Part Microbe, Part Machine: Bionic Leaf Sucks Up Carbon Dioxide As It Makes Liquid Fuel

Source: latimes.com

Published: June 6, 2016

Scientists at Harvard say they've used microbes to build a solar fuels device. (Jessica Polka)

By Amina Khan

A team of scientists at Harvard University says it has come up with a bionic leaf — a system that could use solar power and hydrogen-eating bacteria to generate liquid fuel. The findings, described in the journal Science, offer an alternative path to making carbon-neutral solar fuels.

Part microbe and part machine, the bionic leaf marks a tenfold improvement on the researchers' previous version and could be used to generate all kinds of products, from the precursors for bioplastics to fuel.

"This work is quite significant. … The high performance of this system is unparalleled by any other CO2 reducing system," Peidong Yang, a UC Berkeley chemist and MacArthur "genius" grant winner who was not involved in the paper, said in an email. "In addition, being able to do this at low pressures and at high oxygen concentrations represents another major advancement."

Burning fossil fuel is a dirty process: It pulls out hydrocarbons stored safely in the ground and sends carbon dioxide into the air, releasing a molecule that is contributing both to rising global temperatures and ocean acidification. So getting onto a zero-carbon energy system that uses a totally clean fuel, or at least a carbon-neutral system that recycles the carbon in the air, is of serious importance in the coming decades, scientists say.

Renewable energy — for example, the kind that can be harvested from the sun using photovoltaic solar panels — has long been touted as one of the answers to our deep dependence on fossil fuels. But such systems aren't entirely reliable; sunlight is available only during the day (and even then, only if it's sunny outside).

Researchers have wanted to channel that light energy into a storable fuel, much in the way that plants turn energy into sugars. The process, called artificial photosynthesis, typically involves using electricity from a solar cell to split water into hydrogen and oxygen gas. The hydrogen is collected, and when it is burned in places like the tank of a car, the only byproduct is water.

Study coauthor Daniel Nocera, a Harvard chemist, is one of those scientists: He famously made what was dubbed the "artificial leaf" — a semiconductor wafer coated in a catalyst that could be dropped in water and produce hydrogen gas.

But those systems aren't commercially competitive with fossil fuels yet — and there's no large-scale infrastructure to manage and store it. So some scientists have tried to make hydrocarbons using water, sunlight and carbon dioxide — which has turned out to be an exceedingly complex challenge.

But living cells are quite good at juggling carbon molecules, so Nocera and Harvard systems biologist Pamela Silver decided to put them to work. They used electricity to split water and fed the resulting hydrogen gas to a bacterium called *Ralstonia eutropha*, which uses the hydrogen and carbon dioxide to generate biomass.

But the scientists also took some of the bacteria and changed key genes so that the bacteria produced the alcohol isopropanol instead. Using this system, they've also made isobutanol, isopentanol and PHB, a precursor to bioplastic — and they've done it at rates approaching an estimated efficiency of about 10%. (The bionic leaf also scrubs carbon dioxide from the air at a rate of 180 grams per kilowatt-hour.)

In some ways, it's actually more akin to natural photosynthesis, which doesn't just split water, but also pulls carbon dioxide from the air to make sugars, Nocera said.

"This paper is going the full distance of what I'll call the true artificial photosynthesis," he said.

For the moment, the scientists have been using electricity from the wall, but the system should work the same when hooked up to existing photovoltaic devices, Nocera explained.

That's far better than the approximately 1% achieved by the original bionic leaf the scientists described in the Proceedings of the National Academy of Sciences last year. In version 1.0, they used a nickel-molybdenum-zinc alloy as a catalyst to produce the hydrogen gas — but the process also created too many reactive oxygen species, molecules that are toxic for the bacteria. Because of that, the scientists had to use higher voltages, which also reduced the system's efficiency.

The scientists puzzled over the problem, experimenting with different compounds. ("We messed around for eight months," Nocera said). They finally hit upon a different catalyst, a cobalt-phosphorous alloy, that could generate the gas without producing tons of those reactive molecules. In this gentler environment, the microbes thrived. This also allowed them to use lower voltages, improving the efficiency.

The scientists also developed a strain of the bacteria that was resistant to these reactive oxygen molecules. This didn't make much difference for them because they'd found a better catalyst, but it could be useful for other teams who want to experiment with microbe-based systems but not worry about these potentially toxic chemicals, Nocera said.

The nice thing about this system, the scientist added, is that you don't have to harvest any crops to make these biofuels — which means they avoid some of the criticisms leveled at traditional biofuels, such as ethanol.

"My first impression is that it is well done and carefully executed science," John Turner, a solar fuels researcher at the National Renewable Energy Laboratory in Golden, Colo., who was not involved in the paper, said in an email. But the researcher warned that it remained unclear whether such devices "can really compete against other commercial pathways that can take CO2 and hydrogen to various products."

The next step, Nocera said, was to try to use this process to make nitrogen-based chemicals that could be used in fertilizer.

"Stay tuned because Pam and I are on a path to do nitrogen fixation in the same sort of way we've just done water splitting," he said.

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