Enzymatic recycling of Plastic for a circular economy?

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A plastic world?

Plastic pollution has contaminated the whole planet, from the Arctic to the deepest oceans, and people are now known to consume and breathe microplastic particles as a result. If we continue to dump plastic and not find a way to break down plastic faster, we would soon have a plastic-covered earth.

The Problem

Among common kinds of plastic, polyethylene terephthalate (PET), the most commonly used thermoplastic with which single-use water bottles are often made, are estimated to take approximately 450 years to fully break down. It is currently very difficult to break down PET into its chemical constituents in order to make new ones from old, thus, the efficiency of recycling is very low, and more new plastic is being created from oil each year.

This is a huge problem since plastics are known to cause health hazards like endocrine, skin and reproductive problems, cancer, and hypothyroidism. They also choke sea life, and deliver disease-causing microbes to corals, and cause ulcers, infections or deaths in birds.

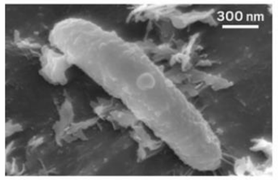
Plastic-eating bacteria?

In 2016, scientists from Japan tested different bacteria from a bottle recycling plant and discovered a bacterium, *Ideonella sakaiensis* 201-F6, that could digest PET. It works by secreting an enzyme known as PETase, which splits ester bonds in PET, leaving smaller molecules that the bacteria can absorb and use as food.

When grown on PET, this strain produces two enzymes capable of hydrolyzing PET and the reaction intermediate, mono(2-hydroxyethyl) terephthalic acid. Both enzymes are required to enzymatically convert PET efficiently into its two environmentally benign monomers, terephthalic acid and ethylene glycol.

PET Depolymerization by Enzymes

I. sakaiensis contains a two-enzyme system for breaking down PET. Its PETase hydrolyzes the ester bonds present in PET with high specificity, resulting in MHET, which is then broken down into its two monomeric constituents by a MHET hydrolase enzyme, or MHETase, on the cell's outer membrane.



Ideonella sakaiensis

Image Credit: Yoshida, S. et al.

Both products are used by the cell to produce energy and to build necessary biomolecules.

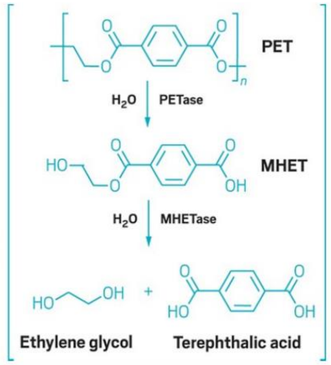


Image Credit: The Medium

Super Enzymes?

Scientists led by J. E. McGeehan in Britain and the USA genetically engineered the *I. sakaiensis* PETase in 2018, and the modified enzyme takes just a few days to start decomposing PET – much faster than centuries in oceans. In 2020, they combined the *I. sakaiensis* PETase and MHETase to produce a very powerful MHETase able to break down natural fibres to allow mixed materials and fabrics, which are typically very difficult to recycle, to be fully recycled. Although the two-enzyme approach was evolved in bacteria to break down natural polymers like cellulose, the combined enzyme would be too large for a bacterium to create. This combined enzyme works six times faster than even the 2018 modified PETase!

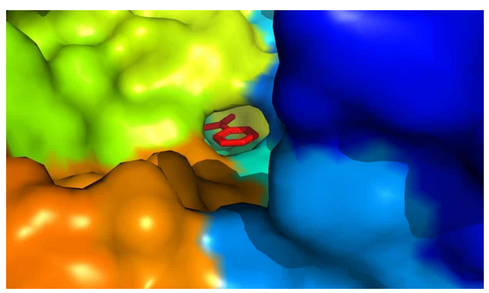


Image Credit: Aaron McGeehan

McGeehan's combined MHETase

Industrial Application

Other groups are also working on the *I. sakaiensis*. Carbios, a French company, developed an organic approach to recycle PET. Generally, opaque or complex plastics, or plastics of textile origin (polyesters) are hard to recycle. Carbios has genetically modified the PETase from *I. sakaiensis* to optimize enzymatic activity to depolymerize 97% of PET starting materials into monomers in 24 hours. This allows infinite recycling of all types of PET waste as well as the production of fully recycled and 100% recyclable PET products. Before exposing PET to its enzyme, Carbios uses a proprietary pretreatment that converts crystalline PET to an amorphous form to facilitate breakdown. The monomers from the depolymerization process, terephthalic acid and ethylene, are purified in order to be re-polymerized into a PET of a quality equivalent to the virgin PET obtained from the petrochemical industry. Currently at the pilot stage, Carbios has successfully produced the first batches of transparent PET bottles from monomers obtained from the depolymerization of PET plastic waste and PET polyester textile waste. The company is now preparing for the first industrial unit for the second half of 2021.

Conclusion

Even though promising new technology is being developed to tackle plastic pollution, we should still help by reducing consumption, reusing and recycling properly.

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