# Well to Wheels

A guide to understanding energy efficiency and greenhouse gas emissions

California
FUEL CELL
PARTNERSHIP

DRIVING FOR THE FUTURE

Updated October 2009

**California** is leading the country—perhaps the world—with aggressive goals and progress for improving air quality, reducing greenhouse gases and decreasing petroleum dependence.

## INTRODUCTION

Californians love their cars, and motor vehicles have been a part of California for more than 100 years, but motor vehicles are a major contributor to poor air quality, global warming emissions and petroleum dependence. Even though vehicles continue to become cleaner and more efficient, California's 25 million cars use about 50 million gallons of gasoline and diesel every day. The emissions from vehicles and fuel production form half of the state's criteria pollutants and create more than 40% of the greenhouse gases. By controlling emissions during fuel production and at the tailpipe, we can significantly reduce the impact of cars and trucks on our environment.

Automakers and energy companies are working hard to meet California's environmental goals while building vehicles that meet consumer expectations and use fuel that's safe, affordable and abundant.

## WELL-TO-WHEELS

Producing and using fuel—any fuel—consumes energy and creates emissions. With modeling software, researchers from government and industry calculate the impact of the fuel during its production and distribution (well to tank), and then as the vehicle uses the fuel (tank to wheels.) The results are combined and presented as well to wheels.

Argonne Labs, the European Council for Automotive Research, the Mizuho Information and Research Institute in Japan, the California Air Resources Board and the California Energy Commission each customized the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) or similar models to evaluate more than 100 combinations of fuel and vehicle, and estimated their impacts on energy and the environment. The resulting data in each report shows similar curves for energy use and emissions.

## CALIFORNIA REGULATIONS

- The California Global Warming Solutions Act (AB 32) requires the California Air Resources Board to develop regulations and market mechanisms that will ultimately reduce California's greenhouse gas emissions by 29 percent by 2020.
- The Air Quality Improvement Program (AB 118) will fund air quality mitigation and clean technology incentive programs. It also establishes the Alternative and Renewable Fuel, Vehicle Technology, Carbon Reduction, and Clean Air Program to provide grants and revolving loans for projects that develop innovative technologies that transform the state's fuel and vehicle types to help attain climate change policies.
- The Low Carbon Standard for Transportation Fuels (EO S-01-07) will reduce the carbon intensity of California's passenger vehicle fuels by at least 10 percent by 2020.
- The Zero Emission Vehicle Program requires automakers to demonstrate and commercialize zero emission vehicles.
- The Greenhouse Gas Reduction Bill (AB 1493) mandated the California Air Resources Board to develop and implement greenhouse gas limits for personal-use vehicles beginning in the 2009 model year.
- The State Alternative Fuels Plan (AB 1007) requires the California Energy Commission to prepare a plan to increase the use of alternative fuels in California.
- The Zero Emissions Bus Regulation, part of the Fleet Rule for Transit Agencies, encourages the use and operation of zero emission buses in urban fleets.

The critics say: It takes more energy to produce hydrogen than you get from it.

## Truth: Well-to-wheels, fuel cell vehicles are more efficient than gasoline cars.

According to the reports, every fuel takes more energy to produce than it yields, which is why it is important to consider the energy efficiency of the vehicle, too.

The production cycle—the well to tank—includes obtaining the fuel source (the feedstock), refining or producing the fuel and transporting the fuel to a station. Each fuel has many production pathways. For example, hydrogen can be produced by electrolysis or by steam reforming. An efficient pathway, however, may not be the cleanest with regard to greenhouse gases and criteria pollutants.

Figure 1 uses data from the Argonne National Labs (ANL) May 2005 report, Appendix C to show the well-to-tank efficiency of common fuels and typical pathways. A higher number is better.

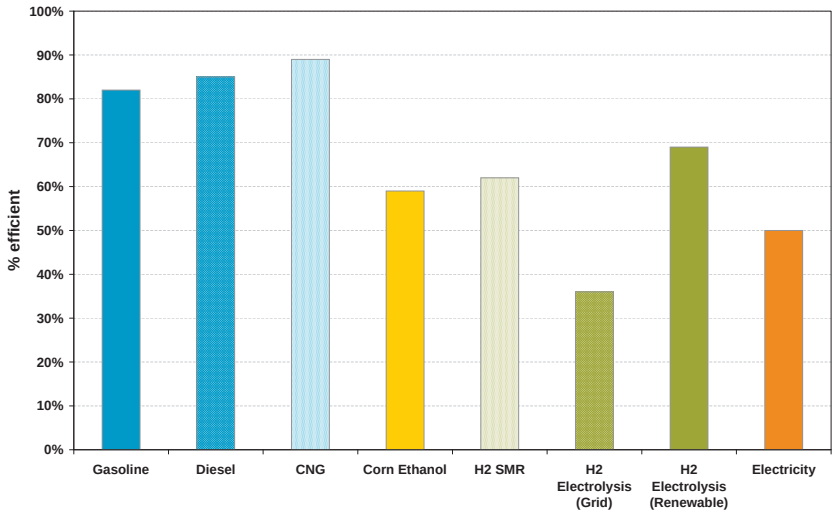


**Figure 1: Well-to-tank efficiencies of fuels**

Producing the fuel is only half the story. Because some vehicles are more efficient than others (the tank to wheels), the reports consider energy use on a well-to-wheels basis.

Figure 2 uses data from the appendixes of the Argonne National Labs and the California Energy Commission reports to show the well-to-wheels energy use in BTUs per mile. Although the numbers are slightly different, both reports show similar well-to-wheels energy use. (Please note that only the CEC report considers battery electric vehicles.) Lower numbers are better.

All reports agree that electric vehicles, those using fuel cells or batteries, are more efficient than combustion vehicles. Fuel cells are 2-3 times more efficient than gasoline engines and about twice as efficient as gasoline hybrids.

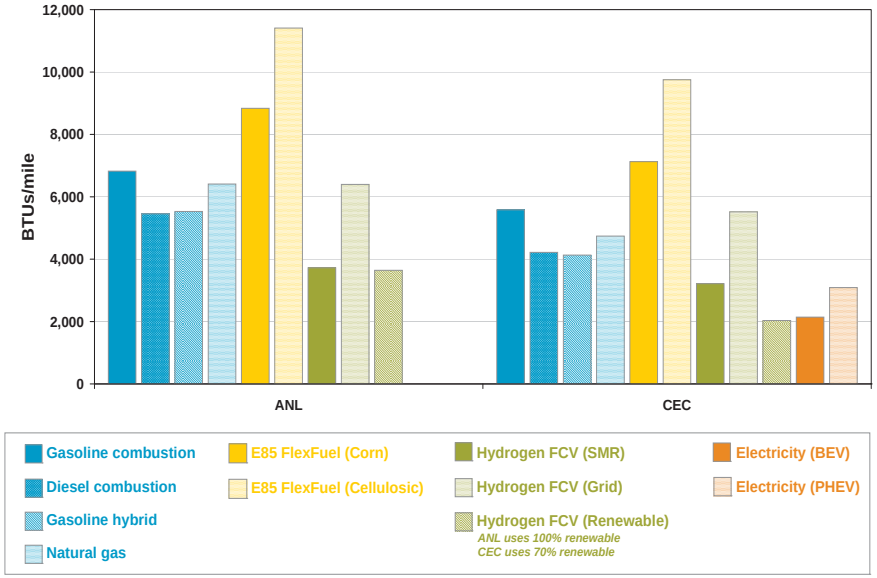


**Figure 2: Well-to-wheels energy use per mile of fuels and vehicles**

The critics say: Using hydrogen from natural gas will not improve air quality or reduce greenhouse gases.

## Truth: When looking well to wheels, hydrogen is a very clean fuel.

The well-to-wheels reports show that hydrogen made from natural gas and used in a fuel cell vehicle reduces greenhouse gases (GHGs) by 55%-65% compared to gasoline used in a conventional vehicle, and by about 40% compared to gasoline in a hybrid engine. When using hydrogen made from clean energy sources, greenhouse gases are zero.

The well-to-wheels studies consider the carbon content of the fuel and the amount of GHGs created during processing. It is possible to have a carbon-free fuel, like electricity or hydrogen, yet still have greenhouse gases associated with fuel production and distribution (the well-to-tank phase).

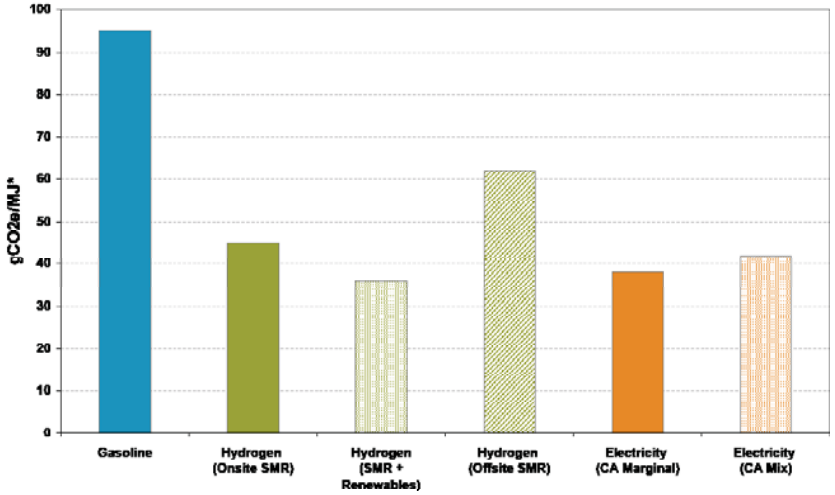


**Figure 3: California Air Resources Board, Low Carbon Fuel Standard Report**

For the Low Carbon Fuel Standard report, the California Air Resources Board compared the well-to-wheels carbon intensity of fuels. CARB used a "California mix" for hydrogen and electricity that includes a proportional amount of each feedstock. CARB found that fuel cell and battery electric vehicles create about two thirds less $CO_2$ well to wheels than gasoline, even when factoring in increases in fuel efficiency of convetional vehicles. (Figure 3)

Figure 4 shows data from the appendices of the ANL and CEC reports for the amount of greenhouse gases (in grams per mile). The CEC report considers hydrogen made with only 70% solar or wind energy and, therefore, has associated GHGs. Lower numbers are better.

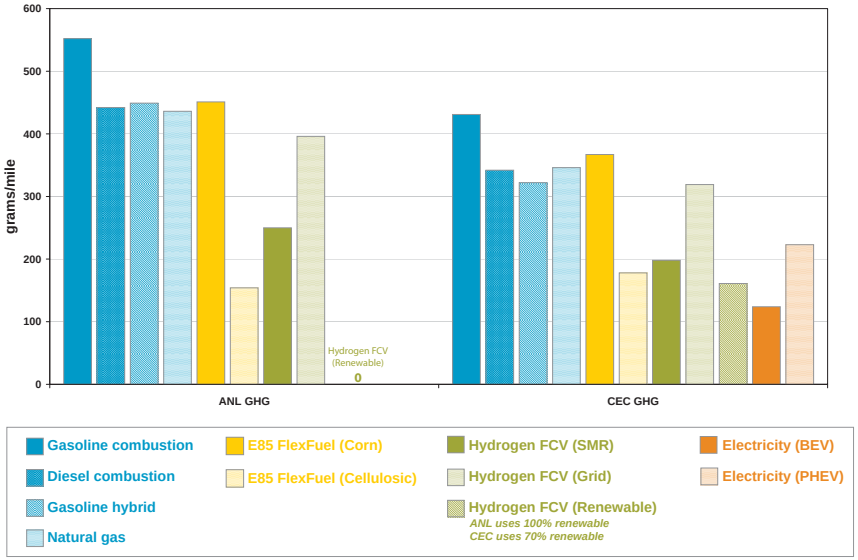


**Figure 4: Well-to-wheels greenhouse gases of fuels and vehicles**

Well to wheels, hydrogen in a fuel cell vehicle substantially reduces greenhouse gases, even when produced from natural gas.

Figure 5 uses the data from the CEC report to compare four major criteria pollutants from gasoline and corn ethanol in conventional engines and hydrogen from natural gas in a fuel cell vehicle. Lower numbers are better.

Hydrogen, along all production pathways, produces almost zero criteria pollutants. Even small numbers of fuel cell vehicles can make an immediate impact on air quality.

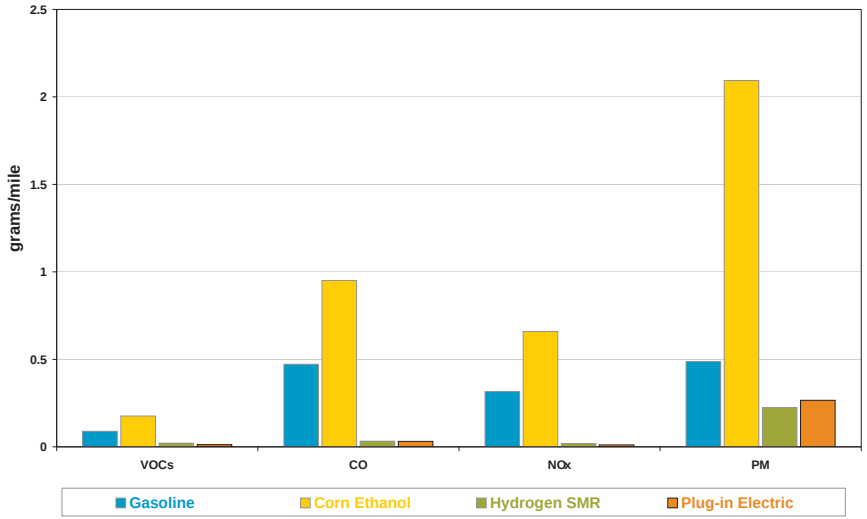


**Figure 5: Well-to-wheels criteria pollutants**

## ENVIRONMENTAL ISSUES

- Air quality—reducing the emissions that contribute to smog and particulate matter in the air we breathe
- Global warming—reducing the amount of greenhouse gases in the atmosphere to slow climate change
- Energy independence—consuming less energy and using a clean energy source to become less dependent on petroleum

According to the California Air Resources Board, **about 60% of California's air pollution is caused by criteria pollutants from vehicles that burn gasoline and diesel.**

## CRITERIA POLLUTANTS

- Volatile organic compounds (VOCs) are any organic compound that evaporates readily to the atmosphere. VOCs significantly contribute to smog.
- Carbon monoxide (CO) is a colorless, odorless, highly poisonous gas.
- Oxides of nitrogen (NOx) are smog-formers and major components of acid rain.
- Particulate matter (PM) is microscopic solid and liquid particles that remain suspended in the air for some time. Particles create a haze and adversely affect health and the environment.

The critics say: Hydrogen fueling requires a massive and expensive infrastructure.

## Truth: A hydrogen infrastructure already exists, but must be expanded for the early commercial vehicles.

Currently, the hydrogen industry has the capacity to produce the equivalent of fuel for about 130 million vehicles worldwide.[1] Today, only a tiny fraction of the hydrogen is for fuel cell vehicles. Most hydrogen produced today is used for making fertilizer, refining gasoline, manufacturing semiconductors and processing food. As with gasoline, hydrogen pipelines exist in many parts of the country and production plants have the potential to expand to meet demand.

We do need to build hydrogen fuel stations. California currently has about two dozen stations in operation and more planned. These early stations were built specifically to fuel small fleets of vehicles. As the number of fuel cell vehicles on California's roads grows, the number of stations must increase, and they need to serve larger numbers of vehicles. The first retail-like station in California opened in Los Angeles in 2008.

The vision for the near future is to deploy larger groups of pre-production fuel cell vehicles in the Los Angeles and Sacramento/San Francisco regions. If hydrogen were available at the equivalent of 2% of existing gas stations,[2] every FCV driver in an urban area will be within minutes of fuel. Figure 6 shows the relationship between average driving time to the nearest station and the number of stations for major metropolitan areas.

The 2009 CaFCP "Action Plan" detailed the need for 46 stations in three areas of California by 2014 to provide fuel for passenger vehicles, transit buses and regulatory development.[3]

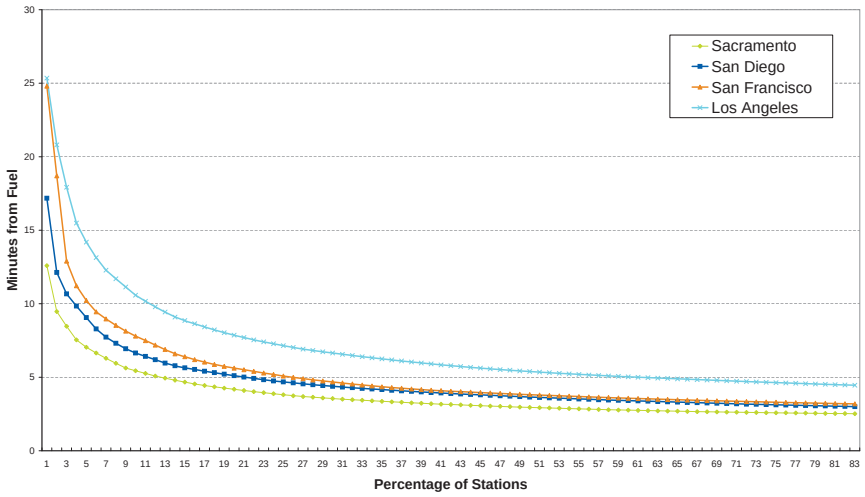


**Figure 6: Relationship between average driving to the nearest station**

Hydrogen stations might be very diverse. Some may sell hydrogen along with gasoline and diesel, and perhaps other alternative fuels like E85. Other stations may be smaller hydrogen-only stations located in the parking lot of a grocery store or an office complex. Home fueling may also be an option. Hydrogen stations can be "energy stations," creating fuel for cars and electricity to power a building.

All fuels need ongoing investment in infrastructure. The Energy Information Office (EIO) at the Department of Energy provides quarterly statistics for a set of consistent energy providers. According to the EIO's Selected Financial and Operating Data report, in 2006 the energy companies surveyed spent $21 billion in capital costs related to domestic oil and gas production. The CaFCP Action Plan estimates the initial hydrogen infrastructure will cost $180 million

Hydrogen requires an investment in infrastructure, but it is an investment that will yield great benefits over time.

1 "10 Things to Know about Hydrogen," $H_2$&You, *www.h2andyou.org*

2 *Detailed Analysis of Urban Station Siting for the California Hydrogen Highway Network* by Michael A Nicholas and Joan Ogden of the University of California, Davis, 2005

3 *Hydrogen Fuel Cell Vehicle and Station Deployment Plan: A Strategy for Meeting the Challenge Ahead,* CaFCP, February 2009

The critics say: We can achieve California's goals with hybrids and plug-in battery electric vehicles.

## Truth: Fuel cell vehicles have the best potential for achieving California's long-term goals.

It is important to make vehicles more efficient, but simply getting more miles to the gallon of gasoline and diesel will not be enough to decrease fossil fuel consumption. Hybridizing these vehicles with batteries does increase efficiency, but not enough in the long term.

The report, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*[4] used data from the Energy Information Office (U.S. Department of Energy) to project fuel use in the future. (Figure 7)

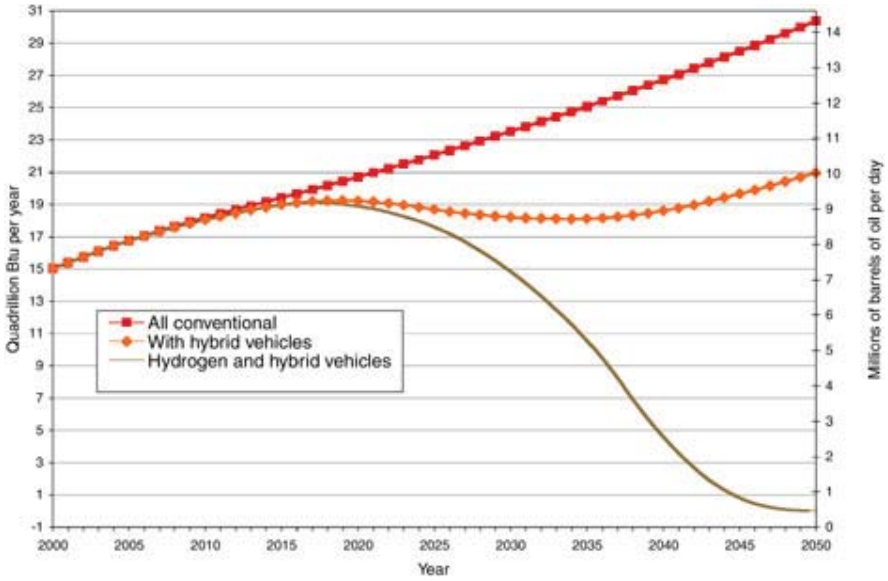


**Figure 7: Projection of future fuel use in U.S.**

Although hybrid vehicles generally are more efficient than conventional vehicles, the report concludes that we need hydrogen-fueled vehicles—and fuel cell vehicles in particular—to dramatically reduce our demand for petroleum.

Electric vehicles—fuel cell and battery—do not emit greenhouse gases or criteria pollutants, but generating electricity or producing hydrogen create both. California has a relatively clean mix of electricity, using mostly natural gas supplemented by clean energy sources. By 2020, 33% of the state's electrcity must come from renewable sources. A cleaner grid reduces GHGs for all fuels.

### THE CALIFORNIA GRID

The well-to-wheels reports evaluate several electricity pathways. One of them is the California electricity mix, which is cleaner than the US average. The California mix consists of natural gas, coal, hydropower, geothermal, nuclear, wind and solar. According to the California Energy Commission, most of the state's electricity comes from natural gas and about 10% from clean energy sources, primarily hydropower. The Renewable Portfolio Standard calls for 20% of California's residential electricity to come from clean energy by 2010. The state has a goal of 33% from renewable sources by 2020.

4 The National Academies, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*, 2004

The CEC's well-to-wheels report is the only report to include battery electric (BEVs) and plug-in hybrid vehicles (PHEVs) with 60-mile battery range. Figure 8 uses data from the report's appendix for estimated well-to-wheels greenhouse gas production in 2012 and 2017 model year BEVs and PHEVs compared to FCVs using two hydrogen pathways, and conventional gasoline vehicles. CEC researchers assumed that all electricity is "marginal," which is cleaner and more efficient than the California mix. Lower numbers are better.

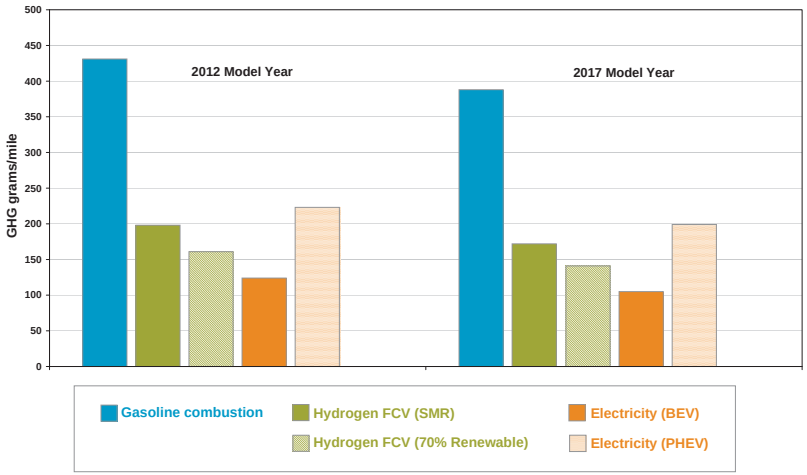


**Figure 8: Well-to-wheels greenhouse gas emissions**

The CEC data shows that fuel cell vehicles using hydrogen produced from natural gas have about 55% fewer greenhouse gases than a conventional vehicle, and fewer GHGs than a plug-in hybrid. In addition, FCVs can use zero fossil fuels while PHEVs are dependant on gasoline at high speeds or when the battery is exhausted.

Like FCVs, battery-electric vehicles are very efficient and emit few GHGs. They are, however, generally smaller vehicles with about half the range of a fuel cell vehicle. The studies did not include the impact of having to recharge a BEV 2-3 times as often as needing to refill a FCV with hydrogen, nor did they include the convenience factor of quick FCV refueling compared to longer BEV charging.

The ultimate goal is 100% renewables to create hydrogen for an FCV or to charge a BEV. Both options require an investment in infrastructure. For plug-in battery vehicles, infrastructure can include installing photovoltaic arrays, smart grids for delivering electricity and charging stations for vehicles. For hydrogen, infrastructure means building refueling stations.

Several stations in California are already using solar or wind energy to create hydrogen from water. Hydrogen can also come from biogas, such as landfill gas, and biomass, such as food processing waste. Hydrogen stations can also become energy stations, providing fuel for vehicles and electricity to nearby buildings.

## A proven way to make hydrogen is in place now.

### We can fuel vehicles with hydrogen today and get clear environmental benefits.

The critics say: We're still using fossil fuels to produce hydrogen.

## Truth: Hydrogen has many feedstocks, including fossil and non-fossil sources.

Today, most hydrogen is made from natural gas. It's safe, efficient and cost effective. A 2% increase in U.S. natural gas production would support 10 million fuel cell vehicles annually.[5] Coal, nuclear energy and biogas can also be used to produce hydrogen.

Additional projects to produce hydrogen from clean energy are underway. In British Columbia, Canada, one project is using waste hydrogen from a sodium chlorate manufacturing plant to provide hydrogen fuel to transit buses and power to a nearby building. Sierra Nevada Brewery in Chico, California, converts methane from a wastewater treatment system into hydrogen for fuel cells that provide electricity as part of the brewing process. The Orange County Sanitation District is building an energy station that will convert sewage waste into hydrogen for vehicles and electricity for the pumping station. National labs and universities in the United States are conducting research that involve collecting hydrogen from sewage treatment plants, bacteria, algae, rice straw and wood chips.

Every region of the world can make hydrogen from its own natural resources. Domestically produced fuel and feedstocks reduce overall emissions and decrease energy use simply because the fuel is not transported by rail, ship or truck. Hydrogen for fuel cell vehicles can also be made at the fueling station, further reducing distribution and transportation costs.

5 "10 Things to Know about Hydrogen," $H_2$&You, *www.h2andyou.org*

The critics say: People will change their lifestyles to have an efficient, zero-emission vehicle.

## Truth: Some people are, but most people want what they have today…only better.

According to a study by the Department of Transportation, Americans average four trips a day, totaling an average 40 miles of travel—most of it in a personal vehicle.[6] The most-recent *American Community Survey: Transportation Profile* conducted by DOT revealed that about 55% of American families have two or more personal vehicles in their household. (Figure 9)

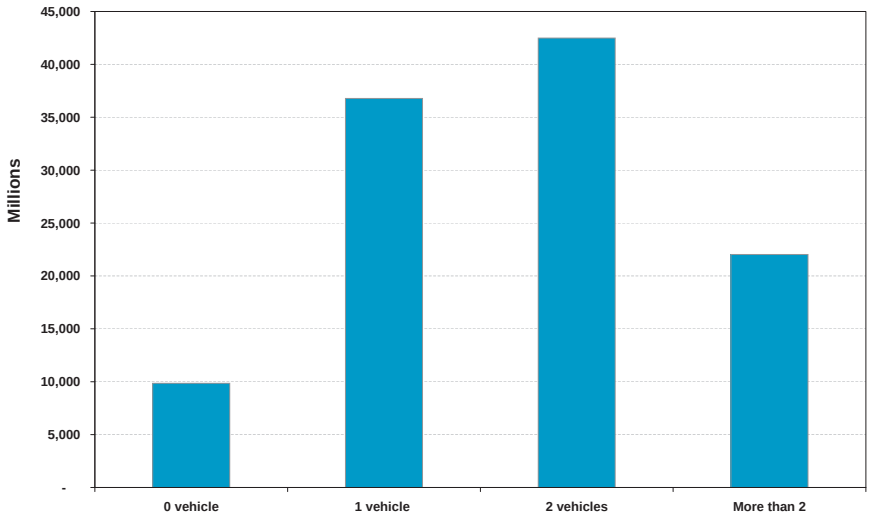


**Figure 9: American family vehicle ownership**

These, and similar studies, lead to the statement that vehicles with limited range will fit most drivers' needs. People do not, however, buy a car for the average day. They buy vehicles for the days that are the exception—those days when they run 100 miles in errands, drive 300 miles to visit relatives, go camping for the weekend, tow a boat or drive the soccer carpool. Most people do not rent a car for the exceptional days, or own a second car that fills those needs. They expect their primary car to fit their lifestyle every day of the week. Fuel cell vehicles using hydrogen are family-friendly, full-function vehicles that fit peoples' lifestyles, are very fuel efficient and have zero tailpipe emissions.

6 2001 *American Community Survey: Transportation Profile*

In October 2007, the California Fuel Cell Partnership surveyed licensed drivers in California about the alternative fuel vehicles they want to drive. Each respondent saw several lists of characteristics, such as speed or range, and was asked to choose one characteristic from each list that was most important in their next vehicle. By a large margin, most respondents wanted a mid-sized sedan, SUV or minivan capable of at least 65 miles per hour and a range of 300 miles between fueling. They also cited zero tailpipe emissions as the most important environmental benefit and fuel efficiency as the most important other characteristic.

**FCVs are the best option for a clean, every-day car, replacing a vehicle that is on the road today.**

## CONCLUSION

Fuel cell vehicles powered by hydrogen offer an excellent choice for meeting California's air quality, greenhouse gas reduction and energy use goals. They will provide California—and the world—with a full-function vehicle that uses less fuel, produces zero tailpipe pollution and uses a domestic fuel source that can be petroleum-free.

When making hydrogen from natural gas, the well-to-wheels GHGs are at least 55% less compared to gasoline through a combustion engine, and about 40% less than that of gasoline through a hybrid engine. Data from demonstration vehicles on California's roads today shows that some FCVs are more efficient than well-to-wheels reports estimated. Some are already exceeding the reports' efficiency projections for 2010 and 2012 model year vehicles.

Automakers plan that fuel cell vehicles will first enter the commercial market in 2015. By 2030, enough people will have replaced a gasoline vehicle with an FCV to impact the environment. As the number of FCVs increases and combustion engine vehicles decreases, researchers project dramatic drops in fossil fuel use, GHGs and criteria pollutants by 2050.

Today, 300 fuel cell vehicles have been placed on California's roads and refuel at more than two dozen hydrogen stations. For more data, research and information about the fuel cell vehicles on the road today, please visit www.cafcp.org/welltowheels.

www.cafcp.org

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The California Fuel Cell Partnership is a collaboration of auto manufacturers, energy providers, government agencies, fuel cell technology companies and transit agencies that work together to promote the commercialization of hydrogen fuel cell vehicles.

The members of the California Fuel Cell Partnership believe fuel cell vehicles powered by hydrogen have the potential to change the future of transportation.

For a complete list of members, please visit us at
**www.cafcp.org**

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