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Greener hydrogen from water

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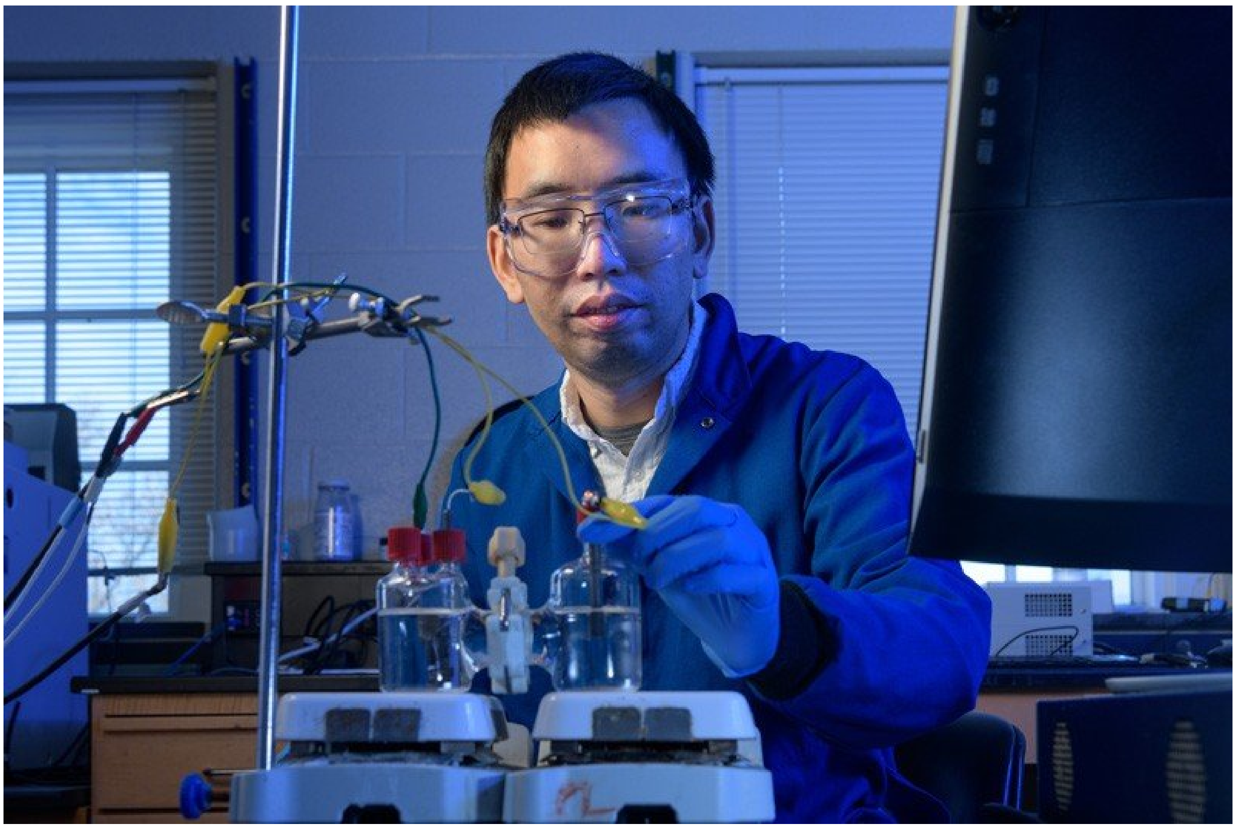


Feng Jiao, an associate professor of chemical and biomolecular engineering and associate director of the Center for Catalytic Science and Technology at UD, in his lab. Credit: University of Delaware

The idea of using hydrogen as the basis of a clean sustainable energy source, often termed a hydrogen economy, has been a topic of conversation for decades. Hydrogen fuel, for example, doesn't emit any carbon dioxide and is considered more sustainable than traditional fossil fuels.

The lightest element on the periodic table, hydrogen is an energy carrier that can be used to power fuel cells in transportation vehicles, buildings or other infrastructure. Hydrogen also can help upcycle things like straw, grasses and other biomass into high-value chemicals used in everything from plastics to paint to personal care items.

But the technology driving these innovations has faced serious challenges, chiefly because freeing hydrogen for these uses is produced mainly through processes that require fossil fuels and come with an environmental cost—carbon dioxide.

Now, University of Delaware engineer Feng Jiao has patented a process that may hold the key to producing greener hydrogen from water using electricity and a copper-titanium catalyst.

A focus on renewables

Jiao, an associate professor of chemical and biomolecular engineering and associate director of the Center for Catalytic Science and Technology at UD, wasn't always interested in water electrolysis, which uses electricity to reduce water into hydrogen gas and oxygen molecules. When he first joined the UD faculty in 2010, his research program focused on the energy storage capability of batteries.

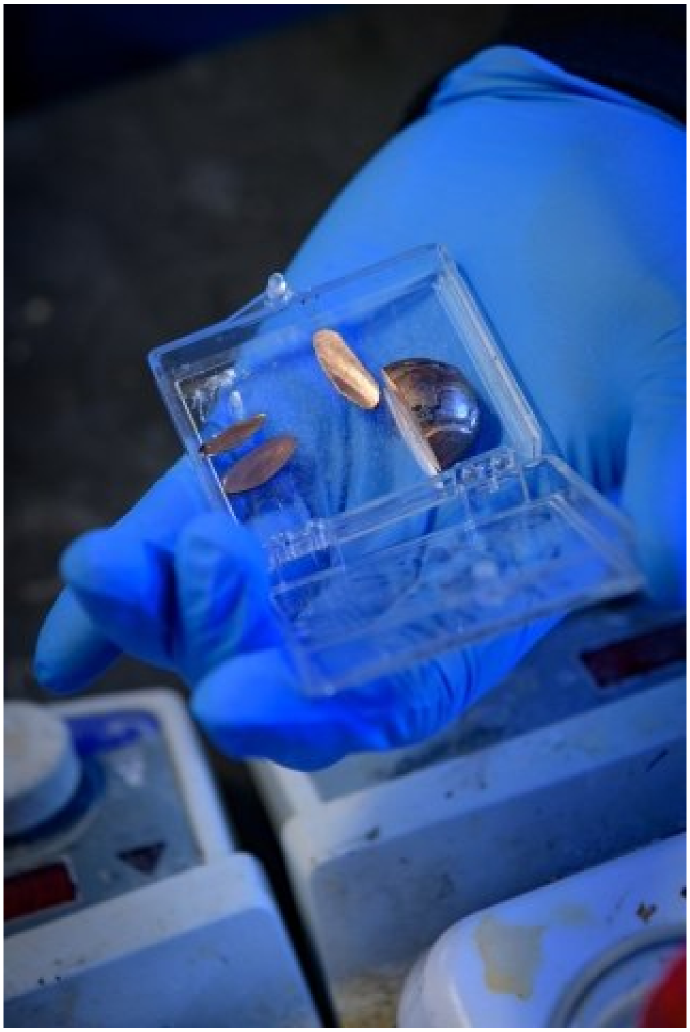
"But we realized that batteries are an expensive technology for large-scale energy storage, so my lab began focusing on beneficial ways to use electricity instead," Jiao said. "Chemical conversion is one way to do this."

Initially, Jiao and his research team focused on developing processes to turn carbon dioxide into useful chemicals, such as ethanol that can be used in synthetic fuels, or ethylene that can be used to produce polymers and plastics. A project, funded by the National Science Foundation and later by the National Aeronautics and Space Administration (NASA), explored ways to convert carbon dioxide to oxygen, something that would be very useful for deep space exploration. Jiao and his students developed an efficient system, but found they needed a better catalyst to drive the reaction.

As they tested different metals for the job, the researchers unexpectedly discovered that a copper-titanium alloy is among only a few non-precious, metal-based catalysts that can split water into hydrogen gas and oxygen, a process referred to as hydrogen evolution. Both copper and titanium are considered inexpensive and relatively abundant when compared with precious metals, such as silver or platinum, typically suited for the job.

Hydrogen is currently produced using what's known as steam-methane reforming, where natural gas and high heat are employed to free hydrogen molecules from methane. Jiao calls it a "dirty process" because when the hydrogen gas is removed, all that is left is carbon, usually in the form of carbon dioxide.

"So, you can produce hydrogen cheaply, but at an environmental cost—carbon dioxide emissions," says Jiao.



Copper alone is not effective at producing hydrogen. But add some interesting chemistry — and a teeny bit of titanium — and a world of possibilities suddenly opens to create catalysts that pull their weight and serve the environment. Credit: University of Delaware

This got Jiao thinking about cleaner ways to produce hydrogen without the environmental cost.

Cleaner, greener processes

Copper is known to be good at conducting both heat and electricity. This is why it is the material of choice for electrical wiring in our homes, cookware, electronics, motor vehicle parts, even air conditioning and home heating parts.

However, copper alone is not effective at producing hydrogen. But add some interesting chemistry—and a teeny bit of titanium—and a world of possibilities suddenly opens to create catalysts that pull their weight and serve the environment.

"With a little bit of titanium in it, the copper catalyst behaves about 100 times better than copper alone," said Jiao. This is because, when paired together, the two metals create uniquely active sites that help the hydrogen atoms strongly interact with the catalyst surface in a way that is comparable to the performance of much more expensive platinum-based catalysts.

While traditional chemical processes start with fossil fuels, such as coal or gas, and add oxygen to produce various chemicals, Jiao explained, with hydrogen the reverse chemical reaction is possible.

"We can start with the most oxidized form of carbon—carbon dioxide—and add hydrogen to produce the same chemicals, which has a lot of potential for reducing carbon emissions," said Jiao, who spoke at a U.S. Senate Committee hearing on carbon capture and neutralization in 2018.

The Jiao team performs a life cycle analysis on each process they invent to evaluate the economics of how the technology stacks up against currently accepted methods. They ask themselves questions such as "Is the invention cost-effective? Is it better or worse than existing technology, and how much can be gained by using the process?"

Early results show that a copper-titanium catalyst can produce hydrogen energy from water at a rate more than two times higher than the current state-of-the-art platinum catalyst. Jiao's electrochemical process can operate at near-room temperatures (70 to 176 degrees Fahrenheit), for the most part, too, which increases the catalyst's energy efficiency and can greatly lower the overall capital cost of the system.

Jiao already has filed a patent application on the process with the help of UD's Office of Economic Innovation and Partnerships (OEIP), but he said more work is needed in terms of scaling the process for commercial applications. If they can make it work, the savings would be big—an alternative catalyst that is three orders of magnitude cheaper than the current state-of-the-art platinum-based catalyst.

Future development efforts will focus on ways to increase the size of the water electrolyzer from lab scale to commercial scale. Additional testing of the catalyst's stability also is planned. The researchers are exploring different combinations of metals, too, to find the sweet spot between performance and cost.

"Once you have the technology, you can create jobs around material supply, manufacturing, and once you can build a product, you can commercialize and export it," said Jiao.

Feng Jiao and colleagues from Columbia University and Xi'an Jiaotong University recently reported their latest findings in an article in *ACS Catalysis*, a journal of the American Chemical Society. His colleague at Columbia University is Jingguang Chen, a former professor in UD's Department of Chemical and Biomolecular Engineering.

More information: Wesley Luc et al. Role of Surface Oxophilicity in Copper-Catalyzed Water Dissociation, *ACS Catalysis* (2018). DOI: 10.1021/acscatal.8b01710