Removing a hydrogen fuel-cell roadblock

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Researchers at the U.S. Department of Energy's Ames Laboratory are employing some modern day alchemy in an effort to find a material with properties of rare and high-priced palladium. If they're successful, it could remove a major roadblock from the path of hydrogen fuel-cell powered vehicles.

Hydrogen fuel-cell technology sounds almost too good to be true. You combine cheap and plentiful hydrogen and oxygen gas, the fuel cell generates electricity and the by-product is simply water. But it's a little more involved.

The key is a proton exchange membrane, or PEM, containing platinum. The platinum acts as a catalyst that separates electrons from the hydrogen gas atoms. The free electrons are gathered as current and the positively charged hydrogen ions pass through the membrane where they readily combine with oxygen atoms to form water. But if the hydrogen gas contains impurities, such as water vapor or carbon monoxide, it can "gum up" the fuel cell's separation membrane, dropping efficiency or halting the process altogether. Pure hydrogen, however, is hard to come by, and that's where palladium enters the picture.

"Hydrogen is tough to handle because of the small size of the atoms and because it naturally wants to bond with other elements," said Ames Laboratory scientist Alan Russell, one of the investigators on the project. "Palladium acts like an atomic filter – the hydrogen atoms readily diffuse right through the metal."

In the conventional approach to purifying hydrogen, an alloy of 73 percent palladium and 27 percent silver is drawn into long thin tubes, about 3 mm in diameter and 20 feet long. Clusters of these tubes are placed inside a vacuum chamber and heated to between 400 and 500 Celsius. Impure hydrogen gas is then pumped into the small tubes, and the hydrogen readily diffuses through the palladium-silver tube walls and is captured in the outer chamber while the impurities travel out the other end of the tubes.

"Palladium is $11,000 a kilogram, and even if you didn't choke at the price, there isn't enough palladium in the entire world to convert the world's automobiles to hydrogen power," Russell said. "So the trick is to find a material with the same properties as palladium that is cheaper and much more readily available."

His use of the word trick isn't a stretch. Not only does the material have to be less expensive and readily available, it has to allow hydrogen to pass through it and be ductile enough to be drawn into long, thin tubes. It also has to resist oxidation, because oxygen and water vapor are commonly present in impure hydrogen. And finally, hydrogen has a nasty habit of making metals brittle, so the metal also has to handle repeated heating and cooling cycles, while loaded with hydrogen, without becoming brittle.

"With so many variables, we don't really have any analytical tools that would let us mathematically predict the ideal composition," Russell said, "so we have to use a Thomas Edison approach – relying on intuition and a fair amount of luck to come up with a combination that works."

The three-year project is being spearheaded by Robert Buxbaum, president of REB Research, a Michigan firm involved in hydrogen filtration and fuel-cell technology. Buxbaum is particularly interested in a membrane reactor which combines hydrogen generation and filtration right at the fuel cell. Buxbaum obtained $2.8 million from DOE to find substitutes for platinum and palladium. Besides Russell and visiting Chinese scientist Jie Zhang, the project includes Larry Jones, director of Ames Laboratory's Materials Preparation Center, as well as researchers at Los Alamos National Laboratory, the National Energy Technology Laboratory, and G&S Titanium, an Ohio-based materials fabrication firm.

Buxbaum proposed developing 100 different alloys, relying on the expertise of Russell and Jones in the field of metals development to pick the mixtures. "It is not by accident that I asked to work with Alan and Larry," Buxbaum said. "They are fantastically talented at what they do," adding that the program in Ames "is the best in the United States and among the best in the world."

Using X-ray diffraction technology to study the crystal microstructure of the materials, Zhang can determine whether the materials show promise in terms of ductility. This provides a shortcut of sorts so that the team doesn't waste time on materials that are potentially brittle. A little more than a year into the project, about 60 binary alloys have been developed with additional ones in the planning stages. The results have been mixed, but Russell indicated one sample is quite promising and several others show promise.

"There have been surprises. Some alloys that you would expect to be ductile turn out to be hopelessly brittle, like glass," Russell said. "We also tried a material with 25 percent ruthenium, an element which is notorious for making alloys brittle, but that material turned out to be quite ductile." Samples produced in Ames are first cold rolled to see if they are ductile. Those showing promise are further tested and shipped to REB Research where they're tested to determine how easily hydrogen will diffuse through the metal. Those showing promise get further testing to see if they can be formed into tubes and how they respond to heating and cooling cycles. But even those materials that are rejected as a palladium substitute, may ultimately wind up as useful for other purposes.

"I think we've got a good chance of finding something that works for hydrogen generation, but even if none of these alloys are good at that, the materials we're working with will certainly have other applications." Buxbaum said. "One metal in particular is an amazing alloy – shiny, ductile, high melting, and totally resistant to aqua regia (a mixture of nitric and hydrochloric acids that dissolves gold or platinum)."

Russell added that the willingness of the DOE to fund such a program is indicative of the commitment to develop alternative energy sources.

"Research funding often depends on your ability to demonstrate specific results," he said. "It's refreshing in a way to get to try traditional metallurgy techniques to try to solve a 21st century problem."

Source: Ames Laboratory

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