JUAN ESTEY/ISTOCKPHOTO

Prospects for an Artificial Leaf Are Growing

Scientists design photosynthesis devices that could make hydrogen or other fuels

IF EVERY LEAF on the planet can do it, maybe we can too. Scientists have long tried to mimic photosynthesis as a way to harness the energy in sunlight and turn it into a usable fuel, just as plants do. There have been big technical challenges for just as long, and though researchers are far from the ultimate goal, last month two groups of scientists described some ways to hurdle those obstacles.

One of the groups, led by MIT chemistry professor Daniel Nocera, found a new way to reproduce part of the photosynthesis process, using light to split water molecules into oxygen and hydrogen. The gases can then be stored and used as a fuel.

Other groups have had some success with this process before, but there were always stumbling blocks that would make it hard to scale up or commercialize, such as extremely acidic or basic conditions, expensive catalytic materials, or both. However, Nocera's group managed to get artificial photosynthesis to work using benign conditions and cheap, abundant materials as catalysts.

Specifically, the team joined a commercially available triple-junction silicon solar cell to two catalysts: cobalt borate for splitting the water molecule and a nickel molybdenum zinc alloy to form the hydrogen gas. The water-splitting reaction achieved a sunlight-to-fuel conversion of 4.7 percent in one incarnation of the device and 2.5 percent in another. The difference between the two was that the more efficient device housed the hydrogen-generating alloy on a mesh wired to the solar cell. The less efficient version needed no wires, and the alloy was instead deposited onto the stainless-steel back of the solar cell.

It is the wireless possibility, where the entire device is self-contained, that researchers say is most exciting. "Because there are no wires, we are not limited by the size that the light-absorbing material has to be," says Steven Reece, a research scientist with Sun Catalytix (a company cofounded by Nocera) who worked on the discovery. "We can operate on the micro- or even nanoscale... so you can imagine micro- or nanoparticles, similar to the cells we've worked with here, dispersed in a solution." The final product could be much larger, too—a leaf-size stand-alone system, for instance. Whatever the size, the researchers believe such devices could help provide power in poor areas that lack consistent sources of electricity.

Sun Catalytix expects to be able to bring the device to the point where a kilogram of hydrogen could be produced for about US $3, according to its chief technology officer, Thomas Jarvi. Given that about 3.75 liters (1 gallon) of gasoline contains about the same amount of energy as 1 kilogram of hydrogen, the cost would compare favorably to gasoline, which is currently higher than $3 per gallon in the United States.

Daniel Gamelin, a professor of chemistry at the University of Washington, who works on related topics but was not involved with the new research, says the MIT and Sun Catalytix work represents an "impressive accomplishment." However, he says, it remains to be seen whether silicon is really the most desirable material to use. Something less susceptible to degrading by oxygen may be a better option, he says.

"For these specific devices, there remain open questions about their long-term stability," Gamelin says. "And their efficiencies would still need to be increased substantially to be commercially viable. But there is obviously potential for improvement on both fronts. In the bigger scheme, [this research] marks important progress toward the development of truly practical solar hydrogen technologies."

Separately, researchers in Illinois demonstrated a different part of the photosynthesis process—a step toward using sunlight to recycle carbon dioxide. In the natural world, the sun's energy extracts electrons from a water molecule. The electrons then reduce CO_2 into fuel (in plants, the fuel takes the form of carbohydrates). University of Illinois graduate student Brian Rosen and other scientists have invented a device that electroreduced CO_2 to carbon monoxide at a lower voltage than previously achieved. The high voltages usually required have been a major stumbling block in the past. Rosen's group brought the voltage down by using a combination of a silver cathode and an ionic liquid electrolyte that presumably stabilized the CO_2 ion. And, according to Rich Masel, who led the research and is CEO of Dioxide Materials, a company working on CO_2 electroreduction with the University of Illinois, this piece of the photosynthesis process could eventually lead to a way to turn captured CO_2 into "syngas"—a mixture of carbon monoxide and hydrogen used in the petrochemical industry to make gasoline and other fuels.

The experiment "shows that one can make syngas efficiently from any source of electricity," Masel says. However, large-scale versions of the device probably can't be cooked up until 2018. "Presently we have demonstrated the process on the 1-centimeter-squared scale. We need to go to the million cm^2 to make significant amounts of gasoline."

Work on artificial photosynthesis has ramped up considerably in recent years. In July 2010, the Department of Energy began funding the Joint Center for Artificial Photosynthesis to the tune of $122 million over five years. The center, with close to 200 members in universities and national laboratories across California, aims to build on nature's photosynthetic design, bridging all the disciplines required, from chemical engineering to applied physics.

In an interview earlier this year, the center's leader, Caltech professor Nate Lewis, told *IEEE Spectrum* that progress is certainly being made, but it isn't clear yet if the right combination of catalysts and light absorbers and everything else that goes into practical artificial photosynthetic devices has been found.

"We're seeing light in the tunnel," he said. "We don't know where the end of the tunnel is. It's a curved tunnel." —Dave Levitan

A version of this article appeared online in September.

Shutdown of Fukushima Reactors Is Ahead of Schedule

Success in cooling the reactors suggests the plant could be stabilized by year's end

This past April, when the Japanese government and Tokyo Electric Power Co. (TEPCO) jointly unveiled their plan to bring the damaged reactors of the Fukushima Dai-ichi nuclear power plant to a cold shutdown and gain control of the release of radioactive materials, they set a tentative completion date for mid-January 2012.

And "tentative" had to be the operative word, for the obstacles TEPCO faced—and to some extent still does face—are challenging in the extreme. They include:

- Fuel rod meltdowns in reactors 1, 2, and 3 due to loss of cooling systems following the 11 March earthquake and tsunami;
- Severe damage to the upper levels of reactor buildings 1, 3, and 4 and slight damage to building 2, stemming from hydrogen explosions;
- High levels of radiation and contaminated rubble, making working conditions hazardous and difficult;
- Thousands of metric tons of contaminated water accumulating on the site and leaking out of the reactors.

It appears, however, that the process is now ahead of schedule. Environment Minister Goshi Hosono, who is also in charge of the Fukushima nuclear accident recovery, told the International Atomic Energy Agency's annual general conference in Vienna on 19 September that Japan was now aiming to complete a cold shutdown of the Fukushima plant by December 2011, instead of mid-January 2012.

Progress was already evident in July, when Hosono announced that workers had completed step 1 of the two-step road map on schedule, reducing radioactive emissions and starting to bring down the core temperatures in reactors 1, 2, and 3.

Hosono attributed the success to the construction of a new cooling system, which had begun pumping water into all three damaged reactors. In addition to cooling, the system also decontaminates the water accumulating in the basements of the reactor and turbine buildings. The contamination is the result of injected water coming into contact with the molten fuel in the pressure vessels.

Critics, however, were quick to question the stability of the system and its ad hoc design. The combination of filtering and decontamination technologies—mainly from the French nuclear giant Areva and the U.S. nuclear waste management company Kurion—includes some 4 kilometers of piping.

The critics have a point. Even with the addition of a reportedly more robust system (to be used in parallel or as backup as needed) from Toshiba and