New aluminum-rich alloy produces hydrogen on-demand for large-scale uses

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Purdue University engineers have developed a new aluminum-rich alloy that produces hydrogen by splitting water and is economically competitive with conventional fuels for transportation and power generation.

"We now have an economically viable process for producing hydrogen on-demand for vehicles, electrical generating stations and other applications," said Jerry Woodall, a distinguished professor of electrical and computer engineering at Purdue who invented the process.

The new alloy contains 95 percent aluminum and 5 percent of an alloy that is made of the metals gallium, indium and tin. Because the new alloy contains significantly less of the more expensive gallium than previous forms of the alloy, hydrogen can be produced less expensively, he said.

When immersed in water, the alloy splits water molecules into hydrogen and oxygen, which immediately reacts with the aluminum to produce aluminum oxide, also called alumina, which can be recycled back into aluminum. Recycling aluminum from nearly pure alumina is less expensive than mining the aluminum-containing ore bauxite, making the technology more competitive with other forms of energy production, Woodall said.

"After recycling both the aluminum oxide back to aluminum and the inert gallium-indium-tin alloy only 60 times, the cost of producing energy both as hydrogen and heat using the technology would be reduced to 10 cents per kilowatt hour, making it competitive with other energy technologies," Woodall said.

The researchers will present findings about the new alloy on Feb. 26 during the conference Materials Innovations in an Emerging Hydrogen Economy, which runs Feb. 24-27 in Cocoa Beach, Fla..

A key to developing the alloy for large-scale technologies is controlling the microscopic structure of the solid aluminum and the gallium-indium-tin alloy mixture.

"This is because the mixture tends to resist forming entirely as a homogeneous solid due to the different crystal structures of the elements in the alloy and the low melting point of the gallium-indium-tin alloy," Woodall said.

The alloy is said to have two phases because it contains abrupt changes in composition from one constituent to another.

"I can form a one-phase melt of liquid aluminum and the gallium-indium-tin alloy by heating it. But when I cool it down, most of the gallium-indium-tin alloy is not homogeneously incorporated into the solid aluminum, but remains a separate phase of liquid," Woodall said. "The constituents separate into two phases just like ice and liquid water."

The two-phase composition seems to be critical for the technology to work because it enables the aluminum alloy to react with water and produce hydrogen.

The researchers had earlier discovered that slow-cooling and fast-cooling the new 95/5 aluminum alloy produced drastically different versions. The fast-cooled alloy contained aluminum and the gallium-indium-tin alloy apparently as a single phase. In order for it to produce hydrogen, it had to be in contact with a puddle of the liquid gallium-indium-tin alloy.

"That was a very exciting finding because it showed that the alloy would react with water at room temperature to produce hydrogen until all of the aluminum was used up," Woodall said.

The engineers were surprised to learn late last year, however, that slow-cooling formed a two-phase solid alloy, meaning solid pieces of the 95/5 aluminum alloy react with water to produce hydrogen, eliminating the need for the liquid gallium-indium-tin alloy.

"That was a fantastic discovery," Woodall said. "What used to be a curiosity is now a real alternative energy technology."

The research is partially funded by Purdue's Energy Center at the university's Discovery Park.

"This technology has exciting potential, and I hope that it receives a fair and detailed evaluation and consideration from the scientific, government and business communities," said Jay Gore, the Vincent P. Reilly Professor of Mechanical Engineering and interim director of the Energy Center.

The slow-cooling technique made it possible to create forms of the alloy containing higher concentrations of aluminum.

The Purdue researchers are developing a method to create briquettes of the alloy that could be placed in a tank to react with water and produce hydrogen on-demand. Such a technology would eliminate the need to store and transport hydrogen, two potential stumbling blocks in developing a hydrogen economy, Woodall said.

The gallium-indium-tin alloy component is inert, which means it can be recovered and reused at an efficiency approaching 100 percent, he said

"The aluminum oxide is recycled back into aluminum using the currently preferred industrial process called the Hall-Héroult process, which produces one-third as much carbon dioxide as combusting gasoline in an engine," Woodall said.

The aluminum splits water by reacting with the oxygen atoms in water molecules, liberating hydrogen in the process. The gallium-indium-tin alloy is a critical component because it hinders the formation of a "passivating" aluminum oxide skin normally created on pure aluminum's surface after bonding with oxygen, a process called oxidation. This skin usually acts as a barrier and prevents oxygen from reacting with bulk aluminum. Reducing the skin's protective properties allows the reaction to continue until all of the aluminum is used to generate hydrogen, Woodall said.

"This skin is like an eggshell," he said. "Think of trying to fry an egg without breaking the shell."

The researchers developed the new alloy in late 2007 and are reporting about it for the first time during the conference.

"We now have a simple process for making 95/5, and we know the process splits water and produces hydrogen until all of the aluminum alloy is used up," Woodall said.

For the technology to be used in major applications such as cars and trucks or for power plants, however, a large-scale recycling program would be required to turn the alumina back into aluminum and to recover the gallium-indium-tin alloy. Other infrastructure components, such as those related to manufacturing and the supply chain, also would have to be developed, he said.

"So the economic risk is large, but the potential payoff is also large," said Woodall, who received the 2001 National Medal of Technology, the nation's highest award for technological achievement.

Aluminum, the most abundant metal on earth, is refined from the raw mineral bauxite, which also contains gallium.

Future research will include work to learn more about the chemical mechanisms behind the process and the microscopic structure of the alloy.

Source: Purdue University

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