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# Hydrogen's Empty Environmental Promise

## by Donald Anthrop

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## Executive Summary

Politicians on both the Left and the Right have increasingly embraced subsidies for hydrogen-powered fuel cells as a promising way to move America away from reliance on petroleum. Although advocates concede that such technologies are at least several decades away from penetrating the market in any significant manner because of cost considerations, less attention has been paid to the environmental implications of such a transition.

Given current technology, switching from gasoline to hydrogen-powered fuel cells would greatly increase energy consumption even if the hydrogen were extracted from water rather than from fossil fuels. That's because it takes a tremendous amount of electricity to harvest hydrogen and to deliver it to consumers. Moreover, a transition from gasoline to hydrogen would nearly double net greenhouse gas emissions attributable to passenger vehicles, given the current fuel mix in the electricity sector.

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## Introduction

Hydrogen energy is all the rage among American politicians at the moment. A $1.8 billion, 10-year federal program to underwrite research in hydrogen-powered fuel cells—termed the "FreedomCar initiative" by the Bush administration—is a popular component of energy legislation passed by both the House and the Senate in 2003. In his campaign for the White House, Sen. John F. Kerry (D-MA) put forth an even more ambitious, $5 billion hydrogen fuel-cell initiative. And even though all observers agree that economically viable hydrogen-powered vehicles will not be available for at least a couple of decades (if then),[1] California governor Arnold Schwarzenegger is promoting the use of state funds to help start building a statewide network of hydrogen refueling stations in the here and now.[2] If hydrogen refueling stations are available, the theory goes, automakers will build vehicles powered by fuel cells and people will buy them.

Before any more taxpayer money is spent pursuing the dream of a "hydrogen economy," however, policymakers need to get out their calculators and seriously consider the environmental costs of bringing this dream to reality. If they do, they'll find that harnessing hydrogen for widespread use in the energy sector will consume more energy than it will save, and it will worsen, not better, environmental quality.

## The Challenge

Advocates of a hydrogen economy do not envision that hydrogen will be burned directly to create energy; instead, they envision using hydrogen primarily as an input for fuel cells. A fuel cell is basically a gas battery, although fuel cells come in a variety of types and employ a range of different materials.[3] Because fuel cells emit only water vapor and heat, environmentalists tout them as a source of pollution-free energy.

That characterization is grossly misleading, however, because it fails to consider the issue of hydrogen production. After all, hydrogen does not exist in subterranean pockets waiting to be tapped by drilling equipment. Hydrogen is an atom fused with other atoms that together constitute molecules of various chemical substances. Separating hydrogen atoms from other atoms on an industrial scale is a technologically challenging and energy-intensive undertaking.

There are basically two ways to produce hydrogen. The first method (called "electrolysis") is to send through water an electric current that separates the water's hydrogen atoms from its oxygen atoms. The second method is to mix steam with some sort of fossil fuel (usually natural gas) in a superheated chamber. The ensuing chemical reaction produces hydrogen.

### The Electrolysis Calculation

Environmentalists and other advocates of fuel cells often cite the electrolysis route as a viable and attractive way to reduce fossil fuel consumption and greenhouse gas emissions. But is it? Let's take a look at the numbers.

It takes 39.4 kilowatt-hours of energy to extract a kilogram of hydrogen from water. But the energy efficiency of the electrolysis process is only about 70 percent (that is, 30 percent of the energy used in the course of electrolysis is wasted).[4]

Let's suppose the electrical energy for the electrolysis process is provided by a coal-fired power plant with an overall conversion efficiency of 40 percent (that is, 40 percent of the thermal energy input to the plant is converted into electrical energy—a typical figure).[5] Accordingly, the energy input to the boiler of the power plant required to produce the kilogram of hydrogen is 140.8 kilowatt-hours.

Now, let's look at the fuel cell. Because the reaction that occurs in the fuel cell produces water vapor, the most energy we could produce from the fuel cell is 33.4 kilowatt-hours per kilogram of hydrogen. Given that the best fuel cells operate at about 70 percent efficiency,[6] the energy actually obtained from the reaction of a kilogram of hydrogen in the fuel cell is 23.3 kilowatt-hours.

There is one final matter to consider. If hydrogen is to be used as a transportation fuel, it must be compressed to at least 4,000 pounds per square inch, and that compression requires energy. After subtracting the energy needed for compression, we find the net output from the kilogram of hydrogen in the fuel cell is only about 17.4 kilowatt-hours.[7]

In sum, one must put 140.8 kilowatt-hours of energy into the front end of a power plant to produce 17.4 kilowatt-hours of electricity from a hydrogen-powered fuel cell in an automobile. The overall conversion efficiency of the whole process is a dismal 12 percent.

Now, let's estimate the electrical output from fuel cells that would be needed to power the U.S. vehicle fleet. According to data from the Bureau of Transportation Statistics, the total vehicle-miles traveled by passenger cars, pickup trucks, vans, and SUVs in the United States in 2000 was 2,526 billion.[8] Extensive tests performed by Southern California Edison Company suggest that it would take an average of at least 0.46 kilowatt-hour of electricity to drive a passenger vehicle a mile down the road.[9] Applying that figure to the total 2,526 billion vehicle-miles traveled in 2000, we find that fuel cells would need to produce 1.16 trillion kilowatt-hours to power the U.S. vehicle fleet. Given the ratios discovered above, that implies the need for 9.38 trillion kilowatt-hours of energy to feed into coal-fired power plants (the equivalent of 32 quadrillion British Thermal Units, or "32 quads" in engineering jargon).

It is interesting to compare that number with the energy content of the U.S. gasoline supply. In 2000 U.S. motor gasoline consumption averaged 8.472 million barrels per day.[10] Since reformulated gasoline has an energy content of 5.150 million BTU per barrel, we find that the energy content of the gasoline consumed in 2000 equals 16 quads, or exactly half the energy required for the fuel-cell route using coal to generate the electricity for hydrolysis.[11]

The environmental implications of moving vehicles with hydrogen-powered fuel cells rather than with gasoline are bracing. Replacing 16 quads of gasoline-fired energy with 32 quads of coal-fired energy to produce electrolysis hydrogen would result in a 2.7-fold increase in carbon emissions.[12] Replacing gasoline with electricity fired by the fuel mix currently employed in the generation sector would increase net carbon emissions from 309 million metric tons to 610 million metric tons.[13]

### Renewables to the Rescue?

Environmentalists argue that renewable energy sources could in theory supply the needed electrical energy and thereby reduce use of fossil fuel and, relatedly, net carbon emissions. The calculations, however, are daunting. Hydroelectric power, for instance, dwarfs all other renewable energy production in the United States, yet the 3.75 trillion kilowatt-hours of electricity necessary to deliver hydrogen from water to fuel cells[14] is almost *15 times* the total hydroelectric energy produced in the United States last year.[15] Given the mounting public pressure to remove existing dams, it's unlikely that the construction of any significant new hydroelectric generating capacity will occur in the foreseeable future.

Photovoltaic (PV) cells, which are used to produce solar power, are an even worse choice. Doing an input-output analysis of the energy obtained from a PV array vs. the energy required to produce it is extremely difficult, but some analysts have performed those calculations and found that it would take about eight years for a PV panel to produce as much energy as was used to produce the panel in the first place.[16] A modern PV panel operating over a period of 25 years can probably be expected to convert no more than about 12 percent of the incident solar radiation striking the cell into electrical energy.[17] Since we need 56.3 kilowatt-hours of electricity to power the electrolyzer in order to obtain an output of 17.4 kilowatt-hours from the fuel cells, if PV cells are used to provide that electrical energy, the efficiency of the whole process is a minuscule 4 percent (that is, 4 percent of the energy in the incident solar radiation captured by the PV cells appears as electrical output from the fuel cells).[18]

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That dismal conversion efficiency has two consequences. First, the energy required to make the PV panel will exceed the energy produced by the fuel cells. Second, the cost of that energy will be prohibitively expensive.

Using wind power rather than solar power requires a different set of calculations. Unfortunately, the data for those calculations are not readily available. Like solar power facilities, however, wind power facilities are quite capital intensive, and the power from those facilities is only intermittently available. Accordingly, the calculations for wind-generated electricity are unlikely to be much different from the calculations for solar-generated electricity.[19]

### The "Steam Reforming" Calculation

Virtually all of the hydrogen produced in the world today is derived from natural gas in a process called "steam reforming." In that process, natural gas is mixed with steam and heated in a reformer tank. Once again, however, the chemical reactions that produce hydrogen require the input of energy. Additional energy inputs are required to generate steam, heat the reformer tank, and separate the products. The overall efficiency of the whole process is only about 30 percent—much less than if the natural gas were simply burned in an electrical power generating plant.[20]

In order to provide the 1.16 trillion kilowatt-hours of fuel-cell output needed to power the U.S. vehicle fleet, 66.7 billion kilograms of hydrogen would be needed. Accordingly, about 15 trillion cubic feet of natural gas would be required to produce that hydrogen by the steam reforming process.[21]

In 2002, the last year for which we have data, domestic natural gas consumption was about 22.6 trillion cubic feet.[22] Thus, powering the domestic vehicle fleet with hydrogen derived from natural gas would increase natural gas consumption by about 66 percent.

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That figure is particularly striking given that domestic production and imports of Canadian gas are declining while demand is rapidly increasing, a combination of events that has sent natural gas prices skyrocketing. Preliminary data indicate that the average wellhead price in 2003 was about $5.10 per thousand cubic feet (mcf) compared with $2.95 per mcf in 2002.[23]

Furthermore, there is growing concern that natural gas prices are destined to remain high and that the imbalance between supply and demand can be satisfied only with imports of liquefied natural gas (LNG).[24] Accordingly, most if not all of the 15 trillion cubic feet of natural gas needed to produce hydrogen for fuel cells would have to come from LNG imported primarily from the Middle East. That would do little to reduce energy costs or enhance the security of our energy supplies.

## Conclusion

The economic problems involved in delivering hydrogen to fuel cells are difficult to remedy because they stem from fundamental thermodynamics. Although technological improvement may well increase the efficiency with which energy is used along some if not all of the production chain, the challenges are so immense that the confident predictions of imminent economic breakthroughs heard from the political class are hard to take seriously.[25]

Decisions about the relative merits of various emerging technologies are best left to the marketplace, where private investors have every incentive to make the soundest bets. If hydrogen-powered fuel cells hold economic promise, investors will have every incentive to promote their development. If they do not, then investors will rightly put their money elsewhere. Subsidies simply impose politically inspired judgments on market actors, and there is no reason to think that those judgments are better informed than the ones that reign in the marketplace.

## Notes

1. According to the U.S. Department of Energy, a hydrogen-powered car costs about $1 million to manufacture today, and its range is limited to about 200 miles before refueling—much less than

the range of a gasoline-powered car. Hydrogen fuel made from natural gas costs about $4 per gallon and hydrogen fuel made from water costs three times that amount. Miguel Bustillo and Gary Polakovic, "Governor Pushes for 'Hydrogen Highways,'" *Los Angeles Times*, January 20, 2004, p. B1. For a more thorough discussion of the steep economic hurdles faced by hydrogen-powered fuel cells, see Joseph Romm, *The Hype about Hydrogen* (Washington: Island Press, 2004).

2. Termed the "Hydrogen Highways" initiative, the plan is intended to locate a hydrogen refueling station every 20 miles along major highways in California by 2010. That would mean 150–200 hydrogen refueling stations at a cost of $250,000–$300,000 per station, the full cost of which would be split between the public and private sectors. The Hydrogen Highways initiative is not unlike a similar initiative undertaken years ago in California that used state funds to help build electric-charging stations along major state roadways—facilities that today go largely unused. See Bustillo and Polakovic.

3. In a fuel cell, two electrodes are separated by some type of electrolyte or proton exchange membrane. Hydrogen under pressure is introduced at the anode and oxygen from air is introduced at the cathode. At the anode, the hydrogen dissociates into electrons, which travel through an external circuit to produce an electrical current, and protons, which travel through the electrolyte to the cathode. At the cathode, the protons combine with oxygen and the electrons that have traveled through an external circuit to produce water vapor. H. Petroski, "Fuel Cells," *American Scientist* 91 (September–October, 2003): 398–402.

4. M. Wang, "Hydrogen a Transportation Fuel," *Oil & Gas Journal* 101, no. 33 (August 25, 2003): 10–12.

5. Harold Schobert, *Energy & Society* (New York: Taylor & Francis, 2002), p. 253.

6. T. Standing, "Making Hydrogen," *Oil & Gas Journal* 101, no. 15 (April 14, 2003): 10–12.

7. Ibid.

8. U.S. Department of Transportation, Bureau of Transportation Statistics, "National Transportation Statistics 2002," Table 1-32.

9. Southern California Edison undertook comprehensive tests of various electric vehicles on the Pomona Loop in Southern California. The test loop, which included city streets, highways, and hilly terrain, was designed to simulate real-world driving conditions. The test vehicles included small electric vehicles (Toyota's RAV4, GM's EV1, and Honda's EV Plus) as well as some larger electric vehicles (the Ford Ranger, Chevy's S10, Nissan's Altra, and the Chrysler EPIC). The average energy consumption for all electric vehicles tested was 0.422 kilowatt-hour per mile traveled, while the average for the larger electric vehicles was 0.46 kilowatt-hour per mile traveled. It's worth noting, however, that even the larger electric vehicles included in the test were smaller and lighter than the full-sized pickup trucks, vans, and SUVs on the road today. Of course, the vehicles tested were electric vehicles, not vehicles powered by fuel cells. In order for a vehicle powered by fuel cells to achieve the results found in the study, it would have to carry a large battery pack (in addition to the steel tank carrying the compressed hydrogen) that could store the energy generated in braking—an economic cost and weight penalty not usually considered in fuel-cell vehicles. California Energy Commission, Southern California Edison Co., "Pomona Loop Test Data," Sacramento, 2001. Unpublished document available from the author.

10. Energy Information Administration (EIA), *Monthly Energy Review*, DOE/EIA-0035(2003/07), July 2003, Table 3.4.

11. Ibid., Table A1.

12. Author's calculation based on data found in EIA, *Emission of Greenhouse Gases in the U.S., 1987–1994*, DOE/EIA-0573(87-94), October 1995, Table B1.

13. Author's calculation based on data found in EIA, *Monthly Energy Review*, DOE/EIA-0035 (2004/02), February 2004, Tables 2.6, 7.2a. In calculating carbon emissions, we used a carbon emission coefficient of 14.9 million metric tons of carbon/quad for the wood and waste. We assumed there were no carbon emissions for the hydro, nuclear, and the other nonhydro renewable energy sources. Since residual fuel oil was 65 percent of the petroleum used for electrical power generation, we used a carbon emission coefficient of 21.49 million metric tons of carbon per quad of energy (the value for residual fuel oil) for the petroleum.

14. Earlier we found that with an electrolyzer operating at an efficiency of 70 percent, an input of 56.3 kilowatt-hours of electricity is needed to produce one kilogram of hydrogen from water. After subtracting the energy loss for compressing the hydrogen, we found that a fuel cell operating at an efficiency of 70 percent produced 17.4 kilowatt-hours from that kilogram of hydrogen. Thus, we need an electrical energy input of 56.3 kilowatt-hours to the electrolyzer to obtain an output of 17.4 kilowatt-hours from fuel cells. Accordingly, 3.75 trillion kilowatt-hours of electricity would be needed to produce the 1.16 trillion kilowatt-hours of output

from fuel cells that would be required to power the domestic vehicle fleet.

15. EIA, *Monthly Energy Review*, February 2004, Table 7.2A.

16. C. Yoder, Alternative Energy FAQ2, http://www.ibiblio.org/ecolandtech/alternativeenergy/faqs/Alternative.Energy.FAQ.2; E. A. Alsema, P. Frankel, and K. Kato, "Energy Pay-Back Time of Photovoltaic Energy Systems: Present Status and Prospects," paper presented at Second World Conference on Photovoltaic Solar Energy Conver-sion, Vienna, July 6–10, 1998; K. E. Knapp and T. L. Jester, "An Empirical Perspective on the Energy Payback Time for Photovoltaic Modules," paper presented at Solar 2000 Conference, Madison, WI, June 16–21, 2000; and U.S. Department of Energy, Renewable Energy Laboratory, "PV FAQs," DOE/GO-102004-1847, January 2004.

17. Ibid.

18. That figure is almost certainly optimistic, however, because the long-term operating efficiency of PV panels is lower than experimental test results in part because the panels get dirty and in real life are not cleaned as often as they should be.

19. Some people might argue that the energy payback time for wind turbines is considerably shorter (about one year, depending on wind speeds) than for PV panels. However, those calculations have been done only for the wind turbine. If we were to use wind energy on the scale necessary for hydrogen production, we would need some enormous installations that would require a large amount of road building into unroaded areas, transportation of the wind turbines to the sites, and annual road maintenance. I am not aware of any calculations that have taken all of those things into account. Moreover, because wind power is intermittent, either several large installations would have to be constructed in various regions of the country—resulting in a large overcapacity—or hydrogen would have to be stored for periods when hydrogen production was inadequate to meet demand, which would require even greater energy inputs. For a more thorough discussion of the economics of wind power, see Jerry Taylor and Peter Van Doren, "Evaluating the Case for Renewable Energy: Is Government Support Warranted?" Cato Institute Policy Analysis no. 422, January 10, 2002.

20. Standing.

21. As noted earlier, the net output from a kilogram of hydrogen in the fuel cell is 17.4 kilowatt-hours. Therefore, 66.7 billion kilograms of hydrogen must be supplied to the fuel cell to produce 1.16 trillion kilowatt-hours. Since 4.30 kilograms of methane are required in the steam reforming process to produce 1 kilogram of hydrogen, 287 billion kilograms of methane are needed, which translates into 15 trillion cubic feet of natural gas.

22. EIA, Natural Gas Overview, Table 4.1, *Monthly Energy Review*, DOE/EIA-0035(2004/02), February 2004.

23. Ibid., Natural Gas Prices, Table 9.11.

24. Colleen Sen, "LNG Poised to Consolidate Its Place in Global Gas Trade," *Oil & Gas Journal* 101, no. 24 (September 23, 2003): 72–81.

25. For an excellent discussion of the poor track record of similar predictions in the energy sector, see Vaclav Smil, *Energy at the Crossroads* (Cambridge, MA: MIT Press, 2003), pp. 121–80.

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