Hunt for renewable plastics clears a hurdle

Solving alkalinity problem may help make plastics from CO_2, water, and electricity

By **Robert F. Service**

Plastics are a climate problem. Making precursors for common plastics, such as ethylene and carbon monoxide (CO), consumes fossil fuels and releases plenty of carbon dioxide (CO_2). In recent years, chemists have devised bench-top reactors called electrochemical cells that aim to reverse the process, starting with water and waste CO_2 from industrial processes and using renewable electricity to turn them into feedstocks for plastics. But that green vision has a practical problem: The cells often consume highly alkaline additives that themselves take energy to make.

"This has been a very challenging scientific problem," says Peidong Yang, a chemist at the University of California, Berkeley. Now, his team and a second group are reporting strides toward solving the alkalinity hurdle. One advance links two electrochemical cells in tandem to bypass the problem altogether, and another turns to an enzymelike catalyst to generate a desired chemical without consuming alkaline additives. The plastics industry isn't about to abandon fossil fuels for CO_2 and renewable electricity, but "the field is picking up steam," says Feng Jiao, an electrochemist at the University of Delaware, Newark.

Companies currently make ethylene, a clear, sweet-smelling gas, by using superheated steam under pressure to "crack" the larger hydrocarbons in oil. Honed for decades, the process is extremely efficient, capable of producing ethylene for about $1000 per ton. But its production generates about 200 million tons of CO_2 annually, 0.6% of the world's emissions.

Electrochemical cells, which operate like batteries in reverse, offer a greener alternative. In contrast to batteries, which convert chemical energy into electricity, electrochemical cells feed electricity to catalysts that make chemicals.

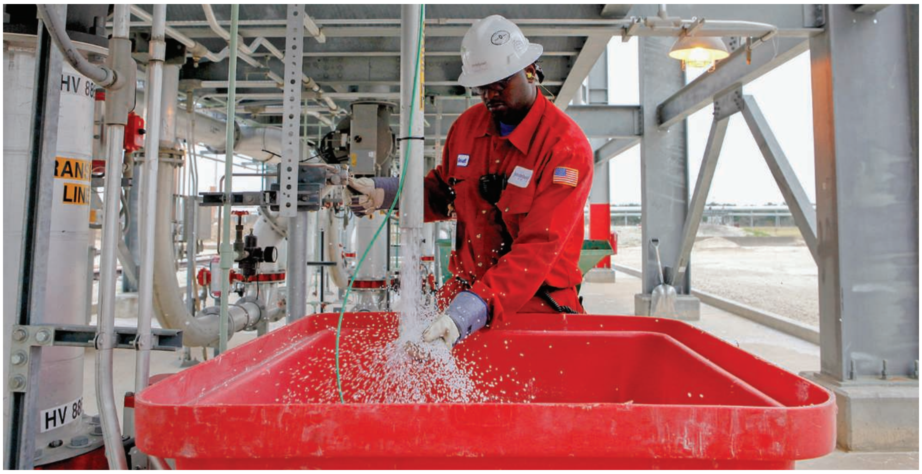
Both kinds of devices rely on two electrodes separated by an electrolyte that ferries charged ions. In electrochemical cells designed to convert CO_2 to more valuable chemicals, the dissolved gas and water react at the cathode to form ethylene and other hydrocarbons. The electrolyte is typically spiked with potassium hydroxide, which allows the chemical conversions to occur at a lower voltage, thereby boosting the overall energy efficiency. And it helps channel most of the added electricity toward creating hydrocarbons instead of hydrogen gas, a less valuable product.

But Matthew Kanan, an electrochemist at Stanford University, notes that the hydroxide carries an energy penalty of its own. The hydroxide ions react with CO_2 at the cathode, forming carbonate, which precipitates out of solution as a solid. As a result, the hydroxide must be continually replenished—and hydroxide itself takes energy to make, making the overall process an energy loser.

In 2019, Kanan and his colleagues reported a partial solution. In place of CO_2, they fed their cell CO, which doesn't react with hydroxide to form carbonate. The cell itself was highly efficient: Seventy-five percent of the electrons they fed their catalyst—a metric referred to as the faradaic efficiency (FE)—went to making acetate, a simple carbon-containing compound that can be used as a feedstock for industrial microbes. The trouble is that making CO normally requires fossil fuels, undoing some of the climate benefits of the scheme.

Now, a team led by Edward Sargent, a chemist at the University of Toronto, has taken this approach a step further. They started with a commercially available device called a solid oxide electrochemical cell, which uses high temperatures to convert CO_2 to CO and could be powered by renewable electricity. The CO flows into another electrochemical cell whose catalysts are tailored to favor the production of ethylene, a more widely used commodity chemical than acetate. The tandem reactor no longer consumes hydroxide and has an FE of 65% for energy stored in ethylene produced by the device, the researchers reported last week in *Joule*. "That's a significant advance," Jiao says.

In the December 2020 issue of *Nature Energy*, Yang and his colleagues reported a very different way to get around the alkalinity problem. In an alkaline electrochemical cell, they redesigned the catalyst to exclude water and hydroxide ions at the sites where it splits CO_2. The device can convert the gas into CO without generating carbonate, a major energy win. But this cell doesn't yet convert that CO and hydrogen from water into ethylene and other hydrocarbons, Yang notes.



Conventional polyethylene production, powered by fossil fuels, could one day be replaced by chemical reactors that rely on renewable energy and consume carbon dioxide.

PHOTO: AARON M. SPRECHER/BLOOMBERG VIA GETTY IMAGES

Better electrochemical cells aren't the only force propelling the research. As wind and solar energy generation burgeons, renewable energy prices are plummeting. Those low energy prices mean that doubling of the overall energy efficiency of tandem electrochemical cells could make them cost competitive with the standard fossil fuel approach for manufacturing ethylene, Sargent and his colleagues report in a December 2020 paper in *ACS Energy Letters*. "We are trying to put that option in play," Kanan says. ■

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