ISTOCK

By Cynthia Washam

Imagine this: It is the day after graduation, and you are about to drive off the parking lot of a car dealership in your brand new Ford Mustang. The seats of your car are made of soy foam, and your car is powered by gasoline made from plants. Ahhh… You sip water from a bottle made from corn after finishing a call on your Samsung Reclaim bioplastic cell phone. You are feeling good about your new freedom and about the number of eco-friendly elements comprising your car. As you pull off, you imagine Henry Ford himself giving you the thumbs up on your new ride.

Why? Well, in addition to creating the first automobile, Ford invented in 1941 what might be considered the first green car. The materials comprising Ford's soybean car were made with hemp, wheat, flax, and soybeans. Unfortunately, poor timing kept the car from ever hitting the road. Shortly after the soybean car made its debut, the United States became involved in World War II. Auto production ground to a halt, as workers shifted to building jeeps and tanks.

COURTESY OF THE COLLECTION OF HENRY FORD

Ford's idea of making plastic from plants was all but forgotten until the 1990s, when people seeking to protect the environment started developing alternatives to conventional, petroleum-based plastic.

COURTESY OF SAMSUNG MOBILE

Today, there is a new breed of car seats, water bottles, and cell phones that are among hundreds of plastic items being promoted as "green"—that is, less harmful to the environment. These items are made of plant-based plastics called bioplastics that could make up 20% of the plastics market by 2020.

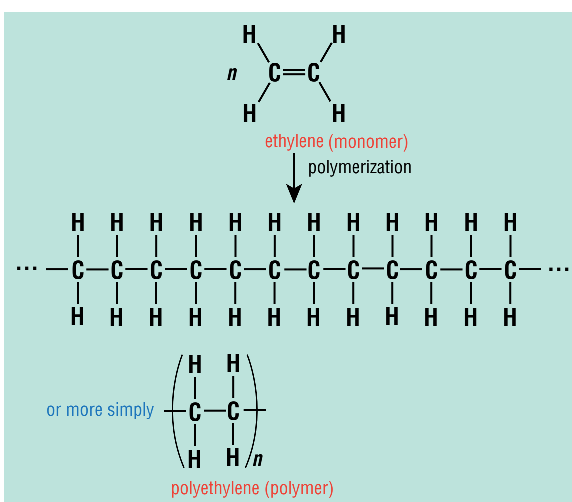

Figure 1. Polymerization of ethylene into polyethylene (*n* is a large number.)

Plastics

Many materials that we use in our everyday life are made of plastics. But what are these plastics made of? Plastics belong to a group of molecules called polymers, which are large molecules made of repeating units called monomers. Most plastics contain between 500 and 20,000 or more repeating units.

Plastics can be produced by bonding together monomers in a reaction called polymerization. For example, a plastic called polyethylene, which is commonly used in grocery bags and packaging, is formed by adding together molecules of ethylene (C_2H_4) (Fig. 1).

Most plastics are made from crude oil. Molecules present in crude oil undergo chemical reactions that create monomers, which are assembled together to make polymers that can be processed into plastics. This process is very common, but it produces pollutants, such as carbon dioxide (CO_2), which contribute to climate change. Also, crude oil is in great demand throughout the world. Scientists estimate that at today's consumption rate, the world's oil supply may dry up in less than 100 years.

To address these two problems, scientists have been looking for the past two decades for new ways of making plastics. One way involves the use of plants as the raw material, instead of crude oil. This type of plastic is called bioplastic.

BAUM GARTEN

Bioplastics

Bioplastics are made by converting the sugar present in plants into plastic. In the United States, that sugar comes from corn. Other countries use sugar cane, sugar beets, wheat, or potatoes. This makes bioplastics renewable and better for the environment than conventional plastics.

Two types of bioplastics are now produced in large quantities. They are called polylactide acid (PLA) and polyhydroxyalkanoate (PHA).

The biggest producer of PLA is NatureWorks, a company located in Blair, Neb. There, corn kernels are milled, a chemical substance called dextrose is extracted, and dextrose is fermented by bacteria or yeast in big vats. The result is lactic acid (Fig. 2), which acts as a repeating unit to make PLA.

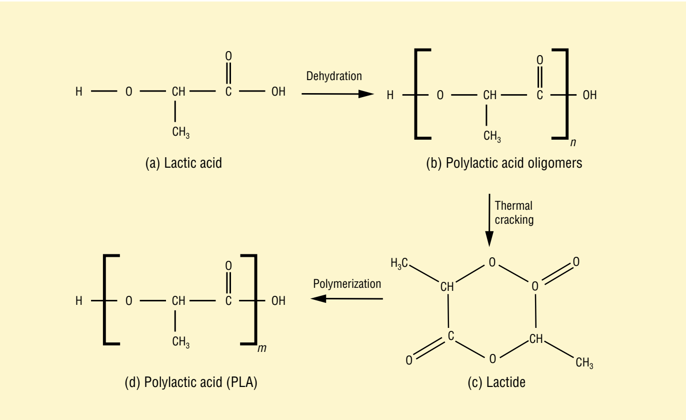

Figure 2. Production of polylactic acid (*n* and *m* are large numbers.)

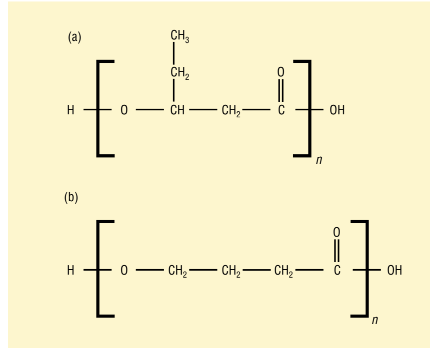

Figure 3. Examples of two PHA molecules: (a) poly-3-hydroxyvalerate; (b) poly-4-hydroxybutyrate (*n* is a large number.)

ANTHONY FERNANDEZ

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Fun accessories made from bioplastics

But lactic acid cannot be directly polymerized into PLA because the chemical reaction that bonds two molecules of lactic acid together also generates water. The water molecules prevent the growing chain of lactic acid molecules from staying together. So, instead of a long chain of lactic acid molecules, many small chains are formed. They are called polylactic acid oligomers (Fig. 2b)—in which “oligomer” means “small chain.”

These small chains are processed in a chemical reaction that leads to smaller lactide molecules (Fig. 2c). The chemical reaction also produces water, which is later eliminated. The lactide molecules act as monomers that are polymerized into PLA (Fig. 2d) in a process similar to the polymerization of ethylene into polyethylene.

The other common bioplastic, PHA, is a polymer produced naturally by bacteria. Different PHA molecules are made by the bacteria. These molecules can consist of more than 150 different types of monomers, leading to materials with very different properties from one another. Two types of PHA polymers are shown in Fig. 3. formed in polymerization reactions that combine more than 150 different types of monomers, leading to materials with very different properties. Two PHA polymers are shown in Fig. 3.

One of the most common consumer products that use bioplastics is the disposable water bottle. The new Dasani “Plant Bottle” is made of 30% plant material. The rest is petroleum-based polyethylene terephthalate, the same plastic used in conventional plastic bottles. Primo water bottles, on the other hand, are made entirely from corn starch.

COCA COLA CORP.

Can you tell the difference?

The bottle on the left is made with polyethylene, the one on the right with 30% plant material. The bottle on the right is better for the environment, so why not use it?

Are bioplastics good for the environment?

Are plant-based plastics every environmentalist’s dream? Some ads for bioplastics may make it seem so, especially when these ads claim that bioplastics generate no waste and produce no pollutants. Let’s examine the facts.

Some environmentalists point out hidden environmental costs, such as toxic pesticides sprayed on the crops and carbon dioxide emissions from harvesting vehicles.

Also, some manufacturers of bioplastics claim that making them does not use up fossil fuels—oil, natural gas, and coal. This is not always true. Although fossil fuels are not used to make many bioplastic products, they are typically used to power manufacturing plants. And producing bioplastics often requires nearly as much energy as producing conventional plastics.

Composting bioplastics

A number of bioplastics, including those made with PLA, are “compostable”: Give them enough heat, moisture, and hungry microbes, and the microbes will break them down into plant material, carbon dioxide, and water. It is the carbon dioxide that concerns some environmentalists.

“This carbon dioxide gas goes back into the atmosphere,” says Richard Wool, a chemical engineer at the University of Delaware in Newark. “So, composting bioplastics seems like a misguided solution.”

Nearly all compostable plastic ends up in a landfill instead of being composted. Like other plastics, bioplastics remain intact, buried in the oxygen-free environment of landfills. But some scientists worry that over many years, bioplastics will slowly decompose, giving off methane (CH_4), a greenhouse gas 20 times more potent than carbon dioxide.

For example, in a landfill, PLA would degrade according to the following reaction:

$$2\ H_2O + C_6H_8O_4\ \text{[PLA repeat unit]} \rightarrow 3\ CO_2 + 3\ CH_4$$

JUPITERIMAGES

The landfill dilemma is unavoidable at a time when only a few parts of the country have the industrial composting facilities needed to break down bioplastics. Also, ineffective labeling keeps many compostable plastics out of the composting mix.

Robert Reed, public relations manager for San Francisco's Sunset Scavenger Company, a private corporation that handles the city's waste recycling and composting, explains that his company's employees remove anything that looks like it doesn't belong with the compostable food scraps and yard waste. "Unless it's clearly marked, it would be impossible for sorting workers to know it's a compostable cup," he said. "The industry needs to more clearly label and identify them."

Recycling offers an alternative, but it is not so easy. Products made from recycled plastics will hold together only if they are made from plastics of the same type. Also, because various plastic types have different melting points, recycling a mixture of plastics is not possible.

Activity:
Make Your Own Compostable Bioplastic

This activity is intended for high school students under the direct supervision of an adult. During the activity, students must wear safety goggles.

With just a few materials that are easily available, you can make your own sample of corn-based plastic. Your sample will share the same corn base as manufactured bioplastics, but the product of this quick-and-easy process will be much softer. Weak bonds cause the sample to dissolve quickly in water, something manufacturers hope does not happen to their bioplastic products.

Here is how to make corn-based plastic:

Materials

1 tablespoon cornstarch
2 drops corn oil
Zip-sealing plastic bag
1 tablespoon water
Food coloring
Microwave oven

ACS STAFF

What to do

Place the cornstarch in the plastic bag. Add corn oil. Add water. Seal the bag, and then mix the ingredients by rubbing outside the bag with your fingers. Add two drops of any color food coloring to the mixture, seal and mix again. Open the zip seal just a tiny bit and put the bag in a microwave oven. Microwave on high 20–25 seconds. Be careful removing your plastic.
It will be hot!

While the plastic is still warm, shape it into a ball. If you want to see your ball degrade, just immerse it in water.

How it works

Before heating, the starch and water molecules combine physically in a liquid mixture, but do not permanently attach. Heating causes the water molecules to move fast enough to penetrate and break up the starch granules, which then tangle together to form polymers. Because the polymers are weaker than commercial bioplastics, they readily break apart in water. Durable commerical bioplastics need heat, microbes, and much more time to biodegrade, which is just fine with manufacturers. After all, who would buy a bottle that dissolves in water?

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—*Cynthia Washam*


BASF

Room for improvement

PLA and PHA are innovative, but with lots of room for improvement. Chemists are already busy creating the next generation of bioplastics. "The use of corn today is just a stepping stone," said Steve Davies, NatureWorks' director of corporate communications.

The new bioplastics will look like conventional plastic and will have less environmental impact than their predecessors. They will be produced in factories powered by wind, the sun, biofuels, and other renewable energy sources, further shrinking their impact on the environment.

Within 10 years, Davies expects his company to move from corn to abundant nonfood crops such as switchgrass. Competitor Metabolix announced in August 2008 that it had genetically engineered switchgrass to produce PHA within its leaves. Once the plastic particles are extracted, with a solvent, the remaining switchgrass could be used to produce fuel, cutting waste down to almost nothing.

In the meantime, *you* can do something to reduce plastic's harmful impact on the environment. It does not cost any money and does not require composting or recycling: "Don't use disposable," said Chris Peck, director of public affairs for the California Integrated Waste Management Board. "What's better than a plastic fork? A metal fork. If you reuse things, you are not throwing them away."

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