Fuel from an Artificial Leaf

Technology that mimics photosynthesis converts carbon dioxide to fuels in a sustainable way

By Javier Garcia Martinez

THE NOTION OF AN ARTIFICIAL LEAF MAKES SO MUCH sense. Leaves, of course, harness energy from the sun to turn carbon dioxide into the carbohydrates that power a plant's cellular activities.

For decades scientists have been working to devise a process similar to photosynthesis to generate a fuel that could be stored for later use. This could solve a major challenge of solar and wind power—providing a way to stow the energy when the sun is not shining and the air is still.

Many, many investigators have contributed over the years to the development of a form of artificial photosynthesis in which sunlight-activated catalysts split water molecules to yield oxygen and hydrogen—the latter being a valuable chemical for a wide range of sustainable technologies. A step closer to actual photosynthesis would be to employ this hydrogen in a reduction reaction that converts CO_2 into hydrocarbons. Like a real leaf, this system would use only CO_2, water and sunlight to produce fuels. The achievement could be revolutionary, enabling creation of a closed system in which carbon dioxide emitted by combustion was transformed back into fuel instead of adding to the greenhouse gases in the atmosphere.

Several researchers are pursuing this goal. One group has demonstrated that it is possible to combine water splitting and CO_2 conversion into fuels in one system with high efficiency. In a June 2016 issue of *Science,* Daniel G. Nocera and Pamela A. Silver, both at Harvard University, and their colleagues reported on an approach to making liquid fuel (specifically fusel alcohols) that far exceeds a natural leaf's conversion of carbon dioxide to carbohydrates. A plant uses just 1 percent of the energy it receives from the sun to make glucose, whereas the artificial system achieved roughly 10 percent efficiency in converting carbon dioxide to fuel, the equivalent of pulling 180 grams of carbon dioxide from the air per kilowatt-hour of electricity generated.

The investigators paired inorganic, solar water-splitting technology (designed to use only biocompatible materials and to avoid creating toxic compounds) with microbes specially engineered to produce fuel, all in a single container. Remarkably, these metabolically engineered bacteria generated a wide variety of fuels and other chemical products even at low CO_2 concentrations. The approach is ready for scaling up to the extent that the catalysts already contain cheap, readily obtainable metals. But investigators still need to greatly increase fuel production. Nocera says the team is working on prototyping the technology and is in partnership discussions with several companies.

Nocera has an even bigger vision for the basic technology. Beyond producing hydrogen- and carbon-rich fuels in a sustainable way, he has demonstrated that equipping the system with a different metabolically altered bacterium can produce nitrogen-based fertilizer right in the soil, an approach that would increase crop yields in areas where conventional fertilizers are not readily available. The bacterium uses the hydrogen and CO_2 to form a biological plastic that serves as a fuel supply. Once the microbe contains enough plastic, it no longer needs sunshine, so it can be buried in the soil. After drawing nitrogen from the air, it exploits the energy and hydrogen in the plastic to make the fertilizer. Radishes grown in soil containing the microbes ended up weighing 150 percent more than control radishes.

Nocera admits that he initially ran the fertilizer test just to see if the idea would work. He envisions a time, however, when bacteria will "breathe in hydrogen" produced by water splitting and ultimately use the hydrogen to produce products ranging from fuels to fertilizers, plastics and drugs, depending on the specific metabolic alterations designed for the bugs.

A significant breakthrough now solves one of the main limitations of current technologies: a group at the University of Illinois at Chicago managed to directly convert CO_2 into carbon monoxide without the need to use pressurized CO_2; rather it pulls it directly from the air. These scientists employed a transparent capsule, made up of a semipermeable resin membrane and filled with water, to capture CO_2 and then transform it into CO thanks to a light absorber coated with catalysts. They then used the CO to produce a wide range of synthetic fuels, including methanol and gasoline.

This and other innovations in the field of artificial photosynthesis have caught the attention of a new generation of entrepreneurs who are taking these discoveries from the lab to the market, driven by the opportunity to produce fuels from renewable sources. Such is the case for Solistra, a company using patented photocatalysts to produce liquid fuels from CO_2 that deliver more energy than they take to make. Synhelion is using solar concentrators to drive the thermochemical conversion of CO_2 into syngas as a precursor to hydrocarbon fuels. A different approach developed by a young company called Dimensional Energy manufactures environmentally responsible polymers and chemical intermediaries using CO_2 as raw material.

These are just a few examples of how the solar-activated conversion of CO_2 into useful chemicals is already creating business opportunities and companies that have the potential to completely transform how we produce all kind of goods, replacing energy-intensive processes by light-activated chemical reactions that mimic how nature does it. SA

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