

Fork it over!

Create Biodegradable Plastic

Bioenergy Education Initiative

Levels:

Grades 6-12

Content Areas:

Chemistry; Engineering; Physical Science

Lesson Time:

Making Utensil: 45 -60 minutes

(Curing Bioplastic: 3-5 days)

Testing & Evaluating Utensil: 45 minutes

Improving Design: 45-60 minutes

Next Generation Science

Standards:

PSA1.A; ETS1.B

MS-PS1-2; MS-ETS1-4

HS-PS1-5; HS-ETS1-3

Objectives & Outcomes:

- Students will develop biodegradable types of plastic and optimize materials to develop a viable product.
- Students will engage in the engineering design and testing process.
- After completing this activity students will be able to demonstrate an understanding of the factors that affect bioplastic characteristics.

Contact:

SMILE Program

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Find more lessons at:

agsci.oregonstate.edu/bioenergy-k-12

Description:

In this lesson students learn how to create **bioplastic** (plastic derived from renewable sources). Using the [engineering design process](#) they will create, test, evaluate and improve a bioplastic utensil made from an animal, alga or plant source. The background material provides an opportunity to teach students about the difference between **degradable**, **biodegradable** and **compostable plastic** and their environmental impact.

Using This Lesson:

The experiment in this lesson is done in small groups. It is broken down into three parts done over two weeks, depending on the drying time, which can take up to a week. In the second half of the lesson, students evaluate the different utensils' material characteristics. They can then redo the experiment to optimize their design. An advanced student option is also available.

The background information is written at a ninth grade level and can be used as reading material for students. Vocabulary words are highlighted in the text and defined. Additionally, leading questions are included to promote discussion and critical thinking.



Why Bioplastic?

There are many types of plastic used in our everyday life. The source, type and chemical composition of plastic determines the size of its **carbon footprint** (total amount of greenhouse gasses produced in its manufacture, use and breakdown). The majority of plastic used today comes from nonrenewable oil.

Some types of plastic are **hydro-degradable** (broken down by water) or **photodegradable** (broken down by sunlight). However, most plastic ends up in landfills and stays there indefinitely because it is not **biodegradable** (broken down by bacteria and fungi). One of the great challenges of the modern era is to develop inexpensive, durable and biodegradable plastic made from renewable sources.

Creating Biodegradable Plastic

Set Up:

To make it easier to manage multiple student groups, create stations where students can get their supplies for making the molds, bioplastic solutions and using the microwave.

Directions:

Part 1: Building the Molds

1. Using aluminum foil, each group will create molds in the shape of a fork handle for each substrate type. They will make three molds for each substrate type, for a total of nine molds. Molds can be as simple as a small container about 1 cm wide, 2 cm deep and 10 cm long. Multiple samples are needed to test and evaluate the characteristics of the different types of bioplastic. The molds should be designed so they won't leak.
2. Number the outside of each mold with a Sharpie marker to keep track of the substrate samples.
3. Spray the molds with non-stick spray.

SOURCE TYPE	WATER	SUBSTRATE	SUBSTRATE AMOUNT	GLYCERIN
Animal	50 ml ($\frac{1}{4}$ cup)	Gelatin	12 g (3 tsp.)	5 drops
Algae	50 ml ($\frac{1}{4}$ cup)	Agar Agar	3 g (1 tsp.)	2.5 drops
Plant	50 ml ($\frac{1}{4}$ cup)	Cornstarch	9 g (2 tsp.)	5 drops

Part 2: Making the Bioplastics

1. For each of the three source types, mix tap water, substrate and glycerin in a heat resistant cup using the proportions in the chart. Stir each cup thoroughly until there are no clumps.
2. Heat each mixture separately in a microwave until it begins to froth usually less than a minute. To prevent boiling over, carefully watch the mixture through the microwave window. Stir after heating.
3. Pour each mixture type into three molds. Try to pour the plastic to the same thickness in each mold (about 0.5 - 0.75 cm).
4. Allow the mixture to dry in a warm place, such as the top of a refrigerator, a food dehydrator or an oven set to 150° F. This can take three to five days.
5. Test and record the materials' characteristics listed in the data chart after the forks are completely dry.

Part 3: Design Improvements

1. BASIC: Based on the initial experiment results, have students choose a substrate they think will provide the best strength for a fork handle. Then have them repeat the experiment, making adjustments in the amount of substrate they think will improve the bioplastic.

Materials:

- 2 feet aluminum foil
- Non-stick spray (Pam)
- Tap Water
- Bio-based substrates:
 - 9 g (2 tsp.) Corn starch
 - 12 g (3 tsp.) Unflavored gelatin
 - 3 g Agar agar
- Appx. 1 TB plasticizer (glycerin)
- Heat-resistant, disposable cups
- Plastic straws for mixing
- Medicine dropper for measuring plasticizer
- Teaspoon
- $\frac{1}{4}$ cup measure

2. **ADVANCED:** In this option, students not only consider the optimal substrate, but also a second variable, the plasticizer (glycerin). Have students repeat the experiment one or more times using the chosen substrate, and adjusting the amount of plasticizer added to the recipe. Ask students to determine what is the role of the plasticizer in the recipe. (Note: Add more plasticizer if the material needs to be more flexible, reduce plasticizer if the material needs to be more solid.) The amount of substrate and plasticizer can be adjusted to develop the ideal mixture.
3. **BASIC & ADVANCED:** After all experiments have been completed, ask students to recommend the process they think would produce the best plastic for a fork handle.

Expected Outcomes:

Substrate – Gelatin substrate tends to produce the strongest material. Results can vary depending on the brand of gelatin used.

Plasticizer – Increasing the amount of plasticizer increases the flexibility of the final product. If no plasticizer is added, the substrates produce brittle material. The amount of plasticizer necessary to make the best bioplastic depends on the brand of the substrate and the drying conditions.

Non-stick spray – It is extremely important to use the non-stick spray; otherwise the aluminum foil molds cannot be removed from the bioplastic.

Drying – While you can dry the molds in the open air, drying the molds in a controlled temperature environment is faster and gives more repeatable results. Good drying methods are to set an oven at 150° F or use a food dehydrator.



We recommended you use heat-resistant, disposable cups, NOT standard plastic cups for this activity, as they tend to melt in the microwave.

Experiment Questions:

Below are basic and advanced level questions and activity enhancements.

BASIC LEVEL

1. Would you recommend making fork handles out of the bioplastic you designed? What would be the advantages and disadvantages? (*Various answers*)
2. What additional experiments would you like to complete if you had time? (*Various answers*)
3. Why are some types of the bioplastic flexible and others brittle? (*The amount of plasticizer affects flexibility. The higher amount of plasticizer prevents complete bonding in the substrate. This allows the material to flex more.*)
4. What type of degradation would be ideal for plastic bottles? (*Ideally the bottles would completely degrade. However, there is a trade off between degradation and the ability for the bottle to hold liquid for a long period of time. A reasonable trade-off could be for bottles thrown by the roadside to be photodegradable.*)
5. What type of degradation would be ideal for plates and plastic utensils? (*A combination of bio- and hydro-degradation would be optimum. This would allow them to degrade quickly in the wet environment of a compost pile.*)

ADVANCED LEVEL – Internet Search Project & Presentation

1. Have students find the chemical bonding structures in the following kinds of biodegradable and non-biodegradable plastic.
 - Polyvinyl Chloride Bonds (non-biodegradable)
 - Gelatin Bonds (biodegradable)
 - Starch Bonds (biodegradable)
 - Agar Agar Bonds (biodegradable)
 - Casein Bonds (biodegradable)
 - Polyvinyl Styrene Bonds (biodegradable)Have them determine what types of elements are bonded in non-biodegradable plastic. (*Primarily carbon-carbon bonds*)
2. What types of elements are bonded in biodegradable plastic? (*These types of plastic have the addition of carbon-nitrogen and carbon-oxygen bonds.*)
3. What are the differences in bonding in biodegradable plastic? What chemical bonds do you think microbes are able to degrade? (*Carbon-nitrogen and carbon-oxygen bonds allow microbes to break the larger structure down. Carbon-carbon bonding is difficult for microbes to break down.*)
4. Explain the differences in chemical bonding between flexible and brittle bioplastic. (*The plasticizer keeps the bonding from occurring between the strands. The more plasticizer that is present in the formula, the more flexible the bioplastic.*)
5. Design a process that would mix the chemicals needed to make plastic forks and dry them. Develop a process that could produce 100 forks an hour. Have the students make a drawing of the process and present it to class.
6. To specifically address the problem of reducing greenhouse gases in the atmosphere, should plastic be biodegradable? Why or why not? What is the difference between biodegradable plastic and bioplastic?

Creating Biodegradable Plastic

Set Up:

In this activity you will develop fork handle molds out of aluminum foil, create different types of bioplastic to pour into your molds, and then test the materials' strength and flexibility.

Directions:

Part 1: Building the Molds

1. Create three molds in the shape of a fork handle for each substrate type using aluminum foil. Make three molds for each substrate types for a total of nine molds. The molds can be as simple as a small container about 1 cm wide, 2 cm deep and 10 cm long. Multiple samples are needed to test and evaluate the characteristics of the different types of bioplastic. The molds should be designed so they won't leak.
2. Number the outside of each mold with a Sharpie marker to keep track of the substrate samples.
3. Spray the molds with non-stick spray.

SOURCE TYPE	WATER	SUBSTRATE	SUBSTRATE AMOUNT	GLYCERIN
Animal	50 ml ($\frac{1}{4}$ cup)	Gelatin	12 g (3 tsp.)	5 drops
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Part 2: Making the Bioplastic

1. For each of the three source types, mix tap water, substrate and glycerin in a heat resistant cup using the follow proportions in the chart. Stir each cup until there are no clumps.
2. Heat each mixture separately in a microwave until it begins to froth, usually less than a minute. To prevent boiling over, carefully watch the mixture through the microwave window. Stir after heating.

Materials:

- 2 feet aluminum foil
- Non-stick spray (Pam)
- Tap Water
- Bio-based substrates:
9 g (2 tsp.) Corn starch
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3 g (1 tsp) Agar agar
- Appx. 1 TB plasticizer (glycerin)
- Heat-resistant, disposable cups
- Plastic straws for mixing
- Medicine dropper for measuring plasticizer
- Teaspoon
- $\frac{1}{4}$ cup measure

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Creating Biodegradable Plastic, continued

- Pour each mixture type out into three molds. Try to pour the plastic to the same thickness (about 0.5 - 0.75 cm) in each mold.
- Allow the mixture to dry in a warm place. This can be three to five days.
- Once the folk handles have completely dried, use the multiple samples you made to test the different substrate materials' characteristics. The chart below has a list of items to test. Record your results.

CHARACTERISTIC	OBSERVATIONS	CORN STARCH	AGAR AGAR	GELATIN
Color & Opacity: Can you see light through the material? Y or N				
Flexibility: Rate 1 = cracks; 2 = stiff; 3 = somewhat flexible; 4 = very flexible				
Freezing: To simulate winter conditions, freeze a sample then rate flexibility.				
Heat: To simulate summer conditions, heat samples up to 120° F under a lamp or in an oven. Rate for flexibility.				
Stain Resistance: Place a drop of coffee or mustard on the plastic. Does it stain when you try to wipe it off? Y or N				
Tensile Strength: Tape pennies, one at a time, on to the end of samples. Hold a sample by one end. How many pennies can you tape on before it breaks?				

Part 3: Design Improvements

- Based on initial results, choose a substrate you think will provide the best strength for a fork handle.
- Repeat the experiment, making adjustments in the amount of substrate you think will improve the bioplastic material.



Plastic: An Overview

What is Plastic?

Plastic is an incredibly versatile material made from **polymers** (a large, chain-like molecule made up of monomers, which are small molecules). It can be made into packaging, cars, machines, clothing, medical equipment and countless other products we use every day. Plastic is virtually everywhere. Just look around for a minute and you'll see how many things are made of plastic.

A Brief History of Plastic

While we tend to think of plastic as a modern invention, humans have been using natural plastic for thousands of years. The first plastic materials were created from organic substances like shellac, egg and blood proteins. Later, plastic was created from chemically modified natural materials like natural rubber, wood and animal tissue. Eventually, plastic materials were made from completely synthetic molecules, such as Bakelite and epoxy.

According to archeological evidence dating to 1600 BC, Mesoamericans used natural rubber to make balls and figurines. In the Middle Ages, cattle horns were treated and used to make windows for lanterns. Later, material mimicking the properties of horns was developed by treating milk-proteins (**casein**) with lye.

Parkesine, considered the first man-made plastic, was invented in 1860. It was a bioplastic made of wood (**cellulose** from plant cell walls) treated with nitric acid. It hardened into a transparent and elastic material that could be molded when it was heated.

In the early 1900s, **Bakelite**, the first fully synthetic plastic, was created using phenol and formaldehyde. The development of new types of plastic continued to explode in the 1940s and 50s and included polystyrene and polyvinyl chloride (PVC); Styrofoam (used for insulation, packaging and cups); and polyethylene terephthalate (PET). PET was one of the few plastic materials that could be used as a replacement for glass, and it eventually led to the widespread use of plastic drink bottles.



The Plastic Problem

Today, most plastic is made from chemicals derived from petroleum, a non-renewable resource. A majority of plastic is also used for disposable, low-cost items like food-wrap and product packaging.

Because most plastic is made from synthetic chemicals, it doesn't break down easily in nature. This makes the plastic pollution cluttering rivers, seas and beaches, all the more harmful to animals and the environment.

Getting rid of plastic can be

extremely difficult. Burning plastic produces toxic chemicals. Recycling it responsibly is also difficult, because each type has to be recycled using a different process.

Looking for Solutions

One way scientists and inventors are trying to solve the plastic dilemma is by creating bioplastic and compostable plastic made from materials that break down quickly.



The most common type of bioplastic is made from renewable material, such as corn starch. It takes less processing, and therefore energy, to make bioplastic. Bioplastics are considered **carbon neutral**, because the plants grown to make the plastic remove as much carbon dioxide from the atmosphere as is put into it during manufacturing process.

Overall, bioplastic does not generally produce a net increase in greenhouse gases when it breaks down, because the plants used to make bioplastic absorbed greenhouse gases when they were growing. Some types of bioplastic are biodegradable and even compostable.

The next page describes the difference between degradable, biodegradable and compostable plastic.



Know the Difference: Degradable, Biodegradable and Compostable Plastic

There are three terms people use when talking about plastic: degradable, biodegradable and compostable. The information below will help clear up what these terms mean.

Degradable Plastic

The word **degradable** simply means something can be broken down. Technically, all plastic is degradable. You can break it with a hammer. You can grind it into a fine powder. Some plastic, however, has chemicals added to it so it can break down faster under certain conditions.

For example, there is a chemical added to petroleum-based plastic that makes it become brittle and crumble in sunlight. This is called **photodegradable plastic**. Other additives can be put into plastic so it will break down by **oxidation** (reaction with oxygen in the air). This type of plastic is called **oxo-degradable plastic**.

These processing methods make the bulk of the plastic seem to disappear; however, the small pieces (some as small as sand) produced are still plastic. Only the size has changed. Over a matter of years, it may be possible for the pieces to become small enough to be assimilated by microorganisms, but research still needs to be done on this. So, if you see a plastic product advertising it is *degradable*, but not *biodegradable* or *compostable*, this is what is happening.

Biodegradable Plastic

Biodegradable plastic can be broken down by the metabolism of bacteria and fungi. When a plastic is biodegradable, it can be digested by these organisms, so the carbon atoms in the chains of the polymer are broken apart and can be used in the creation of other organic molecules.

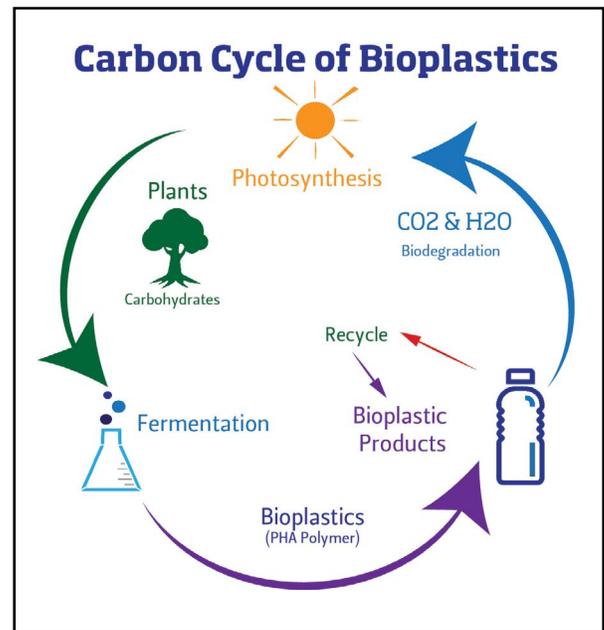
They can be processed by, and become part of, organic living things. However, the breakdown of biodegradable material buried in landfills can be slowed down or even stopped because many of these processes need oxygen and water, and there is little, to none, in landfills.

Some **bioplastic** (made from renewable resources) is processed in a way so that it is **non-biodegradable**. This plastic is still degradable, but it cannot be processed by microorganisms.

Compostable Plastic

By definition, **compostable** products are biodegradable products that degrade in a reasonable time in a compost pile. For example, 60% of the material has to degrade in 180 days.

Compostable plastic degrades by composting to yield CO₂, water,



inorganic compounds and biomass at a rate consistent with other known compostable materials, such as paper. It also leaves no visible, distinguishable or toxic residue. Specific industry standards regulate what can be called compostable. Below is a label from the U.S. Composting Council used to identify compostable plastics.



**This background information was developed with the help of materials from Wikipedia, Green Plastics and Kohala Center. See Resources for full links.*

Next Generation Science Standards

DISCIPLINARY CORE IDEAS:

PS1.A: Structure and Properties of Matter

ETS1.B: Developing Possible Solutions

PERFORMANCE EXPECTATIONS:

PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

ETS1-4: Develop a model to generate data for interactive testing and modification of a proposed object, tool or process, such that an optimal design can be achieved.

PS1-5: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature of

concentration of the reacting particles on the rate at which a reaction occurs.

ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability and aesthetics, as well as possible social, cultural and environmental impacts.

PRACTICES:

- Planning/carrying out investigations.
- Constructing explanations/design solutions.

CROSSCUTTING CONCEPTS

- Structure and function

VIDEO RESOURCES

[Lecture 7: Biomass](#)

[Chemistry](#); Time: 6:21-6:55

This video links provide supporting information. Note the relevant times appropriate to this experiment.

GRANT SUPPORT

This work is part of the Advanced Hardwood Biofuel Northwest project (hardwoodbiofuels.org) and is supported by Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30407 from the USDA National Institute of Food and Agriculture.

Resources:

[Lesson 2: Biodegradable Plastics](#), Sloss, Watters, School Garden Curriculum (November 2011) Department of Human Nutrition, Food and Animal Sciences, University of Hawaii, Kohala Center. Retrieved from <http://www.kohalacenter.org/HISGN/pdf/Lesson2BioplasticsFinal.pdf>.

[The Difference Between Degradable, Biodegradable and Compostable](#) (2012), Green Plastics. Retrieved from <http://green-plastics.net/posts/85/the-difference-between-degradable-biodegradable-and-compostable/>.

[History of Green Plastics](#) (August 2010). Retrieved from http://greenplastics.com/wiki/History_of_bioplastics.

[Biodegradation](#) (August 2010). Retrieved from <http://greenplastics.com/wiki/Biodegradable>.

[Plastic](#) (November 15, 2015), Wikipedia. Retrieved from <https://en.wikipedia.org/wiki/Plastic>.

Additional Resources:

- Green Plastics (greenplastics.com) is an informational site on bioplastic.
- Green Plastics News (green-plastics.net) provides news and information on bioplastic.
- EcNow Tech (ecnowtech.com): Is a manufacturer of custom packaging and molded products.