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RECYCLING

Plastics recycling rocketed forward

Chemists cooked up new tricks to break down polymers

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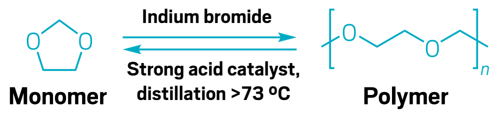
In 2021, plastics recycling got a whole new vibe. At least that's the way Bert Weckhuysen, an inorganic chemist at Utrecht University, puts it. The scientific community has known for years that recycling plastics is an important but difficult problem that has progressed slowly toward solutions.

In the past year, however, "there is really a surge—almost everyone is jumping on things," Weckhuysen says. Chemists are studying many aspects of the plastics recycling problem. They are researching ways to break down plastics with catalysts, studying mechanical recycling, and rethinking how plastics are made in the first place. Plastics have entered a stage of circular thinking, Weckhuysen says, in which scientists design the polymers with a focus on what will happen to the materials after their initial use.

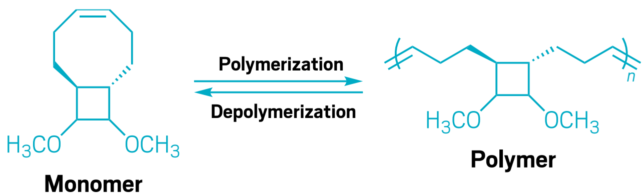
One way researchers designed plastics with reuse in mind was to make plastics out of polymers that can be chemically broken down into monomers, which can then be made into the polymers again. For example, this year, Cornell University chemist Geoffrey W. Coates and coworkers synthesized a polymer



that chemists can both separate into monomers and recover from a mixture of plastics (*Science* 2021, DOI: 10.1126/science.abh0626).

On its own, the polyacetal polymer is stable at temperatures up to 325 °C. But after the researchers added a strong acid catalyst, they could break the polymer down into its monomer constituents (shown) above 73 °C. The monomers are liquid at this temperature, which made it easy for the team to separate them from other plastics that were still solids under these conditions. Brooks A. Abel, who is one of the study's authors and is now at the University of California, Berkeley, told C&EN earlier this year that the researchers picked through recycling bins, chopped up the plastics they found, and dumped the mix into the flask with their polymer to test how easy it was to separate out the broken-down monomers. These samples contained labels, glues, "and probably a little bit of Gatorade," Abel said. Even so, the team recovered as much as 98% of the monomer.

In this same vein, Junpeng Wang and colleagues at the University of Akron developed a polymer that scientists can break into monomers with the help of ring strain (*Nat. Chem.* 2021, DOI: 10.1038/s41557-021-00748-5). The group created a polymer made of cyclooctene monomers in which a four-membered cyclobutane ring is fused to the eight-membered ring. With a ruthenium catalyst, the cyclooctene zips itself into a polymer below room temperature (shown). The material can fall apart into monomers again when the chemists heat it and the catalyst to 50 °C. Without the catalyst, the polymer is stable up to 370 °C. The team can change functional groups on the polymer backbone to tailor its properties. Because of this variability, the researchers think that the polymers could find multiple uses, including as plastics or rubbers.



> **"Everything is made to be stable, to be durable, which is good." But how do you make something that's biodegradable but also stable?**
>
> —**Bert Weckhuysen,** inorganic chemist, Utrecht University

Encapsulated enzymes distributed throughout polycaprolactone can accelerate the breakdown of the material in the presence of heat and humidity. Photos show the material before and after composting for 3 days.

CREDIT: *NATURE*

Developing new types of plastics and polymers that have built-in recycling features is an important approach to the plastics recycling problem, Utrecht's Weckhuysen says. One major question is whether to make plastics biodegradable by design, he says, and this comes down to whether the polymers can still be durable. "Everything is made to be stable, to be durable, which is good," Weckhuysen says. But how do you make something that's biodegradable but also stable?

Ting Xu, a chemical engineer at the University of California, Berkeley, and colleagues have figured out how to make a plastic that's both. The group encased plastic-chomping enzymes in a protective coating and incorporated the resulting nanoparticles into polycaprolactone and polylactic acid plastics as they were being made (*Nature* 2021, DOI: 10.1038/s41586-021-03408-3). When the researchers exposed these plastics to humidity and either heat or ultraviolet light, the protective coating broke down, releasing the enzymes. The team could break down as much as 98% of the polymers in 30 h, depending on the polymer and the temperature. The depolymerization process leaves behind lactic acid, which people can pour down the drain or add to their garden, Xu told C&EN earlier this year.

New plastics recycling technologies and strategies are needed because our society will keep using plastics, Weckhuysen says. "People can complain about plastic, but plastic has brought us a lot," he says. We've seen the importance of plastics during the COVID-19 pandemic, he says. Hospitals need to use plastics to protect staff and patients against infection, such as in plastic face shields or medical waste bags. Our need for plastics will continue in the future, which Weckhuysen says will require chemists to rethink classical plastics.