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By Annie Birdsong

Excerpted from the March/April 2005 WORLD WATCH magazine

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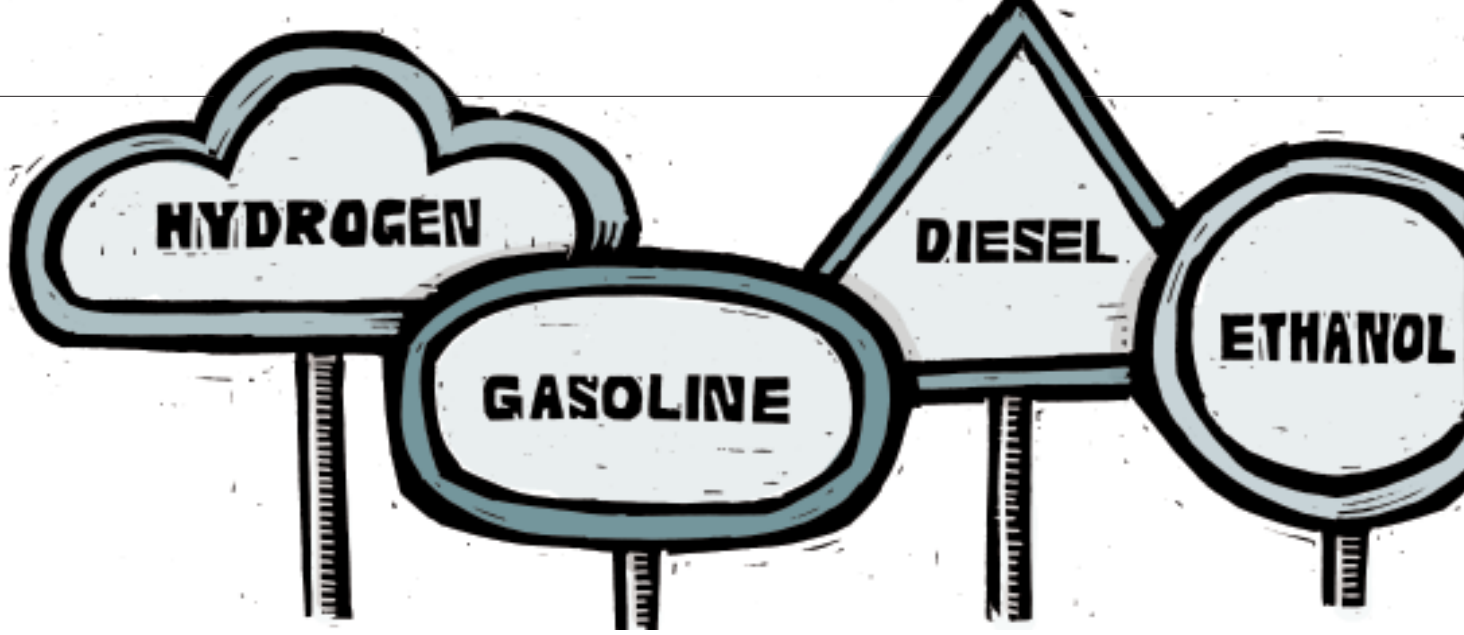


California Drives the Future of the Automobile

By Annie Birdsong

In October 2003, California Governor Arnold Schwarzenegger came to office in a recall election promising to create the world's first "hydrogen highway," with hydrogen fueling stations situated along the state's major roads. "I intend to show the world that economic growth and the environment can coexist," he told constituents in his January 2004 "state of the state" address.

This may sound strange coming from a former Hollywood action hero who has owned at least seven Hummers, gargantuan vehicles that get only 10 to 12 miles per gallon. But Schwarzenegger is coming through on his promise. Six months after taking office, he signed an executive order to develop the new California Hydrogen Highway Network by 2010. The goal is to speed the commercialization of fuel cell vehicles that run on hydrogen, one of the cleanest energy carriers* in existence (see sidebar, next page).

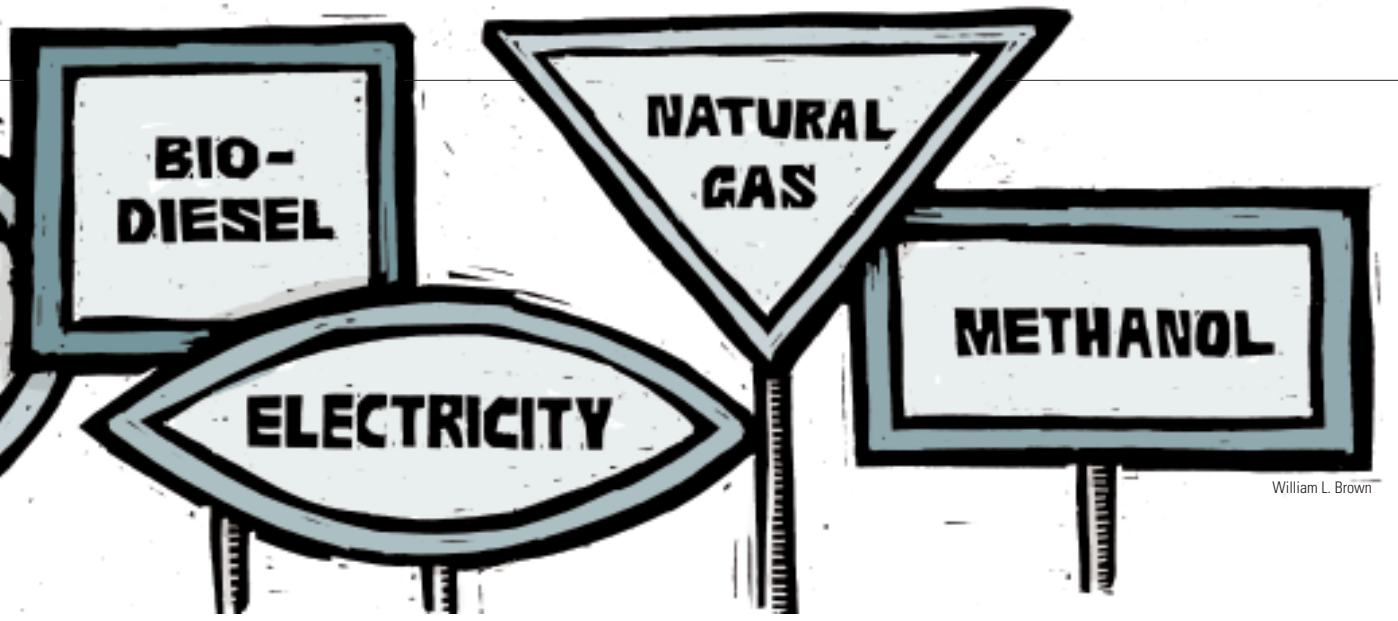
Shifting the state's transportation system, including its 10,000 retail gasoline outlets, away from petroleum and toward alternative fuels would be a milestone for California—and for the world. California currently leads the United States in gasoline consumption; its 30 million cars, trucks, and buses guzzle more than 40 million gallons each day. These mobile sources accounted for nearly 60 percent of the state's carbon dioxide emissions in 2003, and today more than 90 percent of Californians live in areas where air quality fails to meet federal standards.

State officials hope the new Hydrogen Highway will help California meet and even exceed its air pollution targets, among the most stringent in the world. In 1990, the state adopted legislation requiring that 10 percent of new vehicles produced for sale by 2003 be "zero-emissions" (a standard that has since been modified to require that two percent of vehicles sold be zero emissions and another eight percent be low-emission hybrids or super-clean vehicles). And in 2002, California became the first state or country to regulate the global warming impacts of motor vehicles, requiring automakers to cut emissions of carbon dioxide, methane, nitrous oxide, and several other pollutants by 30 percent starting in 2009. Not surprisingly, car companies have contested the ruling in court.

Many analysts view hydrogen as the obvious means of storing and moving energy in a post-fossil-fuel economy. It has strong allure as a long-term gasoline replacement because, unlike carbon-based fuels, it is abundant and releases only water vapor (when used in fuel cells). Moreover, hydrogen can be derived from water using almost any form of energy, including renewable resources such as solar energy, wind power, and biomass derived from crops and waste. (For the near term, however, the most economical source of hydrogen is likely to be fossil fuels, particularly natural gas.)

Terry Tamminen, former head of California's Environmental Protection Agency and now the state's cabinet secretary, has outlined an early network of 150–200 hydrogen fueling stations, or roughly one station every 20 miles along the state's 21 interstate freeways. The

* Strictly speaking, hydrogen (like electricity) is an energy carrier, not a fuel. Coal and oil contain latent energy put there by geologic processes over millions of years, but hydrogen doesn't exist anywhere in untapped pools or deposits. It must be "manufactured" by using another form of energy—which is why it's more accurate to say that it "carries" the energy expended to separate it from water or hydrocarbon fuels. We use the term "fuel" in this article as convenient shorthand.



William L. Brown

Impatience with fossil fuels is shaking California, which is the world's sixth-largest economy and has the dirtiest air in the United States. The state's leaders have their sights set on hydrogen.

pumps will be located in the maintenance yards of bus stations, at rest stops along highways, in the parking lots of "big box" retail stores, and perhaps ultimately at some of the 250 stations that now sell natural gas in the state. The goal is to make hydrogen accessible to most Californians, Tamminen says: "If you get the baseline network evenly distributed around the state, you can give confidence to consumers that…they will find the fuel."

You First

For a long time, hydrogen has been plagued by a "chicken or egg" problem. Developers of hydrogen fueling facilities have been reluctant to invest too heavily in the sites because very few vehicles can actually use them. And with only a handful of filling stations out there, automakers have held back from large-scale production of fuel cell vehicles. "To get this to work, both the hydrogen infrastructure and the technology that uses it need to be developed in parallel," notes Bob Wilkinson, lecturer in environmental studies at the University of California at Santa Barbara.

More recently, investors have embraced a more integrated strategy. The bulk of the funding for California's initial hydrogen network—estimated to cost anywhere from $74 million to $200 million—is expected to come from private partnerships, with

About Hydrogen Fuel Cells

Fuel cells are an electrochemical technology in which hydrogen and oxygen combine in the presence of a catalyst to produce electricity. In a fuel cell vehicle, the electricity is used to power one or more electric motors. The only byproducts are heat and water vapor, making fuel cells one of the few true "zero-emissions" technologies. Fuel cells are also much more efficient than gasoline engines and somewhat more efficient than diesels.

There are at least half a dozen types of fuel cells, with varying compositions, electrolytes, and operating characteristics. Several types, including those that use phosphoric acid and molten carbonate as electrolytes, have been manufactured in sufficient numbers to show their value as power sources for buildings or factories. Proton exchange membrane fuel cells, which operate at much lower temperatures, are favored for development in vehicles despite their current high costs. Some prototype fuel cell vehicles have demonstrated impressive acceleration and driving range, though their manufacturing costs remain very high. They have fewer moving parts, however, and in principle may thus be quieter, smoother, longer-lived, more reliable, and potentially easier and cheaper to maintain, than comparably performing gas-powered vehicles. Also in principle, fuel cell vehicles could even serve as miniature power stations, supplying electricity to the grid during non-use hours.

Some post offices, banks, computer centers, and businesses are already taking advantage of the reliable, uninterrupted, and decentralized energy provided by fuel cells, or are using them for backup power. Fuel cells can also be made very small and could be used to run everything from laptop computers to cell phones, with the hydrogen stored in refillable cartridges no larger than a ballpoint pen.

limited support from federal, state, and local governments. Key players include the California Stationary Fuel Cell Collaborative, a group of organizations working toward the commercialization of stationary fuel cells in the state, and the Sacramento-based California Fuel Cell Partnership, a coalition of public and private stakeholders that seeks to advance new fuel cell vehicle and hydrogen infrastructure technologies. One Partnership member, Toyota, is building some of the fueling stations as well as experimenting with prototype fuel cell vehicles.

Today, enthusiasm for hydrogen is soaring in California. As of December 2004, the state boasted more than a dozen fueling facilities, including sites in Los Angeles, Davis, and Oakland. Another 20 or so are slated for development in the next few years under the Hydrogen Highway initiative. These early stations will provide hydrogen mainly for stationary fuel cells used by buildings and industry, according to state officials. Ultimately, however, they will be used to fuel a growing fleet of fuel cell cars, buses, and other vehicles. The California Fuel Cell Partnership has placed 55 prototype fuel cell vehicles on California roads and plans to have some 300 passenger cars in use by the end of 2007.

California isn't the only place experimenting with hydrogen as a way to meet its future energy and transport needs. In June 2002, a demonstration station offering compressed hydrogen opened in Las Vegas, Nevada, and the city is now converting a fleet of vehicles to run on the gas. A new hydrogen-dispensing pump was also recently installed at a Shell gas station in Washington, D.C.—the first in the country to be housed at a public station, though for now only a handful of vehicles can actually use it. Several other countries have similar visions of hydrogen highways (see sidebar).

A World of Hydrogen Highways?

The United States is far from the only country with dreams of a Hydrogen Highway. Several others, including Canada, China, Germany, Iceland, Japan, and Norway, are eagerly embracing hydrogen's potential. At a 2003 meeting in Washington, D.C., the state secretary of Norway's Ministry of Petroleum and Energy, Brit Skjelbred, announced a 500-kilometer Norwegian Hydrogen Highway, as well as exemptions from registration fees and annual taxes for hydrogen-powered vehicles. Germany opened its first public hydrogen filling station (in Berlin) in November 2004, and China hopes to build facilities in Beijing to support fuel cell buses for use at the 2008 Olympic Games.

Iceland, meanwhile, aims to be the world's first hydrogen-based society, completely free of fossil fuels by mid-century. Shell Hydrogen opened the world's first hydrogen filling station in the capital, Reykjavik, in April 2003. Reykjavik was also the first of 10 European cities to establish a hydrogen bus program as part of the 30-bus Clean Urban Transportation Europe project. Today, white clouds of steam, rather than noxious pollutants, trail from several city buses. Political leaders hope to eventually convert the country's fishing fleet and aircraft to hydrogen as well. They have strong support: according to surveys, public acceptance of Iceland's hydrogen initiative tops 92 percent.

—Lisa Mastny

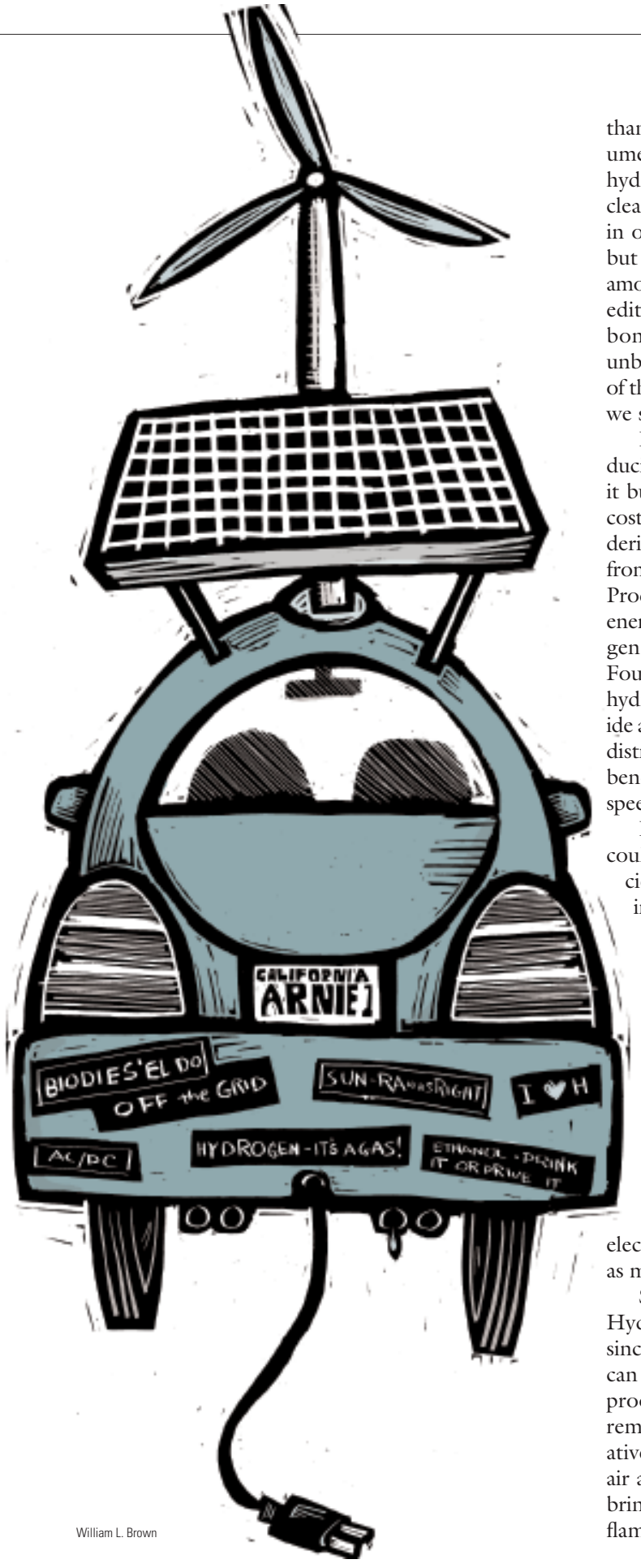
Many Paths

Making hydrogen for fueling is a challenge, however. While the element is abundant in nature, it is usually tied up with other substances, such as the oxygen in water or the carbon in other fuels. To produce the hydrogen, some of the stations along California's Hydrogen Highway will electrolyze water, using electricity to break the molecular bonds and isolate the gas. Other stations will liberate the hydrogen from hydrocarbon fuels, such as natural gas, gasoline, and methanol, via a process known as steam reforming.

Several companies hope to bypass the costly highway infrastructure by bringing hydrogen fueling capacity directly to people's homes. Toronto-based Stuart Energy is developing a home fueler about the size of a dishwasher that will enable homeowners to produce their own hydrogen by water electrolysis. Installed in the garage, the unit could fuel a vehicle overnight, when electricity rates are sometimes lower. (Alternatively, homeowners could install rooftop solar panels to avoid the environmental impacts of fossil-fuel electricity generation.) The Latham, New York-based company Plug Power is working with Honda to develop a home fueler that produces hydrogen by natural gas reforming.

Some drivers prefer not to wait for fuel cell vehicles to come on the market and are instead converting traditional internal combustion engines (ICEs) to burn hydrogen directly. (Fuel cells don't burn hydrogen, they produce electricity without combustion. ICEs, however, can burn hydrogen after engine adjustments.) Several manufacturers, including Ford Motor Company and BMW, have developed demonstration vehicles with hydrogen-burning engines. "We can build and sell them right now," Ford's vice president for environmental and safety engineering, Sue Cischke, told reporters in 2004. The main impediment, she noted, is a hydrogen fueling infrastructure, along with uniform regulations to allow the use of hydrogen vehicles across the United States.

Hydrogen packs in more power per unit of weight



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than gasoline, though much less power per unit of volume, which is why developing ways to store sufficient hydrogen fuel is a top priority. It is, however, much cleaner, releasing fewer byproducts even when burned in ordinary engines. "The exhaust is almost nothing but harmless water vapor plus trace emissions from tiny amounts of engine lubricants," explains Peter Hoffman, editor of the *Hydrogen & Fuel Cell Letter*. "No carbon monoxide or carbon dioxide is emitted. No unburned hydrocarbons, no stench, no smoke, nor any of the other carbon-bearing, earth-befouling discharges we suffer today."

Even though hydrogen itself is clean, however, producing it isn't always environmentally friendly, whether it burns in an engine or powers a fuel cell. The most cost-effective methods of liberating hydrogen today—deriving it from natural gas or water using electricity from fossil-fuel power plants—are still quite polluting. Producing hydrogen is also inefficient, as it takes more energy to isolate the gas than is contained in the hydrogen itself. In a recent report, the libertarian Reason Foundation noted that many of the "clean" benefits hydrogen brings would be offset by the carbon dioxide and other emissions generated in manufacturing and distributing it. The group argues that environmental benefits can be better achieved with lower highway speeds, smaller cars, and increased conservation.

Environmentalists, however, say these concerns could largely be addressed with greater engine efficiencies—which would help offset the energy used in producing the hydrogen—as well as the widespread use of renewable energy for water electrolysis. With solar energy powering the production process, for instance, hydrogen would be the ultimate clean energy carrier, the equivalent of storing sunshine in your tank. Schwarzenegger himself has promised that a "significant and increasing percentage" of the hydrogen offered on his Highway will be produced using renewable energy. (However, he recently vetoed legislation that would have accelerated California's transition to renewables. The bill would have required power suppliers to obtain at least 20 percent of their electricity from renewable sources by 2010, not 2017 as mandated in earlier legislation.)

Safety issues could be another stumbling block. Hydrogen can leak through many substances, and since it is odorless and burns with a clear flame, leaks can be hard to detect. Designing high-pressure, leakproof storage tanks for fueling stations or vehicles remains a challenge. Yet the risk of an explosion is relatively low. The gas is so light that it disperses into the air almost immediately, and it's almost impossible to bring it to an explosion in the open with a spark or a flame. (Contrary to popular perception, the 1937 fire

aboard the *Hindenburg* did not begin with ignition of the hydrogen lifting the airship, but of its highly flammable cellulose, iron oxide, and aluminum skin.)

The Sunny Side of the Street

Dan Sperling, director of the Institute of Transportation Studies at the University of California at Davis, says it's important not to put hydrogen in a negative light. "It does have safety concerns, but so does gasoline. Consider the many fires and explosions from gasoline. None of these would have happened with hydrogen." Some researchers advocate that hydrogen be mixed with a colorant or with small quantities of gaseous hydrocarbons to increase flame visibility. Sensors are also being developed that will detect hydrogen leaks and cause an automatic system shutdown if an accident occurs.

Until hydrogen's kinks are worked out, California is hedging its bets by embracing a range of other automotive technologies in its transition away from fossil fuels. Alternative fuel options include ethanol and biodiesel, a cleaner-burning diesel made from renewable sources such as vegetable oils. California is also doing more than any other state to promote purchases of hybrid vehicles that run on both gasoline and electricity, such as the Toyota Prius, the Honda hybrids (Civic, Accord, and Insight), and the Ford Escape hybrid. Statewide incentives, including purchasing rebates and exemptions from parking fees, appear to be working: of the roughly 84,000 hybrids sold in the United States in 2004, more than a third were bought in California.

Andy Frank, head of the Hybrid Electric Vehicle Design Center at the University of California at Davis, is a strong promoter of "plug-in" hybrids, a transitional technology he says is ready to go. He and his students have converted nine sedans and sport utility vehicles to the technology, which enables the machines to travel up to 60 miles on electricity supplied by a battery, after which the gasoline engine kicks in. Frank says widespread use of plug-in hybrids could cut California's gasoline consumption by 90 percent, given that most of the state's drivers travel only 30 miles a day. With the plug-in option, drivers could recharge the battery at an outlet when not in use, either at home or at any of California's 519 existing electric-charging stations. Frank is now working with a group called the California Car Initiative (CalCars) to promote the wider adoption of the technology.

In the end, while hydrogen's promise is huge, its ultimate place in the energy regime remains murky. There is a serious debate about hydrogen, a debate as volatile as the gas itself. As suggested earlier, hydrogen boosters argue that it is the inevitable fuel system of the near future, while skeptics believe it may be decades, if ever, before hydrogen plays any significant role in the energy economy. The credibility of the hydrogen dream depends heavily on the analytic assumptions used, and the speed with which that dream is realized—or shattered—will be determined by the policy choices governments make.

In that light, California's determined pursuit of its own hydrogen dream is significant. On October 22, Governor Schwarzenegger opened the state's first retail hydrogen fueling station, at Los Angeles International Airport. True to an earlier promise, he pulled up to the pump in a converted hydrogen Hummer. The prospect of multitudes of such vehicles plying the state's Hydrogen Highway could still be distant, but nevertheless the world's transportation future somehow seems a little more hopeful.

Hydrogen Fuel Cell Milestones

1839 Welsh judge and physicist Sir William Robert Grove conceives the first fuel cell by mixing hydrogen and oxygen in the presence of an electrolyte. The device produces water and electricity, though not enough to be useful.

1889 Researchers Charles Langer and Ludwig Mond coin the term "fuel cell" as they attempt to engineer the first practical fuel cell using air and coal gas.

1920s German engineer Rudolf Erren adjusts the internal combustion engines of trucks, buses, and submarines to burn hydrogen or hydrogen mixtures.

1932 Engineer Francis Bacon develops the first successful fuel cell using alkaline electrolytes and nickel electrodes. In 1959 he demonstrates a five-kilowatt fuel cell that can power a welding machine.

1959 At Allis-Chalmers, engineer Harry Karl Ihrig invents a 20-horsepower fuel cell farm tractor.

1960s NASA begins using fuel cells and hydrogen made from water electrolysis to power spacecraft and supply astronauts with pure drinking water.

1994 Daimler demonstrates a fuel cell vehicle, Necar 1. Since then most of the world's major automakers have developed prototype hydrogen fuel cell vehicles.

1998 Two-year road tests begin on three hydrogen buses in Chicago and three in Vancouver, Canada.

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For more information about issues raised in this story, visit **www.worldwatch.org/ww/hydrogen/**.