PLASTICS: A Source of **RECYCLED CARBON**

UCSB researchers delve into new ways to "close the loop" on a major source of pollution

Last October, an article in *SCIENCE* by UC Santa Barbara researchers **Susannah Scott** and **Mahdi Abu-Omar** described a one-pot, low-temperature catalytic method that upcycles polyethylene into high-value alkylaromatic molecules. Polyethylene represents about a third of all plastics, which have a global value of about $200 billion annually.

Scott described the findings as "a demonstration of what can be done, one of an increasing number of possible measures that can be taken to turn the wasteful, linear plastic economy into a more sustainable, circular one."

The paper found widespread interest around the world, and Scott and Abu-Omar, both of whom have appointments in chemistry and chemical engineering, are in the process of proposing to industry the idea of using the alkylaromatic molecules to make biodegradable anionic surfactants, which are used in laundry detergents, soaps, shampoos, toothpaste, dishwashing liquid, and spray cleaners. "You can imagine a company saying, 'We can sell you a bottle of shampoo in which both the bottle and its contents are made from recycled carbon,'" Scott says. "This is feeding into a larger idea of a circular carbon economy."

While the more conventional approach to addressing the increasing problem of plastic waste was "circular plastics" — making new plastics out of used plastics, including the mechanical recycling that is practiced currently — Scott, who holds UCSB's Mellichamp Chair in Sustainable Catalytic Processing, and Abu-Omar, who specializes in energy catalysis and holds the Mellichamp Chair in Green Chemistry, are thinking of how to turn used plastics into new forms of carbon by disassembling the macromolecules they comprise.

"The idea of circular plastics falls short on a number of levels," Scott says. "It's very desirable when it does work, but it works only rarely. When the plastics are mechanically recycled, the properties of the recycled material are almost always inferior to those of the original polymers. And they're much more expensive, so you get the same or worse properties for a much higher price, and there's just no way to easily make that a broad strategy for dealing with the plastics problem."

Their approach has a broader goal. "We're trying to keep carbon in use, to preserve the value of that reduced carbon for as long as possible, because that has energy implications," Scott explains. "In the future, we'll be turning CO_2 into carbon-based products, but that is an energy-intensive process, one you certainly do not want to do with every carbon atom every time you use it."

In as yet unpublished work, Scott and Abu-Omar are examining uses for other molecules obtained directly from polyethylene, in addition to alkylaromatics. They describe what they've done so far as a small-scale proof-of-concept demonstration. "The question then is, how do you turn that into something that you can scale up to deal with the magnitude of the plastic waste problem? It's not at all straightforward," Scott notes.

"We've seen that with the biomass

➤ *Palming converted polymers: Yu-Hsuan "Ariel" Lee, a third-year PhD student in Abu-Omar's group, holds a volumetric flask containing the hydrocarbon products resulting from catalytic conversion of a long-chain alkane.*

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Mahdi Abu-Omar

Susannah Scott

industry, which was supposed to be the solution to everything — providing renewable carbon — but so far has turned out to be the solution to very little," she adds. "The problems are many, and some are similar to the plastics problems. One is that you're dealing with a highly dispersed, highly heterogeneous material that you have to collect, separate, refine, and purify, and you have to get this solid into your reactor so that you can process it. If you want to use it for anything more than simply burning it for energy, just the handling of the solids starts to get pretty tricky."

Another challenge associated with biomass conversion is selectivity. "You might have a mixture of a hundred individually valuable compounds that have no value — because they are a mixture," Scott says. "Making molecules selectively from biomass is a big challenge. We have the same issues with plastics: how do we collect this highly dispersed, highly heterogeneous material and make molecules selectively from it?"

Abu-Omar sees hope for biomass in the fact that some companies, including Dow Chemical, have demonstrated an ability to make polyolefins (polymerized olefins, such as polyethylene) from renewable ethylene that comes from nonfood biomass. "The price difference between that and using fossil fuels is a factor of two, not ten," he says. "That allows you, in the future, when we have renewable sources, to make it so that these carbons and plastics that are important for modern life have a more perfect cycle. You have a renewable carbon source that becomes waste but is not treated as waste, but rather as a new type of feedstock. We can make useful molecules and chemicals from a renewable carbon feedstock that completes the cycle. That is a very new realization.

"All these plastics are a problem, for society and for the environment," he continues. "We're saying, think about this plastic as a feedstock instead of digging a hole in the ground and harvesting petroleum and using that to make all the different things we use in modern life."

While, according to Scott, "It is desirable to make sure that the carbon used to make plastic is reused several times before it returns to the environment," she adds, "The idea of a perfect cycle in which carbon is recycled an infinite number of times defies thermodynamics. You can't actually do that. But it's a legitimate question to ask how many times it is desirable to recycle before you are better off just starting again. When things get so contaminated and dispersed, it takes more energy to collect and purify them than it does to let them decompose and start the chemical transformations again.

"While turning petroleum into ethylene to make polymers is a highly energy-intensive process," Scott says, "there is, thermodynamically, potentially a way to turn a polymer into another polymer — another form of carbon — without investing a lot of energy. That's why I think this circular-carbon idea is a really cool one."

At some point, when the carbon that is used to make the plastics comes from a renewable source, that will close the cycle, even if the end use of the molecules obtained from waste plastics ends up being biodegradable detergents or jet fuels that we end up burning. They become CO_2 and that CO_2 will be used to make the plastics again.

"It's really about getting into those plastics," says Abu-Omar, "because the other choice is, we stop using plastic. That might have some benefits, but there will also be a lot of harms, because plastics have made things we use in the medical field, in safety, in hygiene much more accessible. But we're heading toward a colossal problem with the waste, and we want to find a solution to that, and mining the plastic waste as a feedstock for chemicals, fuels, etc. I think, is the solution. That's what we're advocating for in the work we're doing."

"Traditionally, people who are passionate about sustainability talk about creating new regulations or new economic incentives," says Scott. "And, of course, those are all part of the strategy, but they're not enough. It's clear that they're not enough. Technology is needed. New ways of looking at the material basis of the things we use are needed. It has to be a combination of those things."