

Hydrogen: The Fuel of the Future?

With high U.S. gasoline prices worsened by Hurricanes Katrina and Rita, President Bush has urged Americans to conserve gasoline. Addressing a nation whose fleet of more than 200 million vehicles consumes 11 percent of the world's daily oil output¹, President Bush warned, "The storm has shown how fragile the balance is between supply and demand in America."²

Implicit in the president's comments is the reality that world energy consumption will increase 40-60 percent by 2020. By 2030, the global number of vehicles on the road is expected to rise by 50 percent. The United States currently imports 10-11 million barrels of oil per day—much of it from politically volatile regions of the world and dependent upon large, vulnerable transportation networks. With gas prices already a serious concern, and rising environmental pressures to address sources of global warming, alternative fuels for transport are a topic of serious public interest. Yet, only about 1 percent of vehicles on American roads run on anything other than petroleum.

Possible Alternatives

Feasible alternative sources of energy for transportation include hydrogen, electricity, and ethanol. Ethanol can be produced domestically from agricultural products and is renewable—but it is a land, labor and water intensive approach to fuel production, and international trade in ethanol is difficult because of agricultural protectionist sensitivities. Brazil is currently the world's leading user of ethanol, which powers about 25 percent of its vehicle fleet. Electrically (battery) powered vehicles are a possible alternative to oil—though the vast majority of electrical production is in turn dependent upon hydrocarbons, limiting pollution and consumption benefits. Electrical vehicles are also notoriously plagued with high battery costs and limited ranges and durations of operation.

With these disadvantages in mind, auto industries, science laboratories, and governments have turned greater attention toward hydrogen as a possible alternative fuel to succeed both in widespread production and distribution. The U.S. Department of Energy does not believe that a large scale hydrogen economy is likely until at least 2020, and many believe even that is an overly optimistic timeline. Even if implemented successfully by 2020, hydrogen substitution would take until

Hydrogen at a glance...

11%: The amount of world oil output consumed daily by the United States' 200 million vehicles.

\$8-\$15: Current cost of one kilogram of hydrogen, roughly the equivalent energy of one gallon of gas.

3-5 times: The reduction necessary in cost to make hydrogen a viable fuel, according to the U.S. Department of Energy.

Natural gas: The primary source from which to extract usable hydrogen fuel.

\$1.2 billion: Total projected budget of President George W. Bush's Hydrogen Fuel Initiative, underway since 2004.

\$50-\$200 billion: Amount of investment necessary over a ten to twenty year period to bring hydrogen fuel cell vehicles into mass production, according to Shell.

2040 to reduce U.S. oil imports by 10-11 million barrels per day—the equivalent of *current* oil imports. But to produce hydrogen, natural gas imports would skyrocket.

How Hydrogen Vehicles Work

"Hydrogen vehicle" is the shortened, common reference to a "hydrogen fuel cell-powered vehicle." In these vehicles, stacks of fuel cells—a legacy technology from the U.S. space program—split hydrogen molecules into hydrogen ions and electrons. From these fuel cells, electrons are harnessed to power onboard electrical systems and highly efficient electric motors that drive the vehicles. Oxygen molecules collected from the atmosphere bond with the volatile hydrogen ions in the fuel cells to create the end product of water (H₂O), which is vented into the atmosphere. For this reason, hydrogen fuel cell cars are considered zero emission vehicles. GM compared hydrogen fuel-cell cars to gasoline-powered vehicles and found that utilization of hydrogen cars would result in a 50 percent reduction in energy consumption and a 99 percent reduction in carbon monoxide emissions. Other advantages come in the form of a greatly reduced number of moving parts, no need for engine oil, and greater interchangeability of parts between vehicles.



Fuel cell vehicles have the added bonus of doubling as highly powerful electrical generators. If a mere 4 percent of the current U.S. vehicle fleet were replaced with hydrogen fuel cell vehicles, the combined capacity of these 8 million vehicles would equal the energy production of the entire U.S. electrical grid. The implications of these generators on wheels for emergency application and for use in developing countries and rural areas are potentially immense.

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A possible drawback to hydrogen is that it still requires energy to extract and concentrate in its elemental, usable form. However, this energy input could come from solar or other alternative sources. According to the development strategy of the European Hydrogen and Fuel Cell Technology Platform, hydrogen production would cost US\$1.21/kg² using natural gas, US\$4.53/kg² using grid electricity, US\$7.24-\$9.66/kg³ using wind, and US\$3.62-\$4.83/kg³ using biomass. In fact, through a variety of processes, industry already produces over 50 million metric tons of hydrogen each year for existing uses. GM has claimed that current hydrogen production could fuel 200 million hydrogen fuel-cell cars.

The Current Outlook for Hydrogen

The technology used in hydrogen fuel-cell vehicles is still undergoing serious refinement, but it is operational, largely reliable and acceptably safe. In 2001, Honda became the first automobile manufacturer to open a solar-powered hydrogen production and fueling station. According to the California Hydrogen Blueprint Plan, by the year 2010 California will have 2000 hydrogen cars in operation, with over 100 publicly accessible hydrogen-fueling stations. Hydrogen vehicles manufactured by Daimler-Chrysler, Honda, Toyota, GM and other companies are being tested under real world conditions in cities around the world.

On a hot, late July day, GM brought one of their HydroGen3 vehicles to CSIS following a Global Strategy Institute forum with GM's director of legislative and regulatory affairs, Keith Cole, examining the future of hydrogen vehicles. GM offered to let anyone with a license drive the vehicle, and curious volunteers zoomed around the block for a test drive, surprised by how much power the vehicle had and how quietly it ran.

If only the vehicle had been for sale at the right price, there would have been a number of potential buyers. The vehicle, though, still comes with its own full-time engineer and a price tag of about \$1 million per prototype.

The HydroGen3 vehicle can store 3.1 kg of hydrogen and has a range of up to 249 miles. One kilogram of hydrogen has roughly the energy equivalent of one gallon of gas. With this in mind, it is impressive to consider the efficiency of hydrogen vehicles. This GM

model goes roughly 83 miles per kilogram of liquid hydrogen. The cost of a kilogram of hydrogen is currently between \$8-\$15 due to high transport costs (discussed in the next section), but that cost should fall along with the cost of fuel cell technology and vehicles. The US Department of Energy (DOE) has established a new hydrogen cost goal of \$2.00-\$3.00/gasoline gallon equivalent (delivered, untaxed), reducing by three to five times its current cost. The CEO of Shell Hydrogen, Jeremy Bentham, has stated a similar target price for Shell. To that end, in the past year Shell has opened hydrogen and gasoline combination fueling stations in Los Angeles, Washington, D.C. and Reykjavik, Iceland, and they are planning more in New York City and elsewhere around the world.

Challenges to a Hydrogen Economy

A hydrogen economy faces many technical challenges and high startup costs mainly focused on infrastructure and storage.³ To make hydrogen vehicles practical, hydrogen fueling stations must be constructed and strategically located along roadways and in urban centers. GM proposes that it would cost US\$10-15 billion to establish a network of 11,700 stations in the most populous 100 urban areas in the U.S., and along 130,000 miles of highway connecting important transit zones. Shell Hydrogen has calculated that setting up a functioning network of hydrogen filling stations will cost \$20 billion for the U.S. and Europe, and \$6 billion for Japan. Despite these costs, Shell believes strongly in the future of the technology and has quickly established itself, in partnership with GM, as a leading innovator and advocate of the hydrogen economy.⁴

The cost of the fuel stacks used in hydrogen production and consumption remains too high to be economically competitive with fossil fuel engines. This high cost is due to the precious metals required for reaction catalysts. Hydrogen fuel also



remains too expensive. Much of the current cost of hydrogen is associated with transportation and storage (including in the vehicle). Scientists are, however, developing safer and more efficient methods to store hydrogen using metal hydrides, compressed storage, liquid storage, and carbon nanostructure storage. In order to be economically competitive, the cost of fuel cells must be lowered by a factor of at least 10, and the cost of producing hydrogen must be lowered by a factor of at least 4.⁵ This year, Toyota invested US\$2 million in a joint project with the Savannah River National Laboratory to research less costly solutions to hydrogen storage.



CSIS Global Strategy Institute intern Brandon Lord takes the GM HydroGen3 for a spin around the block in July 2005.

Who will pay?

Despite obvious private sector interest and involvement, many suggest that governments should bear the high costs of research and development to get the hydrogen economy off the ground in a timely way. In his 2003 State of the Union address, President Bush proposed a \$1.2 billion Hydrogen Fuel Initiative that has been funded since 2004 to help push forward with hydrogen technology and application. The E.U. has also acknowledged the role of the government, particularly in encouraging the public to adopt a hydrogen economy.

More realistically, as all parties freely admit, a system of public-private cooperation will be key to pushing forward with this bold initiative. The question will be how much funding is necessary to get the operation off the ground. Shell's Jeremy Bentham has said that bringing fuel cell cars from prototype to mass production will likely cost between \$50 and \$200 billion worldwide over a ten to twenty year period. Even then, Shell believes that hydrogen vehicles will not widely replace hydrocarbon vehicles. However, there will be an attractive market for manufacturers and energy suppliers.

Conclusions

Although hydrogen has gained significant support over the past decade, there are still many uncertainties about its widespread future and even about its potential side effects—environmental and otherwise—if utilized on a massive scale. Currently, natural gas is commonly used as a source from which to isolate hydrogen ions, meaning that unless alternative sources of energy are used, the US will remain dependent on non-renewable hydrocarbons—albeit in a less polluting and more efficient way. The bottom line is that the hydrogen economy is highly unlikely to replace oil in the next twenty years, though its presence as an alternative fuel will continue to grow.

Endnotes

- ¹ Jad Mouawad and Matthew L. Wald, "Prices Cause Concern, but Little Change in Behavior or Laws." *New York Times*, July 12, 2005, C1.
- ² US Department of Energy, "President Discusses Hurricane Effect on Energy Supply." September 26, 2005. Available <http://www.whitehouse.gov/news/releases/2005/09/20050926.html>.
- ³ GM Fuel Cell Technology: Prospects, Promises and Challenges, GM. Available at http://www.gm.com/company/gmability/adv_tech/400_fcv/fc_challenges.html.
- ⁴ Shell, "Lighthouses for Hydrogen" *Shell Venster*, Nov. 2004. Available at www.shell.com/static/hydrogen-en/downloads/speeches/interview_lighthouses.pdf
- ⁵ U.S. Department of Energy: Energy Efficiency and Renewable Energy, "Basic Research Needs for the Hydrogen Economy: A Report by the Basic Energy Sciences Advisory Committee," ix. Available at <http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/beshydrogen.pdf#search='Basic%20Research%20Needs%20for%20the%20Hydrogen%20Economy'>
- ⁶ Tromp, T.K., et al. Potential Environmental Impacts of a Hydrogen Economy on the Stratosphere. *Science* 300(5626): 1740-1742.
- ⁷ David W. Keith and Alexander E. Farrell, "Rethinking Hydrogen Cars," *Science* 301 (2003): 315. Available at: <http://www.ucalgary.ca/~keith/papers/63.Keith.2003.HydrogenCars.e.pdf#search='hydrogen%20cars%20bad'>

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