A 'bionic leaf' could help feed the world

April 3 2017

The radishes on the right were grown with the help of a bionic leaf that produces fertilizer with bacteria, sunlight, water and air. Credit: Nocera lab, Harvard University

In the second half of the 20th century, the mass use of fertilizer was part of an agricultural boom called the "green revolution" that was largely credited with averting a global food crisis. Now, the challenge of feeding the world looms again as the population continues to balloon. To help spur the next agricultural revolution, researchers have invented a "bionic" leaf that uses bacteria, sunlight, water and air to make fertilizer in the very soil where crops are grown.

The team will present the work today at the 253rd National Meeting & Exposition of the American Chemical Society (ACS).

"When you have a large centralized process and a massive infrastructure, you can easily make and deliver fertilizer," Daniel Nocera, Ph.D., says. "But if I said that now you've got to do it in a village in India onsite with dirty water—forget it. Poorer countries in the emerging world don't always have the resources to do this. We should be thinking of a distributed system because that's where it's really needed."

The first "green revolution" in the 1960s saw the increased use of fertilizer on new varieties of rice and wheat, which helped double agricultural production. Although the transformation resulted in some serious environmental damage, it potentially saved millions of lives, particularly in Asia, according to the United Nations (U.N.) Food and Agriculture Organization. But the world's population continues to grow and is expected to swell by more than 2 billion people by 2050, with much of this growth occurring in some of the poorest countries, according to the U.N. Providing food for everyone will require a multi-pronged approach, but experts generally agree that one of the tactics will have to involve boosting crop yields to avoid clearing even more land for farming.

To contribute to the next green revolution, Nocera, who is at Harvard University, is building on the work he's most famous for—the artificial leaf—to make fertilizer. The artificial leaf is a device that, when exposed to sunlight, mimics a natural leaf by splitting water into hydrogen and oxygen. This led to the development of a bionic leaf that pairs the water-splitting catalyst with the bacteria *Ralstonia eutropha*, which consumes hydrogen and takes carbon dioxide out of the air to make liquid fuel. Last June, Nocera's team reported switching the device's nickel-molybdenum-zinc catalyst, which was poisonous to the microbes, with a bacteria-friendly alloy of cobalt and phosphorus. The new system provided biomass and liquid fuel yields that greatly exceeded that from natural photosynthesis.

"The fuels were just the first step," Nocera says. "Getting to that point showed that you can have a renewable chemical synthesis platform. Now we are demonstrating the generality of it by having another type of bacteria take nitrogen out of the atmosphere to make fertilizer."

For this application, Nocera's team has designed a system in which *Xanthobacter* bacteria fix hydrogen from the artificial leaf and carbon dioxide from the atmosphere to make a bioplastic that the bacteria store inside themselves as fuel.

"I can then put the bug in the soil because it has already used the sunlight to make the bioplastic," Nocera says. "Then the bug pulls nitrogen from the air and uses the bioplastic, which is basically stored hydrogen, to drive the fixation cycle to make ammonia for fertilizing crops."

Nocera's lab has analyzed the amount of ammonia the system produces. But the real proof is in the radishes. The researchers have used their approach to grow five crop cycles. The vegetables receiving the bionic-leaf-derived fertilizer weigh 150 percent more than the control crops. The next step, Nocera says, is to boost throughput so that one day, farmers in India or sub-Saharan Africa can produce their own fertilizer.

More information: Sustainable solar-to-fuels and solar-to-fertilizer production, the 253rd National Meeting & Exposition of the American

Chemical Society (ACS), 2017.

Provided by American Chemical Society