Deceleration? Ford engineers celebrate breaking 200 mph with the company's hydrogen car, a technology now out of favor with the Obama Administration.

CREDIT: WENN/NEWSCOM

TRANSPORTATION RESEARCH

Hydrogen Cars: Fad or the Future?

The Obama Administration wants to end the hydrogen fuel cell vehicles program, which proponents see as the ultimate clean-car technology

In May 2007, engineers from General Motors pumped 8 kilograms of compressed hydrogen gas into each of two GM Sequels, among the company's most advanced hydrogen fuel cell cars. The fuel, produced by splitting water into hydrogen and oxygen, was generated using renewable electricity from nearby Niagara Falls, on the U.S.-Canadian border.

The two cars were driven 482 km, from Rochester to Tarrytown, New York. Instead of emitting roughly 90 kilograms of carbon dioxide (CO_2) during the journey, their tailpipes puffed only water vapor. "It was the world's first 300-mile drive that was petroleum-free and emissions-free on a single tank of fuel," explained GM's R&D chief, Larry Burns, at an alternative fuel vehicles meeting in March 2008.

The drive may have been historic, but it didn't impress the Obama Administration. Last month, Energy Secretary Steven Chu announced that the Department of Energy (DOE) was putting the brakes on research into automotive hydrogen fuel cells. Chu cites the cost and durability of vehicle fuel cells, the inability to store large volumes of hydrogen fuel, the absence of a carbon-free way of generating the hydrogen, and the need to build a nationwide refueling infrastructure. The issue came down to a simple question, says Chu: "Is it likely in the next 10 or 15 or even 20 years that we will convert to a hydrogen-car economy? The answer, we felt, was no."

But many scientists and energy experts believe Chu asked the wrong question and, therefore, made the wrong call. No alternative-vehicle technology will make a major impact on carbon emissions, petroleum use, or anything else within the next 20 years, they say, because it takes longer than that for a new technology to displace what is already on the road. In the long run, they say only two technologies—hydrogen fuel cells and electric vehicles—are capable of getting the job done. And only one variation, plug-in hybrids, will be on the market anytime soon. "There are uncertainties with both these technologies," says Joan Ogden, who heads the sustainable transportation energy program at the University of California, Davis. "So the idea of taking one off the table seems shortsighted."

Some influential politicians are also unhappy with Chu's proposed policy shift and have vowed to block the cuts. "I, for one, am not interested in shutting down these research projects," says Senator Byron Dorgan (D–ND), who chairs the spending panel that will act on the president's 2010 budget request, which saves $100 million by eliminating the vehicle portions of the program while maintaining $68 million for stationary fuel-cell power plants viewed as closer to the market. Speaking at a hearing last month during which Chu laid out the Administration's plans, Dorgan declared, "We are going to do everything we can to continue the [vehicle program]."

Making the case

Invented in 1839, fuel cells use catalysts to combine hydrogen and oxygen to produce water and electricity. Their ability to generate electricity without CO_2—at least within the fuel cell itself—has spawned recurring visions of a carbon-free hydrogen economy. The Bush Administration embraced the idea in 2003 when it rolled out what became a $1.5 billion research program to make hydrogen fuel cell vehicles practical and affordable. Since then, car companies have spent billions of dollars of their own money and produced two generations of cars, 318 of which remain on the road. Toyota, GM, and Honda have said that they will continue to invest in the technology regardless of what DOE decides to do.

Hydrogen proponents don't dispute that hydrogen fuel cell technology lags a few years behind plug-in hybrids. However, they argue that it's improving rapidly in virtually all areas. "We cannot abandon one of the most promising technologies around just because it is not ready for commercialization in the next 2 years," says Ronald Grasman, an automotive engineer who manages fuel-cell market development for Daimler in Kirchheim, Germany.

Grasman and others point out that the ultimate goal is not how quickly alternative-fuel vehicles are adopted but how fast greenhouse gas emissions and the use of petroleum can be reduced. Even if plug-in hybrids hit the market first, their impact on carbon emissions will be modest initially because they rely on electricity generated primarily by burning fossil fuels. A recent analysis by C. E. "Sandy" Thomas, whose Virginia company H2Gen Innovations makes reformers that convert natural gas into hydrogen, found that hydrogen cars would actually reduce CO_2 emissions more than plug-ins would by 2030, and the gap widens as the decades pass.

A big reason is their source of power. Most electricity in the United States is generated by burning coal, Thomas notes, and coal emits nearly twice as much carbon as does natural gas, the fuel most commonly used to generate hydrogen. In addition, fuel-cell electric engines are twice as efficient as the combustion engines that are still required in hybrids. A clean, carbon-free source of energy is needed for either fuel cell or electric vehicles to meet their potential, Thomas acknowledges.

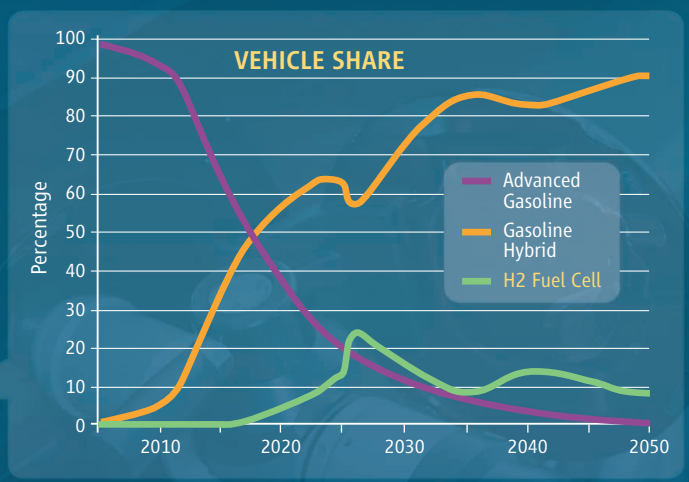
The Obama Administration has already called for cutting U.S. carbon emissions 80% below 1990 levels by 2050. In the transporta-

Published by AAAS

THE CASE **AGAINST** HYDROGEN FUEL CELL CARS...

Energy Secretary Steven Chu says there are no quick fixes to these pressing technological challenges:

- **Inexpensive and long-lasting fuel cells**
- **Adequate fuel storage capacity at a reasonable price**
- **A carbon-free way to generate the hydrogen**
- **A nationwide refueling system**



▲ **Niche player.** Hydrogen cars lose out to gasoline hybrids under this DOE scenario, in which storage costs remain high.

tion sector, which accounts for more than one-quarter of all carbon emissions, "you can't accomplish that without hydrogen vehicles," says Robert Shaw Jr., a venture capitalist and founder of Aretê Corp. in Center Harbor, New Hampshire. Shaw was vice chair of a National Research Council (NRC) panel that looked at the viability of hydrogen cars and their potential impact by 2050.

The NRC report, published last year, concluded that improvements in conventional vehicles, switching to gas-electric hybrids, and using biofuels would be the best first step in reducing CO_2 emissions. But "hydrogen offers greater longer-term potential," reads the report. "The greatest benefits will come from a portfolio of R&D technologies that would allow the United States to achieve deep reductions in oil use" by 2050. A follow-on NRC panel is now reviewing the role of plug-ins.

An uphill road

DOE officials, from Chu on down, would probably agree with that overall assessment of the promise of hydrogen vehicles. But that doesn't mean they think they're a safe bet. "There is really a lot of progress, but issues remain," says Sunita Satyapal, who directs DOE's hydrogen program.

One major concern is price, in particular, the high cost of precious-metal catalysts. Today's fuel cell engines could be built for $73 a kilowatt if mass-produced, according to a recent DOE estimate, a 74% drop since 2002 but still more than twice the 2015 target price.

The range of today's cars is also a problem. High-pressure tanks used by today's fuel cell cars hold enough fuel for the average fuel cell car to travel 320 km, according to the latest tally from researchers at the National Renewable Energy Laboratory in Golden, Colorado. By 2015, DOE hopes to achieve 480 km, a distance that would satisfy consumers.

Durability is another issue. Some of the fuel cell cars have operated for 2000 hours without need of servicing, the equivalent of driving 96,000 km, and DOE would like to boost that number to 5000 hours. Finally, despite hydrogen's widespread use in industry, no infrastructure exists for producing vast amounts of hydrogen and delivering it to drivers when and where they need it.

Given these hurdles, Chu and his DOE colleagues argue that it makes more sense to focus on areas with the potential to make the quickest impact, notwithstanding that the average car stays on the road for 15 years. "With plug-in vehicles, you can start that process now," says Patrick Davis, who heads DOE's Vehicle Technologies Program in Washington, D.C. "With other technology, you have to start that clock later." Mass-produced hydrogen cars may be 2 decades away. And if the onboard hydrogen-storage problem isn't solved, customers simply won't buy the cars.

Fuel-cell cars aren't the only alternatives facing a rough road, however. Battery electric vehicles (BEVs) have cost and technology problems of their own. Mass-produced BEVs with a range of more than several dozen kilometers are years away. And better batteries will be expensive.

A 2007 study by automotive engineers John Heywood and Matthew Kromer at the Massachusetts Institute of Technology in Cambridge projected the cost of various advanced technologies and found that all make a bigger dent in the wallet than advanced internal combustion engines. A plug-in hybrid with an all-electric range of only 16 km would cost an extra $3000, for example, whereas an electric vehicle with a range of 320 km would add $10,200 to the sticker price. The long-distance winner, a hydrogen car that could travel 400 km between fill-ups, would cost an extra $3600.

"None of these technologies are free," Shaw says. Adds Heywood: "It's really battery cost versus fuel-cell cost. Cost reduction is a major challenge for both these paths." Klaus Bonhoff, managing director for Germany's National Organization for Hydrogen and Fuel Cell Technology, agrees: "People are overselling battery technology today. They will not be able to do the [complete] job that people expect."

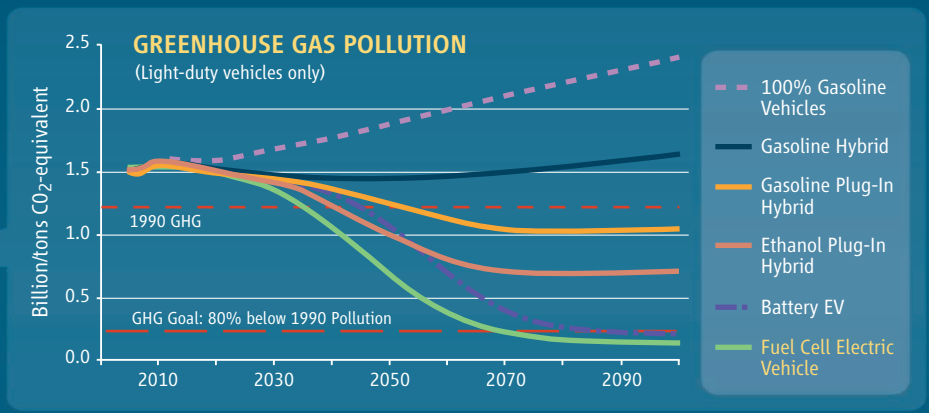
(IMAGES) PEG SKORPINSKI; NATIONAL HYDROGEN ASSOCIATION; (GRAPH) ADAPTED FROM D. L. GREENE *ET AL.*, OAK RIDGE NATIONAL LAB (2009)

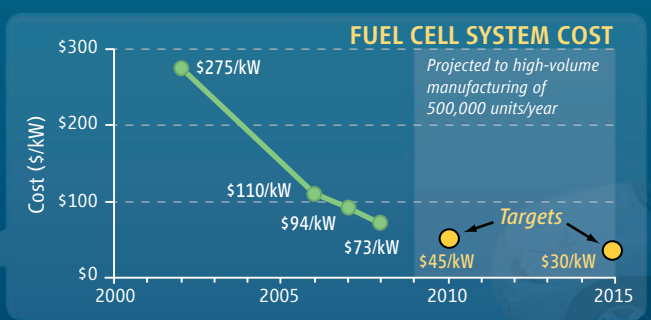
Published by AAAS

THE CASE **FOR** HYDROGEN FUEL CELL CARS...

Proponents say hydrogen cars are a good bet because:

- They will eventually deliver the biggest reduction in greenhouse gas emissions
- Electric vehicles face similarly tough challenges
- The nation needs a balanced fleet of alternative vehicles
- The cost of making the fuel cells is approaching DOE targets





▲ **Clean sweep.** Fuel cell vehicles reduce greenhouse gas emissions faster than any other technology in the U.S. fleet.

CREDITS (TOP TO BOTTOM): C. E. THOMAS/NATIONAL HYDROGEN ASSOCIATION ANNUAL CONFERENCE (2009); SUNITA SATYAPAL/DOE (2009)

Both technologies need to develop a better way to deliver energy to consumers. Hydrogen would appear to face the bigger challenge: Only 71 hydrogen refueling stations exist in the United States and Canada, and the distribution system is likewise scant. The NRC panel estimated that the U.S. federal government would need to spend about $10 billion between 2008 and 2023 to develop a self-sustaining hydrogen-fuel infrastructure and another $44 billion on tax credits and other subsidies, while industry invests $145 billion.

In comparison, the nation already has an electric utility grid, and a 2006 study by researchers at the Pacific Northwest National Laboratory found that the existing grid could charge up to 70% of all cars and light trucks in the United States if they were plug-ins that were charged overnight when idle generation capacity is available. But battery-powered cars also need sockets into which to plug. A 2008 study by researchers at the Idaho National Laboratory estimated it would cost $878 to $2146 to add the home circuits needed to charge a plug-in. And recharging takes several hours, compared with just a few minutes for a hydrogen fill-up.

Then there's fuel storage, which DOE's Satyapal says remains a "significant challenge" for hydrogen cars. In recent years, DOE has backed research on some 200 different storage materials, ranging from packing hydrogen into metal solids called metal hydrides to a slurry of alane powder in a light mineral oil. To date, none meets DOE's targets for storing and releasing enough hydrogen fuel on demand.

But automotive engineers don't seem overly concerned. Daimler's new B-class fuel-cell engines have a range of 400 km using a tank that pressurizes hydrogen to 700 bar, and GM's Sequels have already gone farther than that. In addition, reducing the size and weight of the fuel cells and other electronic systems has left more room for larger storage tanks. "Storage technology is not the issue," Daimler's Grasman concludes.

The trends are similarly positive with respect to improving the durability of fuel-cell engines, lowering the cost of producing hydrogen, and finding a low-carbon means of doing so. Lab-based fuel cells have far surpassed DOE's 5000-hour benchmark, and natural gas can be turned into hydrogen for $3 per kilogram of hydrogen (the equivalent to how far a car will go on a gallon of gasoline). As renewable-energy technologies improve, they can be used to generate hydrogen as well as electricity.

The road ahead

Given this progress, many hydrogen experts were caught off-guard by Chu's announcement last month. "Everybody I know in the hydrogen field is just puzzled by this decision," Shaw says. Philip Ross, a retired chemical engineer from Lawrence Berkeley National Laboratory and member of a DOE technical panel that is supposed to advise DOE's upper management on the hydrogen program, says Chu did not contact the committee before announcing his new direction.

Chu and his aides also did not reply to requests from *Science* for comment. However, when he announced DOE's fiscal year 2010 budget, Chu said the department is not giving up on fuel cells altogether. In addition to continuing to support stationary fuel cells, DOE will back basic research to improve the catalysts and other components of the systems.

Even if Congress restores the program's funding, some hydrogen backers worry that Chu's statements have already damaged the industry. "It has really hurt the public perception of this field," Grasman adds. Such skepticism, when combined with the industry's overall financial woes, could undermine corporate support for the technology, Grasman contends.

That outcome would leave Chu in the position of supporting a policy that could significantly delay the potential climate and energy-security benefits he believes alternative vehicles can deliver. Says Shaw: "If you want to get to the volumes [of cars] necessary to make an impact, you have to begin immediately."

–ROBERT F. SERVICE

Published by AAAS