U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Bioproducts: A Clean Energy Solution

In an effort to build a 100% clean energy economy and achieve net-zero emissions no later than 2050, the United States is investing in research to develop innovative products made from biological material. Reducing greenhouse gas (GHG) emissions to meet these goals will require more than solely replacing fossil fuels used for transportation. Reductions must also come from changes to the way that everyday items are made and used. Bioproducts can help by not only replacing, but often improving upon everyday petroleum-based products.

While petroleum is most often associated with fuel, as much as 16% of each barrel of oil is used as an ingredient in the production of plastics, fertilizers, detergents, rubber, lubricants, clothing, cosmetics, and other common household items.[1] Organic material—ranging from municipal waste to agricultural and forestry refuse—can also be used to create bioproducts in lieu of petroleum-based products. The U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) supports research to make bioproducts more affordable, available, and easier-to-create.

Many common products developed from petrochemicals can be supplemented or developed with biomass feedstocks. These include nutritional supplements, plastic building blocks, water bottles, laundry detergents, auto parts made of carbon fiber, and cosmetics and perfume. *Photo courtesy of DOE.*

A Second Chance at Carbon

Bioproducts are often produced when remnants from the production of biofuels (think ethanol or any other fuel derived from biomass like plants, algae, or animal waste) are put to productive use. For example, when biomass is broken down for conversion to biofuels and biochemicals, some organic compounds are washed away in the aqueous waste stream. The presence of those compounds means that the waste stream can't just be flushed into the sewer, presenting an additional disposal cost to the refinery. To address this, researchers at the National Renewable Energy Laboratory (NREL) developed a method to isolate valuable monomers from those organic compounds that can be turned into phenol and catechol. These compounds can be used for biotransformation and employed in the construction of electronics, pharmaceuticals, and a variety of other products.[2]

BETO-funded research by the renewable chemicals and advanced biofuels company, Gevo, led to the production of isobutanol—an intermediate chemical that can be used in the manufacture of renewable fuels and products.[3] Traditionally derived isobutanol is a component of many solvents and coatings, like varnishes and lacquers.With additional processing, isobutanol can be converted to isobutylene, which is a key compound in plastics, rubber, and other products traditionally made from petrochemicals.

Improving on the Originals

Bioproducts are more than just substitutes for plastics and other petroleum-based products; they can often be an improvement over the original.

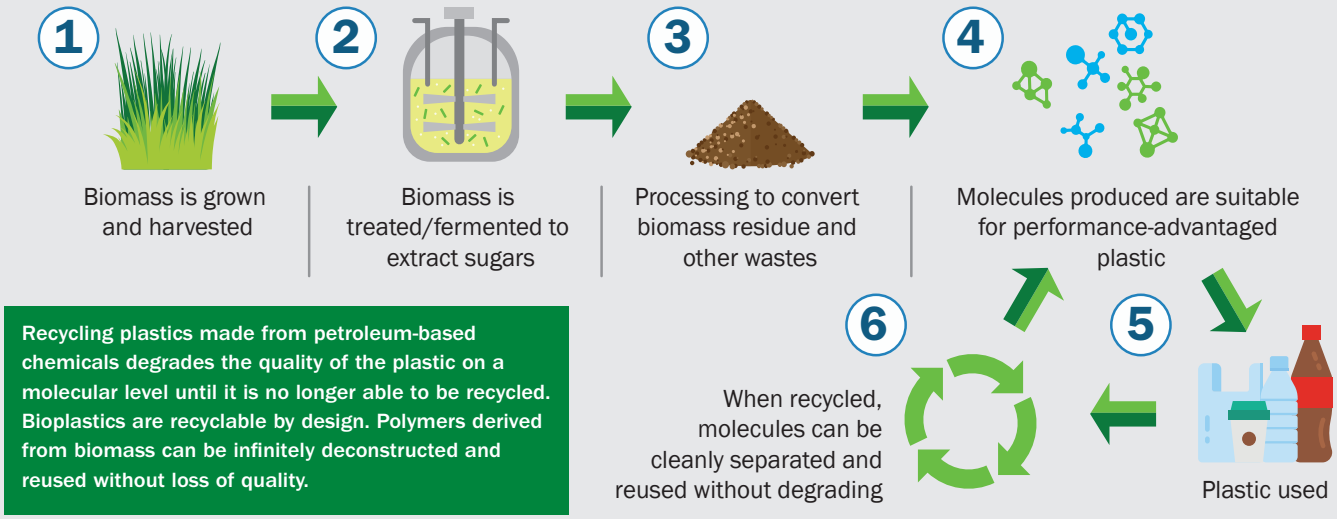
BETO has explored the molecular rationale for the superior barrier properties behind polyethylene furanoate (PEF)—a replacement for PET in plastic bottles. Using similar chemistry, Avantium—a renewable chemistry technology company—teamed up with Coca-Cola to use PEF in the development of a better soda bottle. This polymer provides a stronger barrier to oxygen, carbon dioxide, and water than traditional petroleum-based plastics. In addition to being recyclable and degradable, PEF bottles can be made with less than one-fifth of the amount of material as their petroleum-based counterparts. This means that the use of PEF both reduces waste and increases the shelf life by lowering any loss of carbonation.[4]

Flip-flops are the world's top-selling footwear, with around three billion pairs produced every year from petroleum-based polyurethane. Because flip-flops are considered inexpensive and, therefore, disposable, many end up in landfills or the ocean, making polyurethane from shoes one of the ocean's top pollutants.[5] Using algal cultivation research funded by BETO, biomaterials technology company Algenesis created biodegradable flip-flops derived from renewable algae cutting down on plastic waste.[6]

Bioproducts can also improve on their petroleum-based counterparts by eliminating

1 energy.gov/eere/bioenergy/downloads/bioproducts-enable-biofuels-workshop-summary-report
2 pubs.rsc.org/en/content/articlelanding/2019/GC/C9GC00902G
3 gevo.com/wp-content/uploads/2021/05/Gevo-Whitepaper-%E2%80%93-Isobutanol-Production-Process.pdf
4 avantium.com/lead-products/#pef
5 ucsdnews.ucsd.edu feature/a_flip_flop_revolution
6 algenesismaterials.com/algenesis-products

Upcycling with Biomass



Recycling plastics made from petroleum-based chemicals degrades the quality of the plastic on a molecular level until it is no longer able to be recycled. Bioplastics are recyclable by design. Polymers derived from biomass can be infinitely deconstructed and reused without loss of quality.

deadly chemicals from their manufacturing process. Carbon fiber is used in the construction of motorcycle helmets, car parts, and racing bicycles because it has a material strength rivaling that of steel or aluminum at a fraction of the weight. But the petroleum-based process for making acrylonitrile (ACN), one of the key ingredients in carbon fiber, also produces highly toxic hydrogen cyanide as a byproduct. At NREL, scientists have eliminated the poisonous chemical from the production process by converting, separating, and catalytically processing biomass into ACN using three separate biologically-derived intermediates.[7]

Designing with Recycling in Mind

While petroleum-based plastics can be recycled, the process can break structural bonds—making the new recycled plastic inferior in quality. After a few cycles, recycled plastic degrades to the point that it is no longer usable and must be discarded. The BETO-supported BOTTLE consortium is developing bio-based plastics that can be made recyclable-by-design.[8] This means the molecules that form the bioplastic can be separated without being damaged, then reused in new products, and subsequently recycled again in an infinite loop.

Manufacturing a Cleaner Future

Cleaner energy production alone will not be enough to achieve the GHG emission reduction goals of net-zero emissions no later than 2050. Sustainable, biomass-based replacements for plastics and other petroleum-based products that are used daily are a crucial component of reducing GHG emissions, motivating BETO and its partners to advance the development of dozens of bioproducts.

BETO is researching ways to reduce the carbon output of fuels and replace carbon-emitting products we use every day. Progress in these areas will contribute to the U.S. commitment to reduce GHG emissions and improve sustainability in the decades to come. ■

About the Bioenergy Technologies Office

BETO supports research, development, and demonstration to enable the sustainable use of domestic biomass and waste resources for the production of biofuels and bioproducts. BETO's overall goals are designed to:

- Lower costs and reduce technology risks for production of biofuels and bioproducts
- Improve environmental benefits of bioenergy production
- Reduce greenhouse gas emissions from the transportation, industrial, and agricultural sectors to address the climate crisis
- Support the scale-up of sustainable, low-carbon biofuel production technologies
- Create economic opportunities and good-paying jobs in agriculture and manufacturing sectors.

Meeting these goals requires significant and rapid advances in technology development and innovation across the entire biomass-to-bioenergy supply chain.

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BIOENERGY TECHNOLOGIES OFFICE

For more information, visit:
energy.gov/eere/bioenergy

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[7] nrel.gov/news/features/2018/nrel-shifts-carbon-fiber-research-into-second-gear.html
[8] bottle.org