Novel sugar-to-hydrogen technology promises transportation fuel independence

The hydrogen economy is not a futuristic concept. The U.S. Department of Energy's 2006 Advance Energy Initiative calls for competitive ethanol from plant sources by 2012 and a good selection of hydrogen-powered fuel cell vehicles by 2020.

Researchers at Virginia Tech, Oak Ridge National Laboratory, and the University of Georgia propose using polysaccharides, or sugary carbohydrates, from biomass to directly produce low-cost hydrogen for the new hydrogen economy.

According to the DOE, advances are needed in four areas to make hydrogen fuel an economical reality for transportation – production, storage, distribution, and fuel cells. Most industrial hydrogen currently comes from natural gas, which has become expensive. Storing and moving the gas, whatever its source, is costly and cumbersome, and even dangerous. And there is little infrastructure for refueling a vehicle.

"We need a simple way to store and carry hydrogen energy and a simple process to produce hydrogen, said Y.-H. Percival Zhang, assistant professor of biological systems engineering at Virginia Tech.

Using synthetic biology approaches, Zhang and colleagues Barbara R. Evans and Jonathan R. Mielenz of ORNL and Robert C. Hopkins and Michael W.W. Adams of the University of Georgia are using a combination of 13 enzymes never found together in nature to completely convert polysaccharides ($C_6H_{10}O_5$) and water into hydrogen when and where that form of energy is needed. This "synthetic enzymatic pathway"research appears in the May 23 issue of PLoS ONE, the online, open-access journal from the Public Library of Science.

Polysaccharides like starch and cellulose are used by plants for energy storage and building blocks and are very stable until exposed to enzymes. Just add enzymes to a mixture of starch and water and "the enzymes use the energy in the starch to break up water into only carbon dioxide and hydrogen,"Zhang said.

A membrane bleeds off the carbon dioxide and the hydrogen is used by the fuel cell to create electricity. Water, a product of that fuel cell process, will be recycled for the starch-water reactor. Laboratory tests confirm that it all takes place at low temperature -- about 86 degrees F -- and atmospheric pressure.

The vision is for the ingredients to be mixed in the fuel tank of your car, for instance. A car with an approximately 12-gallon tank could hold 27 kilograms (kg) of starch, which is the equivalent of 4 kg of hydrogen. The range would be more than 300 miles, Zhang estimates. One kg of starch will produce the same energy output as 1.12 kg (0.38 gallons) of gasoline.

Since hydrogen is gaseous, hydrogen storage is the largest obstacle to large-scale use of hydrogen fuel. The Department of Energy's long-term goal for hydrogen storage was 12 mass percent, or 0.12 kg of hydrogen per one kg of container or storage material, but such technology is not available, said Zhang. Using polysaccharides as the hydrogen storage carrier, the research team achieved hydrogen storage capacity as high as 14.8 mass percent, they report in the PLOS article.

The idea began as a theory. The research was based on Zhang's previous work pertaining to cellulosic ethanol production and the ORNL and University of Georgia researchers' work with enzymatic hydrogen production. UGA Distinguished Professor Adams is co-author of the first enzymatic hydrogen paper in Nature Biotechnology in 1996. The researchers were certain they could put the processes together in one pot. They tested the theory using Oak Ridge's hydrogen detectors and documented that hydrogen is produced as they predicted.

Mielenz, who heads the Bioconversion Group in ORNL's Biosciences Division, attributed the successful research to a unique collaborative working relationship between scientists, lab divisions, and universities.

"Pairing our biomass conversion capabilities with facilities for studying renewable hydrogen production in the lab's Chemical Sciences Division was a key to this project,"Mielenz said. "This also shows the value of partnerships with universities such as Virginia Tech and the University of Georgia."

It is a new process that aims to release hydrogen from water and carbohydrate by using multiple enzymes as a catalyst, Zhang said. "In nature, most hydrogen is produced from anaerobic fermentation. But hydrogen, along with acetic acid, is a co-product and the hydrogen yield is pretty low -- only four molecules per molecule of glucose. In our process, hydrogen is the main product and hydrogen yields are three-times higher, and the likely production costs are low – about $1 per pound of hydrogen. "

Over the years, many substances have been proposed as "hydrogen carriers,"such as methanol, ethanol, hydrocarbons, or ammonia – all of which require special storage and distribution. Also, the thermochemical reforming systems require high temperatures and are complicated and bulky. Starch, on the other hand, can be distributed by grocery stores, Zhang points out.

"So it is environmentally friendly, energy efficient, requires no special infrastructure, and is extremely safe. We have killed three birds with one stone,"he said. "We have hydrogen production with a mild reaction and low cost. We have hydrogen storage and transport in the form of starch or syrups. And no special infrastructure is needed."

"The next R&D step will be to increase reaction rates and reduce enzyme costs," Zhang said. "We envision that in the future we will drive vehicles powered by carbohydrate, or energy stored in solid carbohydrate form, with hydrogen production from carbohydrate and water, and electricity production via hydrogen-fuel cells.

"What is more important, the energy conversion efficiency from the sugar-hydrogen-fuel cell system is extremely high – greater than three times higher than a sugar-ethanol-internal combustion engine,"Zhang said. "It means that if about 30 percent of transportation fuel can be replaced by ethanol from biomass as the DOE proposed, the same amount of biomass will be sufficient to provide 100 percent of vehicle transportation fuel through this technology."

In addition, the use of carbohydrates from biomass as transportation fuels will produce zero net carbon dioxide emissions and bring benefits to national energy security and the economy, Zhang said.

Source: Virginia Tech