'Apollo Program' for hydrogen energy needed, researcher says in Science

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What if all the vehicles now on the road in the United States were suddenly powered by hydrogen fuel cells? Stanford researchers say in a June 24 article in the journal *Science* that such a conversion would improve air quality, health and climate--especially if wind were used to generate the electricity needed to split water and make hydrogen in a pollutionless process.

Similarly to how gas is pumped into tanks, hydrogen would be pumped into fuel cells, which rely on chemistry, not combustion, to power vehicles. (As hydrogen flows through fuel-cell compartments, it reacts with oxygen to produce water and energy.) Associate Professor Mark Z. Jacobson and graduate student Whitney Goldsborough Colella (both in the Civil and Environmental Engineering Department) and Consulting Professor David M. Golden (Mechanical Engineering Department) report that annually such a conversion could prevent millions of cases of respiratory illness and tens of thousands of hospitalizations and save more lives than were lost in the World Trade Center attacks.

"Converting all the current vehicles to fuel cell vehicles powered by wind would save 3,000 to 6,000 lives in the United States annually, and it could be done at a fuel cost that's comparable to the cost of gasoline, and less than the cost of gasoline when you consider the health effects of gasoline," said Jacobson, who has no financial interest in any wind or hydrogen endeavor but whose commitment to clean air is manifest in his choice of car (a Toyota Prius), house (it's solar-powered) and career (atmospheric scientist).

Sponsored by the Global Climate and Energy Project at Stanford and by NASA, the Science study compared emissions that would be produced in five cases--if all vehicles on the road were powered by 1) conventional internal-combustion engines, 2) a combination of electricity and internal combustion of gasoline, as in hybrid vehicles, 3) hydrogen generated from wind electrolysis, 4) hydrogen generated from natural gas and 5) hydrogen generated from coal gasification.

Wind is the most promising means of generating hydrogen, said Jacobson, who with former postdoctoral fellow Cristina Archer recently published a study that mapped global winds and showed the world, especially the United States, has more than enough wind to meet all its energy needs. Jacobson envisions wind turbines generating electricity on wind farms that are linked in a network to ensure energy production even when parts of the grid have windless days. The electricity would travel through transmission lines to a filling station--similar to today's gas stations. There, it would enter an electrolyzer, passing through water and splitting it into oxygen, which would be released into the air, and hydrogen, which would get compressed and stored.

A lot of hydrogen is currently produced by another method Jacobson's group analyzed: steam reforming of natural gas. If you take methane, the main component of natural gas, and expose it to steam, the final products are primarily carbon dioxide and hydrogen. While the production of carbon dioxide, a greenhouse gas, is undesirable, the process produces about 55 percent less carbon dioxide than does internal combustion, Jacobson said. Other pollutants result as well, such as oxides of nitrogen and carbon monoxide, but these are still far lower than emissions from gasoline combustion. Steam reformers could be placed at individual filling stations, and methane could be piped in through existing natural gas lines. But natural gas supplies are limited and subject to price fluctuations that hurt the long-term feasibility of this option.

The third hydrogen production method the researchers analyzed is coal gasification, in which hydrogen could be produced at centralized plants, compressed and most likely transported in trucks. Coal is mostly carbon, but also contains hydrogen and sulfur. Exposed to water at high temperature and high pressure, it chemically reacts to yield carbon monoxide and hydrogen. More oxygen is added to turn carbon monoxide into carbon dioxide. So the end products are carbon dioxide and hydrogen gas. Compared with natural gas, it takes a lot more coal to make hydrogen. That translates into more carbon dioxide production than with natural gas as a hydrogen source.

Hybrid vehicles were better at reducing carbon dioxide than vehicles using hydrogen from coal gasification, Jacobson said. But health costs were lower with coal gasification compared with hybrids, which produce more pollutants since they employ a combustion process.

A hydrogen economy

"Switching from a fossil-fuel economy to a hydrogen economy would be subject to technological hurdles, the difficulty of creating a new energy infrastructure, and considerable conversion costs but could provide health, environmental, climate and economic benefits and reduce the reliance on diminishing oil supplies," the Stanford authors wrote.

While envisioning such a switch may seem like a purely academic exercise, it's not. Such exercises inform policy--albeit sometimes too late. Currently congress is debating an energy bill that contains a $4,000 tax credit for diesel vehicles--the same break hybrid vehicles get--because of their perceived higher mileage compared to gasoline vehicles. But a study led by Jacobson and published in 2004 by Geophysical Review Letters showed that converting the U.S. vehicle fleet from gasoline to diesel vehicles--even with advanced emissions and particle control technologies--would actually increase photochemical smog, particularly in the Southeastern United States. The reason is that even advanced diesel vehicles may emit more oxides of nitrogen than do gasoline-powered vehicles, and these oxides spur ozone production. Jacobson believes such a tax break may provide an unintentional incentive to damage people's health.

Computer simulations that model the effects of future vehicle fleets may help society assess its best energy options. "Going down the hydrogen pathway is a good thing overall and it's a practical thing, and it's going to be beneficial in terms of air pollution and climate and health," Jacobson said.

The hydrogen economy is on the horizon. California already has several hydrogen filling stations, and Gov. Arnold Schwarzenegger has proposed an ambitious network of hydrogen filling stations by 2010. Most car manufacturers have prototype hydrogen fuel cell vehicles. Los Angeles even has a test fleet of hydrogen buses.

While some are concerned about hydrogen's explosiveness, Jacobson said another property of hydrogen--its lightness--may lessen this danger. He cited an example of two cars--one conventional, one hydrogen-powered--that were hit from behind. The car powered by an internal combustion engine became engulfed in flames when its gas tank was punctured. But when the hydrogen car's fuel cell was punctured, since hydrogen is 14 times lighter than air, the flames just shot straight up. The car was saved.

Hydrogen's volatility, however, underscores the need to develop tight seals to prevent leakage from storage tanks, filling stations and the fuel cells themselves.

Because wind generation of hydrogen provided the best health and climate benefits, the researchers did a cost analysis to compare the cost of a gallon of gasoline with that of a gallon of hydrogen generated by wind electrolysis. The cost of making hydrogen from wind is $1.12 to $3.20 per gallon of gasoline or diesel equivalent ($3 to $7.40 per kilogram of molecular hydrogen)--on par with the current price of gas. But gasoline has a hidden cost of 29 cents to $ 1.80 per gallon in societal costs such as reduced health, lost productivity, hospitalization and death, as well as cleanup of polluted sites. So gasoline's true cost in March 2005, for example, was $2.35 to $3.99 per gallon, which exceeds the estimated mean cost of hydrogen from wind ($2.16 equivalent per gallon of gasoline).

The Stanford study, unprecedented in its detail, used an inventory of more than 600,000 pollution sources reported by the U.S. Environmental Protection Agency from August 1999. Colella altered the EPA emission inventory in response to each of the different scenarios. Her work led to a separate paper as well, now in press at the Journal of Power Sources. Golden contributed expertise in atmospheric chemistry, and Jacobson plugged Colella's new emission scenarios into his own computer model to run simulations and analyze the resulting costs and effects.

"We believe the results are conservative since health costs associated mostly with particles are now thought to be greater than those used in our study," Jacobson said. "In addition, in the future we will have more fossil [fuel] vehicles than we currently have. So the future health benefit of switching will be greater than in our current study, which assumes an instantaneous switch."

But no matter how many vehicles are on the road, fuel-cell vehicles using hydrogen from wind are not going to produce any real pollution, he emphasized.

"Hybrids are a stepping stone, but they can't be the final destination because even though they result in an improved efficiency over the current vehicle fleet, their numbers will increase," Jacobson said. "Carbon dioxide and other pollutant emissions associated with hybrids will increase as well. So this is not a viable, long-term solution in the presence of a growing population and the desire of many developing countries to industrialize."

Next the group plans to look at the effects of converting all power plants to hydrogen fuel cell power plants. They also plan to explore the long-term effects of switching to a hydrogen economy on global climate change and the ozone layer.

'Apollo Program'

Jacobson advocates an 'Apollo Program' for generating electricity from wind and producing hydrogen using wind-generated electricity. Such a program would involve fossil sources paying their true health and climate costs. For example, some old coal-fired plants are exempt from modern performance standards required by Clean Air Act amendments and therefore run inexpensively while saddling society with huge hidden costs. An Apollo Program would provide additional subsidies for wind and other renewable energy sources. While wind subsidies are on the order of $100 million per year, Jacobson said, other energy sources hog subsidies of $15 to $20 billion. He advocates supporting the infrastructure needed for wind production of hydrogen to a level similar to the $20 billion recently proposed for a new natural gas pipeline from the continental United States to Alaska.

"If you want to encourage hydrogen and [wind-produced] hydrogen, then you do need to undertake an Apollo Program because even though the cost of a new wind turbine averaged over a long time is similar to a new coal or natural gas power plant, there's no incentive to replace these other sources with wind."

Source: Stanford University