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Tweaked cyanobacteria can churn out a plastic precursor, potentially replacing fossil fuels

ClimateWire

By Niina Heikkinen and ClimateWire | August 17, 2015 | 0

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From polyester shirts, plastic milk jugs and PVC pipes to the production of high-grade industrial ethanol, the contribution of the chemical feedstock ethylene can be found just about everywhere around the globe.

But ethylene's ubiquity as a building block in plastics and chemicals masks an underlying environmental cost. The cheap hydrocarbon is made using petroleum and natural gas, and the way it is produced emits more carbon dioxide than any other chemical process. As concerns about levels of CO_2 in the atmosphere have grown, some scientists have been experimenting with ways to make ethylene production more green. At the Department of Energy's National Renewable Energy Laboratory (NREL), researchers are finding unexpected success with the help of cyanobacteria, or blue-green algae.

Jianping Yu, a research scientist with NREL's Photobiology Group, is leading a team of researchers who are working with these organisms. In his lab, they have been able to make ethylene directly from genetically modified algae.

The researchers were able to accomplish this by introducing a gene that coded for an ethylene-producing enzyme—effectively altering the cyanobacteria's metabolism. This allows the organisms to convert some of the carbon dioxide normally used to make sugars and starches during photosynthesis into ethylene. Because ethylene is a gas, it can easily be collected.

Making ethylene doesn't require many inputs, either. The basic requirements for cyanobacteria are water, some minerals and light, and a carbon source. In a commercial setting, CO_2 could come from a point source like a power plant, Yu said.

If this alternative production method becomes efficient enough, it could potentially replace steam cracking, the energy-intensive method currently used to break apart petrochemicals into ethylene and other compounds. Because the algae take in three times the CO_2 to produce a single ton of ethylene, the process acts as a carbon sink. That would be a significant improvement over steam cracking, which generates between 1 ½ and 3 tons of carbon dioxide per ton of ethylene, according to the researchers' own analysis. The captured ethylene gas can then be transformed for use in a wide range of fuels and products.

"I think it's better to turn CO_2 into something useful," Yu said, comparing the approach to other methods of carbon capture. "You don't have to pump CO_2 into the ground, and [the products] will last for many years."

Engineering genes to suck up carbon

Yu and his colleagues weren't the first to come up with the idea of using cyanobacteria to make ethylene. The process was first attempted by researchers in Japan more than a decade ago. At the time, the researchers were not able to produce ethylene reliably. When Yu read the study years later, he thought that by genetically altering a different strain with which he had worked closely (*Synechocystis* sp. PCC6803), he might be able to make ethylene production more consistent.

The researchers are able to make ethylene from algae by altering a part of the organism's metabolism called the tricarboxylic acid (TCA) cycle, which is involved in biosynthesis and energy production. In genetically unaltered blue-green algae, the cycle can only take in a relatively small fraction, or 13 percent, of the 2 to 3 percent of fixed CO_2. But in Yu's lab, the algae are able to send three times more carbon to the TCA cycle and emit 10 percent of the fixed carbon dioxide as ethylene—at a rate of 35 milligrams per liter per hour. That might not sound like very much, but it represents a thousandfold increase in productivity since he first began working with the cyanobacteria in 2010. By the end of this year, Yu is aiming to increase that productivity to 50 milligrams.

"This is by no means close to the upper limit," he said, explaining that the ultimate goal will be to convert 90 percent of fixed carbon to ethylene. "I cannot see why it cannot go higher; I haven't run into a brick wall yet. I don't know what would prevent that from happening, but of course it could."

Surprisingly, even though the cyanobacteria are producing more ethylene, the organisms are still growing at the same rate as non-ethylene-producing algae. The results demonstrate that the cyanobacteria's metabolism was much more flexible than previously thought, according to Yu.

"It's like a person that's losing blood all the time but appears healthy," he said.

Yu and his colleagues aren't certain how this is happening, but the mutation that enabled ethylene production has also stimulated photosynthesis.

"This system gives us a new insight into photosynthesis and gives us hope that we can learn from this and increase photosynthetic activity," he said.

That insight into cyanobacteria's metabolism is as important a finding as the creation of organisms that can consistently produce ethylene, said Robert Burnap, a professor of microbiology and molecular genetics at Oklahoma State University. He was not involved with the study, but did provide a reference for Yu's application to this year's R&D 100 Awards. Yu is now a finalist in the Mechanical Devices/Material category.

"It's surprising how adaptive the metabolism is. It's producing something it's not evolved to make. There was a lot of controversy over whether or not that was even possible to have consistent ethylene production. It shows it is flexible," he said.

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The research could help other scientists better understand metabolic pathways in other plants and even in humans. The TCA cycle is even active in our cells' mitochondria, Burnap said.

"What makes this study really special is the depths of analysis that they went into," he said, describing the research as a whole as a "seminal piece of work."

Manufacturing centers ... in ponds?

It's still much too early to say when or even if these algae will produce ethylene at a commercial scale. Yu estimates that development to that stage could take more than 10 years.

"It will take a lot of work to improve carbon efficiency to 50 percent or higher," Yu said.

Philip Pienkos, principal manager of the Bioprocess R&D Group at NREL's National Bioenergy Center, said the project is beginning to focus more on the development side, even as Yu continues to work to achieve higher ethylene volumes.

"How do you recover ethylene? What do you do with the biomass? This project is poised to answer these important questions," Pienkos said.

Sometime next year, the researchers plan to move their work outdoors to see how the algae behave in an environment that more closely resembles how they would be grown commercially.

"We have to get a real scalable ethylene process so we have a better sense of what this will look like," Pienkos said.

Yu envisions the cyanobacteria growing either in ponds, or possibly vertically, on newspaper-like sheets. In either case, the solid or liquid cultures would have to be enclosed to capture the ethylene, he said.

There are also some safety concerns associated with producing large quantities of the gas. The hydrocarbon and oxygen that are also produced by the algae are flammable, and certain safety precautions would have to be put in place to safely collect ethylene.

Even if the cyanobacteria can create large volumes of ethylene, their success will depend on whether the product can become cost-competitive. That won't be easy because petrochemical-based ethylene is cheap and widely available. According to the researchers' economic analysis, ethylene made from petrochemicals cost $600 to $1,300 per ton, while the gas coming from the algae is estimated to be about $3,240 per ton.

Proving the system's economic viability down the road will also help maintain research funding from the Department of Energy, Peinkos said.

"Algae is not the primary focus of DOE; they've spent decades supporting work in cellulosics. Algae is a much smaller portfolio, and most of the work is in conversion directly to liquid fuels," he said. "Ethylene stands out a little bit because it's not a fuel, but it can be a fuel feedstock."

Winners of the R&D 100 Awards will be announced in November.