Lesson Plan: Turning Food Waste into Food Packaging, featuring Bananas

Grade Level: High School Chemistry

Lesson Duration: 2-3 class periods (45-60 minutes each)

NGSS Standards:

- **HS-ETS1-1:** Analyze a global challenge (e.g., plastic pollution) and design solutions.
- **HS-ETS1-2:** Design solutions to complex real-world problems.
- **HS-PS1-3:** Plan and conduct investigations to compare properties of substances.
- **HS-LS2-7:** Design and evaluate solutions for reducing human impacts on the environment.
- **Science & Engineering Practices:** Developing and using models; Planning investigations; Designing solutions
- **Crosscutting Concepts:** Structure and function; Stability and change; Systems thinking

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Lesson Objectives:

By the end of the lesson, students will be able to:

1. Explain how biopolymers and natural fibers can replace petroleum-based plastics.
2. Describe how chemical and physical processing changes material properties.
3. Design and test biodegradable packaging prototypes.
4. Analyze the environmental benefits of using food waste in manufacturing.

Background and Introduction

Food waste and food loss are major issues in today's world. Not only does food waste reduce edible food, but it also wastes the resources used to produce it including water, fertilizers, land, and money. Currently, an estimated 30% of the global food supply is lost or wasted across the entire supply chain, from farms to households. This wasted food contributes to nearly 10% of global greenhouse gas emissions, making it a significant environmental concern.

Efforts to reduce or repurpose food waste include using scraps for animal feed, composting, redistributing unsold food, or converting waste into fertilizers or energy. However, many of these strategies are underutilized, and large quantities of food still end up in landfills. Even when reduction strategies are used, they cannot fully reverse the environmental impacts already caused by producing the food in the first place.

Agriculture and the food industry are also major contributors to plastic pollution. Over 400 million tons of petroleum-based plastic are produced each year, and many plastic products can take up to

1,000 years to degrade. This long lifespan leads to pollution, land use issues, ecosystem endangerment, and greenhouse gas emissions. There are also social and economic sustainability concerns, particularly related to the migration of plastic from packaging into food and the ingestion of microplastics by humans. Once ingested, plastics have been linked to liver damage, disruptions in enzyme and lipid metabolism, and impacts on the reproductive system. Additional concerns include the financial costs of pollution, effects on lifestyle, and mental health, and impacts on cultural heritage. Despite these concerns, plastics remain widely used because they are inexpensive, lightweight, durable, and effective at protecting food from pathogens and spoilage. However, these advantages do not guarantee long-term food security and do not eliminate the problem of food waste.

One way to address both food waste and plastic pollution is through waste valorization, such as turning food waste into biofilms or bioplastics; i.e., plastic-like materials created from biological sources. Many food waste steams contain components suitable for building a plastic or film matrix. Common waste sources such as fruits, grains, vegetables, dairy and seafood products are rich in proteins, carbohydrates (including fiber, starch, pectin), and lipids that can be used in bioplastic production (**Fig. 1**).

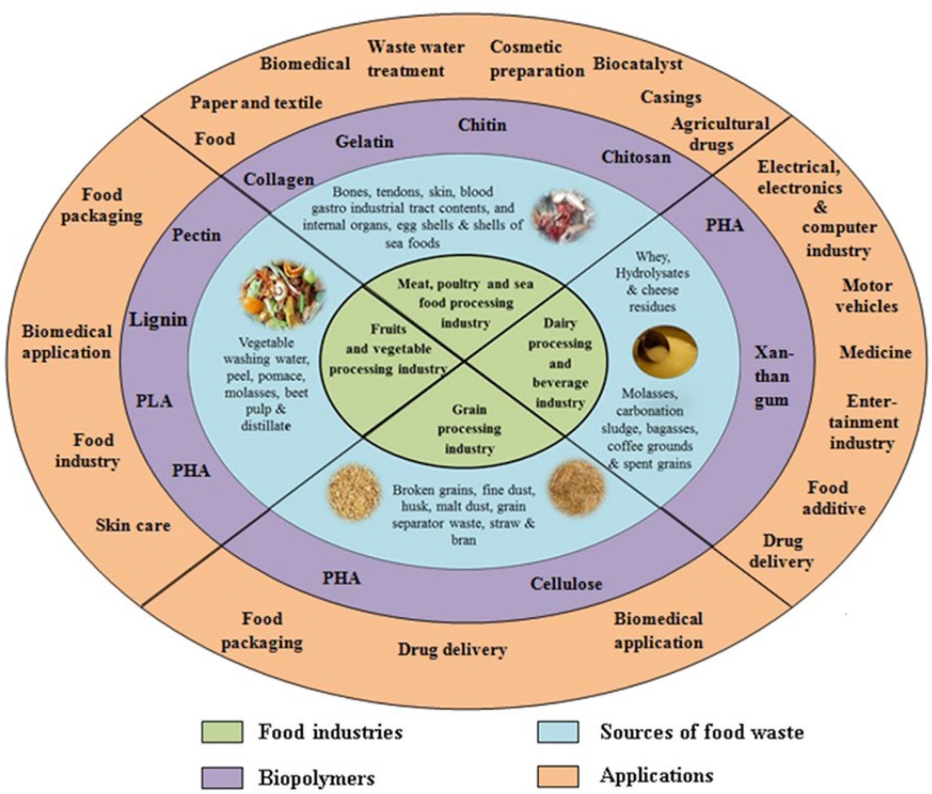

Figure 1 - Applications of biopolymers produced from different food processing waste streams. Schematic from: [*https://doi.org/10.1016/j.heliyon.2020.e04891*](https://doi.org/10.1016/j.heliyon.2020.e04891)

Biofilms and bioplastics are sustainable alternatives to conventional, petroleum-based plastics. They are typically made from natural polymers such as starch, cellulose, pectin, proteins, or combinations thereof. These polymeric materials can form thin, flexible films or molded plastic-like structures that are biodegradable, non-toxic, and often compostable. Because they break down naturally, they reduce long-term pollution and lower environmental impact compared to traditional plastics. Bioplastics can be engineered for a range of uses, including food packaging, edible coatings, and agricultural applications. Although bioplastics currently represent a small portion of the packaging industry, interest in them is growing rapidly as scientists, businesses, and policymakers look for solutions that reduce waste while maintaining food safety and quality.

Banana peels are a great example of waste material from a high school lunchroom that can be valorized. Bananas are among the most widely consumed fruits in the world, and their production generates a substantial amount of waste. Every year, an estimated 36 million tons of banana peels are discarded globally. Despite their abundance, banana peels are not currently used in most large-scale food waste reduction efforts.

Banana peels are an attractive raw material for bioplastic and biofilm production for several reasons:

- High fiber content: Banana peels are rich in cellulose, hemicellulose, and lignin—key structural fibers that help form strong, flexible biofilms.
- Pectin and starch: These carbohydrates act as natural binders and thickening agents, which improve film formation.
- Biodegradability and non-toxicity: Products made from banana peels break down naturally and do not introduce harmful chemicals into the environment.
- Low density and good mechanical properties: Banana-peel-based bioplastics can be lightweight yet durable, making them suitable for packaging applications.
- Readily available and inexpensive: Since banana peels are typically discarded, they provide a low-cost, large-volume resource for sustainable material development.

Researchers are increasingly exploring bioplastics as a model for circular economy practices: turning waste into a valuable material while reducing environmental harm. For example, researchers in Audrey Girard's food chemistry lab at UW-Madison are investigating how proteins can be turned into sustainable packaging. This lesson plan gives students an opportunity to experiment in the bioplastic arena using banana peels as biopolymer material.

Lesson Structure

This lesson can be divided up to suit class time availability and student interests. One example of lesson set-up across three 45-minute class periods is shown.

The hands-on experimental portion of this lesson provides some structure (fiber extraction, creation of biopolymer-based carton and film, suggested analyses for the film) and a lot of room for experimentation. We provide a few experimental variables (fiber pretreatment), but students could also look for other ingredient (e.g., use other food wastes like avocado peels), recipe (e.g., add other plasticizers or strengthening agents), and processing (e.g., make films thinner/thicker) variables. It is intentionally written to be open-ended, allowing for student exploration. Notes on alternative methods and further experimentation ideas have been added in red throughout the exploration (hands-on experiment) section in the teacher's version.

- **Day 1 – Introduction & Fiber Extraction**
  - Engagement (10 min)
  - Fiber extraction (35 min) – have pretreated fibers and water boiling before students arrive, will have to finish post-extraction treatments for students
- **Day 2 – Create Packaging Materials**
  - Carton and film formation (45 min)
- **Day 3 – Packaging Testing & Wrap-up**
  - Carton and film analyses (20 min)
  - Explanation (10 min)
  - Elaboration (15 min)

Figure 2 – Examples of biomaterials made from banana peels in this lesson. Left – carton procedure using potassium metabisulfite pre-treatment and drying/curing in a silicone cupcake mold. Right – film procedure with acetic acid pretreatment and drying/curing in a silicone petri-type dish.

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1. Engagement – Hook & Introduction

- **Demonstration**
  - Provide students with different examples of packaging and ask them to assess its biodegradability.
    - A supplement to in-class examples could be built from information available via resources such as:
      - WWF Australia – [The Life Cycle of Plastics]

        - Packlane – How long does biodegradable packaging take to decompose?
        - Sustainable Packaging Coalition – Compostable Packaging Guide
    - Discuss the circular economy and biodegradable materials. Potential discussion questions include:
        - How much food waste do we generate?
        - What happens to plastic packaging after use?
        - Could food waste become packaging?

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2. Exploration – Hands-On Experiment

Materials Needed:

Banana peels, water, potassium metabisulfite, acetic acid, corn starch, glycerol, HCl, NaOH, and pectin

Beakers, hot plates, sieve, blender or mortar/pestle, graduated cylinders, scale, oven, pipettes, molds (e.g., cupcake pans and petri dishes), and test tubes

The following procedures will create materials, but the procedures are not optimized. They are relatively simple procedures to illustrate biomaterial formation. They can also serve as starting points for further experimentation and development of materials.

Fiber Extraction Procedure:

- Frozen banana peels Green banana peels have ~ 11% starch, but that decreases as the fruit ripens and the starches are hydrolyzed. From a practical standpoint (and the idea of using food waste), it's easiest to save up banana peels over a period of time in the freezer. Besides the likelihood that banana peels are not collected at the green-ripe stage, freezing also leads to enzymatic browning (polyphenol oxidase activity). Students could assess the effects of ripeness and enzymatic browning of banana peels on cartons/films.
- Pre-treatment:
    - 1. None
    - 2. Soak banana peels for 30 min in a 1% potassium metabisulfite solution
    - 3. Soak banana peels for 30 min in a 2% acetic acid solution
    - These treatments generally inactivate enzymes in the peel and prevent microbial growth, alongside likely altering the fibers, pectin, and starch in the peel.
- Extraction: Boil banana peels for 30 min in water
    - Dry: Bake for 30 min at 100 °C, then blend into a paste (with blender or mortar/pestle)
    - Wet: Blend into a paste and then sieve to remove excess liquid

Carton Creation Procedure:

- Mix 25 g paste (dry extracted material) with:
  - 3 mL 0.1 N HCl To help hydrolyze starch and improve material properties.
  - 2 mL glycerol
  - After mixing the above, then add 3 mL 0.1 N NaOH to neutralize pH
- Cast in dish (e.g., cupcake pan for shape). Dry at 120 °C for 2 h

Film Formation Procedure:

- Mix 50 g paste (wet extracted material) with:
  - 3.5 mL of glycerol
  - Heated corn starch
    - Mix 1 g corn starch with 25 mL water and heat at 85 °C for 30 min
  - Heated pectin
    - Mix 0.3 g pectin with 15 mL of water and heat at 85 °C for 15 min
- Cast in dish (e.g., petri dish). Dry at 40 °C for 24-48 h

Suggested analyses:

- Carton testing
  - Compression test – weight required to collapse structure
  - Water permeability – measure how much water moves through carton
  - Water solubility – measure how much of the carton is insoluble
  - Drop test – place an egg or water balloon inside the carton. Drop from increasing heights to determine is ability to absorb impact.
- Film testing
  - Flexibility – bend the film to test its breakability
  - Strength – pull the film apart, try to measure how far it pulls apart before breaking
  - Tear resistance – how much force does it take to tear the film into two
  - Water permeability – measure how much water moves through film
    - Option 1 – place film on a paper towel, add a drop of colored water to top of film and monitor towel for any water that passes through
    - Option 2 – place film over top of a jar filled with dried indicating desiccant, seal edges with parafilm and place in a humid environment, measure the weight gain of the desiccant (water gain) after given time
  - Water solubility – measure how much of the carton is insoluble
- Next steps – Challenge students to modify their carton/film recipes and procedures to increase performance.

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3. Explanation – Conceptual Understanding

When students heat the banana peel mixture with various treatments, they are breaking down the peel's natural fibers and polysaccharides—primarily cellulose, hemicellulose, starch, and pectin. As the material mixtures are prepared, these molecules interact to form a polymer network. When the mixture is dried and sets, the water evaporates and these polymers lock together into a flexible, film-like material. In other words, students are transforming natural biopolymers into a type of bioplastics.

During the results discussion, students can compare various properties of their bioplastics such as carton/film thickness, flexibility or brittleness, tear strength, surface texture, color or opacity. Differences in these properties can be linked back to ingredients and processing. For example, more plasticizer (like glycerin) often increases flexibility but may reduce strength (e.g., tear strength). Higher fiber content may make the film stronger but less uniform. Students can also reflect on challenges they encountered, such as uneven spreading, clumps of fiber, or cracking during drying.

This discussion helps students develop conceptual understanding of polymer formation, structure-property relationships, how natural materials can replace synthetic plastics, the limitations of early-stage, experimental materials.

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4. Elaboration – Real-World Applications & Deeper Thinking

Have students consider real-world bioplastics applications. Explore questions such as:

- What properties must packaging have to be useful?
- For which applications would banana-based bioplastics be suitable? Unsuitable?
- The cartons/films made in this lesson could also be used as broader bio-materials. For instance, the carton could be used as a planter (similar to a peat pot), and the film could serve as weed suppression material (e.g., to replace plastic).
    - What other applications could these be used for aside from food packaging?
    - What properties would be needed to create successful materials for these applications?
- What challenges exist in commercializing bioplastics (e.g., cost, durability, infrastructure for composting, consumer acceptance)?
- How do bioplastics compare to traditional plastics in terms of environmental impact across their life cycle?

Students could also investigate how companies and researchers are turning food waste streams into new materials, encouraging them to see the broader circular economy connections.

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5. Evaluation – Assessment & Reflection

Possible assessment components:

- **Lab Report or Claim-Evidence-Reasoning (CER):** Students articulate what happened during their bioplastic creation, support claims with observations, and explain using scientific principles.
- **Property Comparison Chart:** Students evaluate their film's characteristics and compare them with classmates' samples.
- **Sustainability Analysis:** Students evaluate whether their bioplastic is an improvement over conventional plastics and justify their reasoning.

Reflection prompts may include:

- What worked well in your bioplastic preparation? What would you change next time?
- Which materials/ingredients or processing steps had the biggest impact on your final product?
- Which final product do you think would work best for food packaging, and why?
- How could your bioplastic be improved to make it more useful?
- What other common food waste sources could be used to create bioplastics?
- What did you learn about the relationship between food waste and sustainability?
- How does this activity change the way you think about plastic use in everyday life?

Differentiation & Extensions

- **For Advanced Students:**
    - Research commercial bioplastics like PLA and compare/contrast them with banana peel materials (made in this lab) and petroleum plastics.
    - What makes an item biodegradable? Compostable? Look into municipal composting and home composting…what products can be composted or not? Relevant to bananas: produce stickers used to identify and scan produce in stores are often not compostable and can be a nuisance for commercial composting operations.
- **For Struggling Students:** Provide reference materials and allow group discussions for better understanding.
- **Extension Activity:** Compost the materials and monitor decomposition.

Teacher resources

1. Synthesis of bioplastic from banana lesson plan from Chemical Safety in Science Education
2. Royal Society of Chemistry (RSC) – Bioplastic from Potato Starch
3. FAO – Global Food Loss and Waste Database Comprehensive data on global food waste patterns and causes.
4. EPA – Sustainable Management of Food – Classroom Resources
5. USDA BioPreferred Program Explains certification, definitions, and examples of biobased materials.
6. ACS Middle & High School Chemistry Teacher Resources – Plastics Go Green A slightly dated but chemistry-focused discussion of plastics and bioplastics.
7. Ellen MacArthur Foundation – Teaching Resources Education and learning resources about circular economy, particularly *Lesson 6: Redesigning Plastics*.

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