cost of hydrogen compare to gasoline?

Based on current analysis, the cost of hydrogen will be comparable to gasoline, on a per-mile basis. As infrastructure develops and volumes increase, costs will further decrease and hydrogen will be cheaper than gasoline. Currently, a kg of hydrogen costs between $10 and $17 at California hydrogen stations, which equals about $5 to $8.50 per gallon of gasoline, however, manufacturers include free hydrogen fuel for several years when selling FCEVs.

## How much do FCEVs cost?

As of 2017, the Toyota Mirai is available starting at $57,500 before incentives. With current incentives in place, the cost comes down to about $45,000 with $15,000 of fuel cost included for the first three years. Leases for Hyundai, Honda and Toyota FCEVs are available for $2,900 – $2,500 down and $369 – $350 per month with fuel included.

## Aren’t fuel cells too expensive to become mainstream?

Fuel cells are getting closer to cost-competitiveness, due to improvements in performance and volume. The Department of Energy’s research and development efforts helped cut fuel cell costs in half since 2007, while increasing its durability four-fold2. They are widely used in variety of applications, ranging from vehicles to material handling. For example, you can now buy or lease a hydrogen fuel cell car in California and companies such as FedEx, Sysco, Walmart and Coca-Cola are using fuel cells to power forklifts. In addition, Sprint and AT&T are using them as emergency backups to power cellphone towers across the country.

## Why build hydrogen fuel cell vehicles when there are already gasoline, diesel and electric cars?

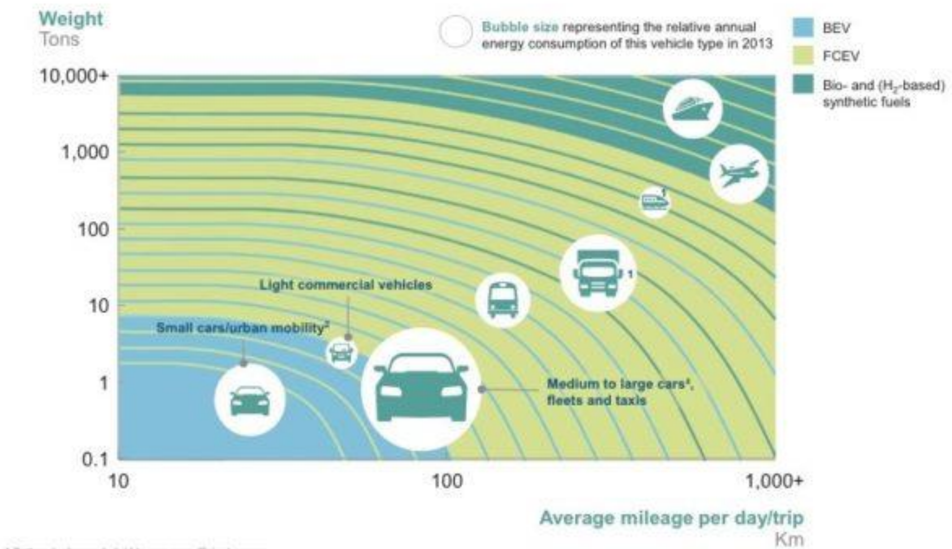
Both hydrogen fuel cell and battery vehicles are electric vehicles, and electric vehicles create no tailpipe emissions, significantly reducing health impacts from emissions. Not only do all electric vehicles have no emissions, they can also both be produced with renewable energy, addressing the considerable greenhouse gas emission contribution of the transportation sector to climate change. However, battery electric vehicles have certain limitations that may hamper widespread adoption across all transportation sectors. BEVs tend to have shorter ranges and require longer times to fully recharge to allow for the full range. Hydrogen Fuel Cell Electric Vehicles (FCEV) provide the same driving experience as a regular gasoline or diesel vehicles, and can be fueled in a similar time (3-5 minutes), and can provide high power (larger vehicles), and long ranges (300 to 400 miles).

**Long Answer:**
Both Battery Electric (BEV) Cars and Fuel Cell Electric (FCEV) cars are Electric Vehicles. The difference is BEV store the energy needed on board in Batteries, and the FCEV’s store the energy in a tank of hydrogen similar to gasoline vehicles. The fueling time for FCEV is 3-5 minutes, as opposed to hours for a BEV. The range for FCEV is a function of how much hydrogen is stored on board; current vehicles are 300 to 400 miles. Even the most advanced

BEV’s (like the Tesla) are on the order of 270 miles for the 85D on the EPA 5-cycle Range. Car manufacturers recognize that BEV’s fit well into the low power, short range part of the market (city cars), and FCEV will satisfy the rest of the market (larger passenger cars, SUV’s, trucks, even class 8 tracker trailer trucks). They are both electric vehicles which offer the attractive driving experience of an electric vehicle (no torque interruption, all time 4 wheel drive, exciting acceleration).

Figure 5: FCEVs will play an essential role in decarbonizing transport

Projected economic attractiveness



1 Battery-hydrogen hybrid to ensure sufficient power

2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Source: Toyota, Hyundai, Daimler

# Infrastructure

## Is establishing a hydrogen infrastructure cost effective?

Yes. The infrastructure requirements for hydrogen are similar to the requirements for compressed natural gas (CNG) infrastructure currently being developed to serve natural gas vehicles. Assuming a 100,000 mile-lifetime for a FCEV, estimates for the roll-out of a hydrogen infrastructure in a mature market range from $1,000 to $2,600 per vehicle, or about $0.01 to $0.03 per mile. The cost of hydrogen infrastructure, along with the cost of hydrogen, is steadily declining and, in a mature market, is estimated to be similar to BEV charging infrastructure on a per-vehicle basis. Indeed, in a mature market when the fueling station business model returns a profit to the station owner the infrastructure will grow with the increased demand without further government support.

## How much will the initial startup of a hydrogen infrastructure for coverage cost?

The building of the hydrogen fueling infrastructure during the initial stages, to establish the needed coverage, is not as expensive as one might think. According to McKinsey & Company, the societal cost for deploying a H2 infrastructure on a per-vehicle basis is similar to that of BEV recharging infrastructure. Early stations may not reach profitability until the FCEV market grows and more vehicles are on the road. However, it is generally recognized that these early "coverage" stations need to be put in place before the market of FCEVs is established. Energy Independence Now studied the issue for the State of California. Government support is essential in the early stages of the infrastructure roll out. California has committed $20 million per year for the next 10 years to help support the initial construction of 68 stations for coverage, followed by an additional 32 stations for capacity growth (a total of 100 stations). These funds will also help support the stations' operations and maintenance to ensure their operations during the early stages of the infrastructure build out. It is assumed that the early "coverage" stations (0<68) will service up to 20,000 FCEVs, with 100 stations needed to support 20,000 to 30,000 FCEVs. Hyundai recently received over 20,000 lease applications for their FCEV vehicle lease program in Los Angeles, which is an indicator of early demand for the vehicles that will utilize the hydrogen infrastructure.

Capital costs in California, where hydrogen infrastructure is being built out today, are estimated from $0.9 million, for a 100- to 170 kg/day station, to $1.4 million for a 250 kg/day station for early (2013) market fueling. For stations built in 2015 to 2017, the capital cost is estimated to be $0.9 million for a 250 kg/day station and $1.5 to $2.0 million for a 400 to 500 kg/day station.

## Can I drive across California with a FCEV?

The roll out of hydrogen stations in California is tailored to match the way most people drive and get fuel: several stations near home, work, stations in popular destinations and "connector" locations so customers can drive throughout the state. By 2022, 100 stations are expected statewide.

## How many hydrogen fueling stations will be needed in California and in the U.S. to establish a robust infrastructure network?

While it is too early in the development of the FCEV market to identify an exact number, the goal is to establish a sufficient number of strategically located stations to meet consumer expectations for location, convenience and availability. These strategically located stations will establish coverage to enable the market deployment of FCEVs. As the market matures, increased numbers of hydrogen stations will serve a growing demand from the FCEV fleet to provide the needed capacity. However, the model demonstrates that hydrogen stations do not need to be built on the same scale as the current gasoline infrastructure to support the coverage required for initial introduction of FCEVs.

In California, 100 stations are planned to be funded by 2022, which would support 68,000 cars.

## What regulatory changes are needed to accelerate the expansion of hydrogen infrastructure?

Much has been learned in the development of early hydrogen facilities through private and public collaboration including the industry's work with the U.S. Department of Energy's Fuel Cell Technologies Office. Defensible and technically sound model codes have been developed and adopted at the national level. While codes will continue to evolve with the technology, they are already facilitating deployment of hydrogen infrastructure as they are being adopted and implemented at the local level.

While the process for permitting and construction of a hydrogen fueling station is similar to the process for a gasoline fueling station, local authorities having jurisdiction will need education about hydrogen behavior and about national hydrogen-related codes.

Also, as hydrogen and gasoline have different properties, the fueling stations will have different designs. It is expected that there will be municipal variations in permitted procedures, design specifications and installations. However, station developers are moving away from unique station designs toward more standardized facilities to streamline local permitting and construction processes.
Modifications to dealerships facilitating FCEV vehicle maintenance are also being pursued. As with fueling stations, education of local authorities about the vehicles, fuel, updated codes and standards are key to efficient deployment of FCEVs.

## How can I get a station in my neighborhood?

Most California stations receive co-funding from the California Energy Commission. CEC's competitive grant process usually denotes areas that are priorities for hydrogen stations. Station developers often look for existing gas stations that:

1. Have enough space for the equipment
2. Are zoned to allow dispensing of alternative fuels. (Many cities specify that a station dispenses liquid fuels.)
3. Are in good standing with the surrounding community.

It is also helpful if the city is a proponent of zero-emission vehicles. Incentives and benefits for drivers of plug-in vehicles should extend to FCEVs. It is recommended to work with a city's business community, which might be a Chamber of Commerce or an Economic Development Department, and with sustainability groups that plan and prepare for plug-in vehicles. Most of the PEV work can include FCEVs by simply replacing the "p" with a "z."

# Environmental Considerations

## Does making hydrogen create pollution?

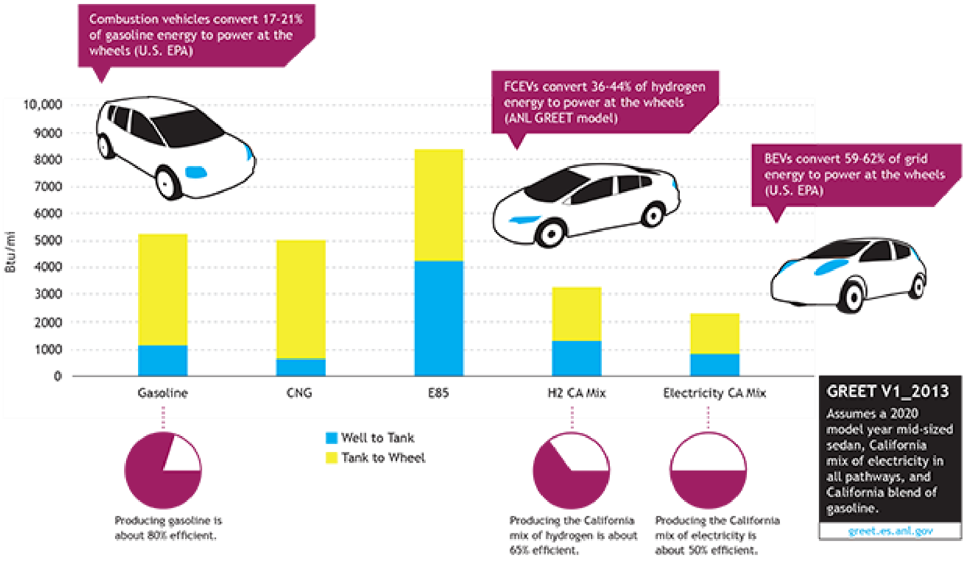
All fuels create some form of pollution. Well-to-wheels studies, which compare various fuel pathways and vehicle types, show that hydrogen produced from natural gas and used in a fuel cell vehicle is twice as efficient and 55% cleaner than gasoline through a conventional vehicles. Hydrogen produced from renewable energy is even better.

## How much hydrogen is renewable?

In California, at least 33% of all hydrogen used for transportation is generated from renewable resources, since that is required as part of the fueling station development process. Right now, renewable hydrogen is still more expensive, in part due to a lack of large scale renewable hydrogen production facilities that decrease the price of hydrogen. With greater adoption of hydrogen in California, the price for renewable hydrogen will decrease.

### ENERGY

W2W efficiency is the number of BTUs needed to drive one mile including all the inputs such as diesel to drive a tractor to farm corn, natural gas to heat water for gasoline or hydrogen, and electricity to run dispensing equipment. Fewer BTUs indicate a more efficient well-to-wheels system.



### ENERGY EFFICIENCY & FUEL ECONOMY

Energy efficiency is important, but not the whole picture. Fuel economy—"miles per gallon"—is a result of engine (or motor) efficiency, size, weight, road conditions and driving style. A bus and a car could both have a fuel cell that operates at 60% efficiency, but because the bus is heavier and stops and starts often, it will have a lower fuel economy than the car.

## Why make hydrogen from renewable energy?

Using excess renewable energy to produce hydrogen is a great way to increase renewable energy production while also making GHG-free transportation fuels. In California, 350 out of 365 days in the year, renewable energy production is curtailed or wasted. This will only increase with greater share of renewable electricity on the grid.

# Applications for Hydrogen Energy and Fuel Cells

## How versatile are Hydrogen energy and Fuel Cells?

Fuel Cells have a variety of applications and can be categorized into three groups:

Portable Power Generation is a compact, portable fuel cell systems that can be used to recharge batteries or directly power consumer electronics (e.g. laptops and smartphones). Portable fuel cells can also supply off-the-grid back-up power in remote locations or on-the-go power.
Stationary Power Generation can be an important part of distributed generation, and are often used as primary or backup power for large energy infrastructures. This is a highly efficient use of
fuel cells, 50 percent electricity generation and more than 90 percent with heat recovery. Stationary Power Generation has no need for long transmission lines, which cause power loss. There are three main applications for stationary fuel cells:
CHP Systems range from .5 kilowatts (kw) to several megawatts (mw) and use heat and electricity generated by the fuel cell to maximize fuel efficiency. The heat (which is lost in other systems) can be used to heat water and/or provide space heating for a building. A CHP fuel cell system operates at 80-95 percent efficiency. In Japan, more than 120,000 CHP units have been installed in homes. The U.S. has seen installations in grocery stores, office buildings, hospitals and other facilities, ranging from 200kw to 1 MW.
UPS Systems provide uninterrupted power and primarily used for backup power during grid outages. UPS systems offer a replacement to diesel-powered emergency generators in hospitals and server farms. During Hurricane Sandy, UPS systems equipped on cellphone towers kept communication links open.
Primary Power Units are large stationary units that can act as the primary source of energy for a facility or for the grid. Many large corporations (Apple, Verizon and eBay) use fuel cells as primary sources of power. In 2013, Dominion opened the largest fuel cell facility at 14.9 MW. The world’s largest is in Seoul, South Korea at 59 MW.
Power for Transportation: Fuel cells can be used to power any vehicle (scooters, forklifts, trucks, buses, trains, boats, aircraft and cars). Fuel cell-powered forklifts are popular in warehouses around the world. Automakers are adopting fuel cells and have already hit the US market.

## What is Power-to-Gas?

Power-to-Gas (P2G) is the only technology capable of providing storage at terawatt-hour scale without location limitations. Renewable electricity is used to create hydrogen, which then is stored in a storage system like tanks, caverns, or the natural gas grid. Using the natural gas grid would allow for very large amounts of renewable hydrogen to be stored very economically, as very little new infrastructure needs to be build.

# Safety

## Is hydrogen safe?

Hydrogen is just as safe as any other transportation fuel (i.e. gasoline, diesel and natural gas). The tanks are put through rigorous testing including crash tests, gunfire and performance requirements. They are also made of high-strength composite materials that are much stronger than steel. For example, testing tanks are subjected to more than twice the maximum pressure they experience under normal service conditions to ensure high-quality performance. In addition, hydrogen fuel stations have redundant protection systems in place, so it's virtually impossible to over-pressurize a vehicle fuel system. FCEVs and the fueling stations to supply the hydrogen are just as safe as conventional systems today. All FCEVs have to meet the same rigorous federal safety standards that apply to all consumer vehicles.

Hydrogen has been safely produced and used in the U.S. industrial sector for more than half a century. As with every fuel, safe handling practices are required but hydrogen is non-toxic and does not pose a threat to human or environmental health if released.

Hydrogen codes and standards are in place at the national level to ensure that hydrogen fueling stations are as safe as their gasoline counterparts. These national codes and standards are being adopted at the local and regional level.

**Long answer:**
How safe is gasoline, natural gas, propane, acetylene, any other energy carrying substance? Any volatile substance that when combined with an oxidizer (most commonly air), in the right proportions has the potential to ignite releasing energy in the form of heat. It is this reaction that powers our vehicles (conventional internal combustion engines), heats our homes, cooks our food, and process heat for steel manufacturing, etc. We have learned to design systems that use these energetic substances safely; hydrogen systems are designed to be no riskier than their conventional fueled counterpart.
For example; fueling at a hydrogen fueling station, and the risk associated with fueling a hydrogen vehicle at one of these stations is lower than the risk of walking across the street, built to the NFPA 2 code yields no greater risk than fueling at a conventional gasoline fueling station.

## The Hindenburg exploded – can that happen with other hydrogen uses too?

A common misunderstanding is what caused the Hindenburg Accident – Hydrogen did not cause that incident. The cause was a static charge release to the skin of the air ship. This skin material had a composition similar to that of rocket fuel. Note that, the airship did not "explode", it burned – consistent with the discussion about oxidizer mixing with the hydrogen no air got into the nose of the air ship – it stayed aloft while burning – no explosion – the hydrogen burned off.

The Hindenburg was a terrible accident – it was an accident in which 62 out of 97 passengers survived, while 35 people died. Many of these fatalities occurred when the passengers jumped to the ground. Many other air accidents have had considerably higher fatalities and are much less remembered, e.g. the ValuJet Flight 592 accident in Miami, Florida, in which 110 people died due to an engulfing fire which started in the cargo department. The ValuJet incident, from a lost lives perspective, was a lot worse than the Hindenburg, and yet people get on airplanes every day.

## Can Hydrogen or Fuel Cells explode or self-ignite?

If hydrogen is allowed to mix with air before it is ignited, this could lead to an explosion. However, should a release occur and it ignited immediately, no explosion would occur and the hydrogen would simply burn. Much care is taken to ensure that should such a leak occur, the hydrogen is vented to a safe location where it can burn out safely.

**Long Answer:**
With most energetic substances, they need to be mixed with an oxidizer before they can react releasing their stored chemical energy. For example, gasoline not in the presence of an oxidizer (air), will not catch fire (explode), neither will natural gas (mostly methane). Hydrogen is no different, in the absence of an oxidizer it cannot react. What is particularly interesting in the transportation application is that should a hydrogen tank be punctured (a highly unlikely event) hydrogen will escape but the properties of hydrogen and the behavior of this unintended release prevent air (oxygen) from entering the tank. Even if the escaping hydrogen catches on fire, that flame cannot propagate into the tank, igniting the hydrogen inside. There is no oxidizer in the tank, only fuel. This is not true for all other common energetic substances like gasoline, natural gas, propane … for these substances, air can get into the tank and mix with the energetic fuel and ignite inside the tank.

## What happens when hydrogen leaks?

Hydrogen systems are designed to handle hydrogen leaks in a safe manner.

**Long Answer:**
This depends on the type of leak. Typical hydrogen storage systems are either pressurized or liquid. There are other technologies but these are the most common. For large hydrogen installations, liquid is preferred, for smaller and on board a Fuel Cell Electric Vehicle, pressurized systems are currently preferred.
**Liquid storage:**
Liquid hydrogen is very cold and requires well insulated tanks to hold the hydrogen. These tanks are double walled vacuum sealed and are at low pressure. This is a very mature industry with decades of safe handling – the space shuttle uses liquid hydrogen. The handling of liquid hydrogen is and will be in the foreseeable future handled only by trained professionals.

**High Pressure Storage:**

At a stationary storage facility, hydrogen can be stored under high pressure. Following NFPA 2, the facility is engineered in such a way that should a leak occur it will be directed away from any other hazards where it can be safely mitigated. While it is highly unlikely that such a leak would occur, they have happened and the safety systems responded exactly as intended with no serious consequences.

Light duty vehicles (passenger cars) use high pressure systems to store the hydrogen on board the vehicle. Buses and other vehicles are also using high pressure systems, although not as high as passenger vehicles. This is beneficial to extend the driving range. These tanks are extraordinarily robust carbon fiber wrapped tanks. This technology was developed for the space program and has been improved for commercial applications. These tanks must undergo very extensive testing as dictated by the Global Technical Regulation 13 (GTR 13) and SAE 2579. This testing is much more extensive than tests used for natural gas tanks. They undergo fire tests, pressure cycle testing, temperature cycling, munition fire, drop tower and much more. These tanks survive serious auto accidents, since by design, should a vehicle get into an accident with another (gasoline) vehicle and a gasoline fire should occur, engulfing the hydrogen vehicle, a temperature actuated pressure relief valve (TPRD) opens and the escaping hydrogen is directed to the ground. This entire event is designed to last about 5 minutes for a full 4 kg tank. Because of the properties of hydrogen and the behavior of these releases, no air can get in the tank eliminating the possibility of a tank explosion. This scenario occurs only if an engulfing fire is present – a hazard much worse than the controlled hydrogen jet flame.

On board a vehicle, the hydrogen is transferred from the high pressure storage tank to a low pressure delivery system and then to the fuel cell. Should that low pressure system be compromised, say in an accident, the fuel system immediately shuts down and closes the in tank valve to make sure no high pressure hydrogen escapes. This leaves a very small quantity of low pressure hydrogen that could escape the fuel system. Hydrogen, being 14.4 times lighter than air and diffusing 3.8 times faster than methane, in this buoyancy dominated flow will go up and diffuse to concentrations below the lean hazardous flammability limit very quickly. Should it ignite there is not sufficient quantities of hydrogen to be of concern. The damage and hazards due to the crash event are conceivable a greater danger.

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[1] US DOE, energy.gov/eere/fuelcells
[2] Hydrogenics, hydrogenics.com