Chemistry and biology unite to recycle mixed plastics

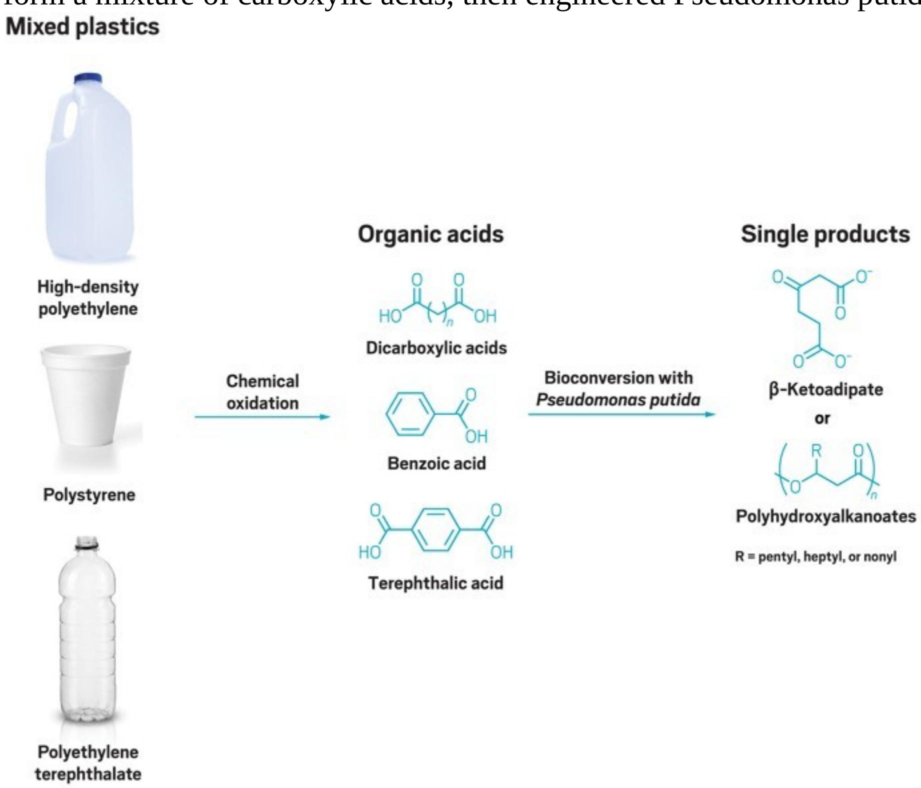
No presorting needed in 2-step process that turns multiple plastics into single products

by Mark Peplow, October 13, 2022

A two-stage process that combines the power of chemistry and biology can convert mixtures of common waste plastics into single products, potentially overcoming a major obstacle in recycling (Science 2022, DOI: 10.1126/science.abo4626).

Plastic waste contains a mélange of materials, so it typically goes through a laborious sorting process to separate certain types of plastic for mechanical recycling. For example, polyethylene terephthalate (PET) and high-density polyethylene (HDPE) can be chopped up and used to make new products. But most other plastics cannot be recycled in this way, including composite materials that are difficult to tease apart. Overall, the US recycles less than 10% of its plastic waste, with the remainder landfilled, incinerated, or dumped, according to the US Government Accountability Office.

MIXED PLASTICS TO MONOMERS
A two-step chemical and biological recycling process can convert a feedstock of multiple types of plastic into single products.
A mixture of plastics can be converted into single products using a tandem chemical-biological process. In the first step, polyethylene, polystyrene, and polyethylene terephthalate are chemically oxidized to form a mixture of carboxylic acids, then engineered Pseudomonas putida bacteria digest these acids to make polyhydroxyalkanoates or beta-ketoadipate, depending on the strain used.



Credit: C&EN/Shutterstock Source: Science 2022, DOI: 10.1126/science.abo4626.

Although a growing number of chemical processes are able to break down polymers into their constituent monomers, which can then be turned into fresh plastics, very few can tackle mixtures of plastic waste. Another option involves high-temperature pyrolysis, which chews up mixed plastics into a hydrocarbon oil that can feed ethylene crackers. But pyrolysis is energy intensive, and critics have questioned its environmental credentials.

The new recycling process seeks to address these drawbacks by integrating chemical and biological processes (shown). First, it uses air to oxidize polymers into different carboxylic acids, with the help of cobalt and manganese ions as catalysts and N-hydroxyphthalimide as an initiator. “Unlike pyrolysis, this makes compounds that are water soluble, so they’re bioavailable,” says Gregg T. Beckham of the National Renewable Energy Laboratory, part of the consortium Bio-Optimized Technologies to Keep Thermoplastics out of Landfills and the Environment (BOTTLE), which led the research.

After the metal catalysts have been recovered, engineered Pseudomonas putida bacteria get to work on the soup of carboxylic acids, digesting them through multiple biochemical pathways into a single product—an approach known as biological funneling. One strain of bacteria makes polyhydroxyalkanoates (PHAs), which are used in biodegradable packaging; another produces β-ketoadipate, which can be transformed into easy-to-recycle, nylon-like materials. In principle, other engineered bacteria could convert the chemical oxidation products into a variety of alternative molecules.

“This sort of integration is pioneering and unique, in terms of plastic conversion,” says Ning Yan, a chemical engineer at the National University of Singapore who works on chemical recycling of mixed plastics and was not involved in the research. Tandem chemical-biological processes have long been used to convert biopolymers like cellulose into useful compounds, but this particular approach has not been used for plastics, he says.

In one iteration, the researchers turned a mix of PET, HDPE, and polystyrene into β-ketoadipate with a yield of 57%, which Yan says is impressive. “Organic chemists would not be able to convert that complex mixture [of carboxylic acids] into a single product with 57% yield,” he says, laughing.

Both stages of the process were inspired by existing technologies, which suggests that it should be amenable to industrialization, the researchers say. Since completing this work on proof of principle, they have been testing their system with other polymers. “We have done this with many substrates now, and we have not yet found a plastic that cannot be broken down,” Beckham says.

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