BIOFUELS AND BIOPRODUCTS (HS)

Fermentation factories

Focus questions	How can fermentation produce a renewable fuel source?
Learning target	Students will develop a model of fermentation and explain how ethanol is made.
Vocabulary	Renewable fuels, nonrenewable fuels, energy positive, glucose, distillers grain

HS-LS2: Matter and Energy in Organisms and Ecosystems

Performance expectation HS-LS2-3	**Classroom connection:** Students create models to construct an explanation of fermentation and suggest improvements to increase the amount of ethanol produced within their plastic bag environment.

Science and engineering practices

Constructing Explanations and Designing Solutions	**Classroom connection:** Students make a quantitative and/or qualitative claim regarding the relationships between the dependent and independent variables in the fermentation process.

Disciplinary core ideas

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems	**Classroom connection:** Students apply scientific reasoning to models to link evidence to explanations describing the anaerobic process of fermentation.

Cross-cutting concepts

Energy & Matter	**Classroom connection:** Students examine energy and matter relationships to design solutions for how matter may create renewable energy for human use.

This lesson focuses on Constructing Explanations and Designing Solutions as a means to make sense of the phenomena introduced. Students will develop experimental models to generate data in order to construct explanations about the relationships between the components of the fermentation process and to predict how those relationships can be manipulated to produce carbon dioxide. Students will design solutions to make the fermentation process as efficient as possible and generate the maximum amount of ethanol in a small bag environment.

Background

Human consumption of fuel is on the rise as both population and affluence steadily increase. **Renewable fuels,** such as ethanol, can help to decrease the need for **non-renewable fuel** sources such as crude oil. In addition, ethanol has replaced methyl tertiary-butyl ether (MTBE) as the major octane source in gasoline which has resulted in gasohol blends of up to 10% in almost every pump in the United States. Ethanol is a renewable fuel source that is both **energy positive,** which means it generates more energy than it consumes, and helps to reduce greenhouse gas emissions. Most gasoline contains 5-15% ethanol as an additive to help to increase octane ratings (`motorbiscuit.com/why-is-ethanol-added-to-gas`).

The phenomenon used to introduce this unit helped students to generate questions. In this lesson, students create models of fermentation factories to determine which feedstock(s) might generate the most ethanol.

Materials

- Yeast
- Warm water (95° F/35° C)
- Liquid glucose or crushed glucose tablets
- Corn flour
- Amylase
- Glucoamylase
- Snack-sized bags
- Thermometer
- Possible materials for student use:
  - Snack-sized bags
  - 50 ml water
  - 1 tsp. yeast
  - ¼ tsp. enzymes (amylase, glucoamylase)
  - 1 tsp. sugars (simple & complex) as feedstocks: corn flour, corn starch, corn syrup, honey, and glucose
  - Ruler to measure gas volume
  - Index card or clipboard to measure gas volume

Teacher preparation

1. Create the following bags 25–30 minutes prior to class. If possible use warm water (95° F/35° C) to hydrate the fermentation bags. Remove all of the air from the bags, seal, and incubate the bags in a warm location (98.6° F/37° C) for optimum fermentation. Remove the bags from the incubator and ask the students what they are observing. Allow the students to generate discussion with their observations. Do not confirm or deny ideas as you lead the conversation with your students.

Bag ingredients					
A	1 tsp. yeast	50 ml water	1 tsp. glucose		
B	1 tsp. yeast	50 ml water	1 tsp. corn flour		
C	1 tsp. yeast	50 ml water	1 tsp. corn flour	¼ tsp. glucoamylase	
D	1 tsp. yeast	50 ml water	1 tsp. corn flour	¼ tsp. amylase	¼ tsp. glucoamylase

2. Ask: What is occurring in each of the four bags? Write the ingredients of each bag on the board and have students brainstorm observations or questions surrounding the function of each ingredient individually for 1 minute. Have them record both the bag contents and their observations on their charts for later use.
3. Have the students share their observations in a small group for three minutes. Generate class discussion by asking groups to share their observations with the class.
   Possible observations or questions about the Corn Fermentation in a Bag ingredients.
   - Glucose is a simple sugar (monosaccharide).
   - Yeast are organisms/decomposers that eat sugars.
   - Starch is a complex sugar (polysaccharide).
   - Fermentation occurs when yeast consume sugar (glucose) and produce alcohol (ethanol) and carbon dioxide.
   - Bag A produced the most CO_2 in 20 minutes (glucose).
   - Bags B and C did produced very little CO_2 in 20 minutes.
   - Bag D produced the second largest amount of CO_2 in 20 minutes.
   - What do amylase and glucoamylase do? How do they function with sugars or yeast?
4. Copy the problem below to give to students or read to students:
   Human consumption of fuels is on the rise as both population and affluence steadily increase. **Renewable fuels**, such as ethanol, can help to decrease the need for **non-renewable fuel** sources such as gasoline refined from crude oil. In addition, ethanol has replaced methyl tertiary-butyl ether (MTBE) as the major octane source in gasoline, which has resulted in gasohol blends of up to 10% in almost every pump in the United States. Ethanol is a renewable fuel source that is both **energy positive**, which means it generates more potential energy than it consumes, and helps to reduce greenhouse gas emissions. More cars are on the road than ever before, so we need to be able to produce high-quality ethanol quickly and efficiently to fuel the increase of active automobiles.

   Fermentation is an anaerobic process where yeast consume sugars to produce alcohol and carbon dioxide. Ethanol is created when yeast consume **glucose** (simple sugar). Ethanol in the United States is produced by breaking down corn flour to create glucose, which is then consumed by yeast to produce CO_2, ethanol, and distillers grains. **Distillers grains** are the leftover corn fiber, protein, and oil that result from the breakdown of starch in corn.

   Here is the equation for the fermentation of glucose into ethanol and carbon dioxide.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{2 ethanol}}{2CH_3CH_2OH} + \underset{\text{2 carbon dioxide}}{2CO_2}$$

5. Read the challenge to the students: *Create the greatest volume of ethanol (measured by the volume of carbon dioxide generated) in the shortest time possible.*

   Students should work in groups of 2–3 individuals for this challenge. Review the criteria and constraints for the challenge.
6. Have students observe the following criteria and constraints
   - Plan an experiment/several experiments to produce ethanol in a small bag environment.
   - Students may only use the following materials/amounts provided by the teacher.
   - Students may have 1 or more class period(s) to experiment on the initial design(s) based on their group plan.
   - Data must be collected and analyzed to provide evidence for an explanation and future design solution.
   - Students report back to the class and provide future design solutions as a result of your current explanation.

7. Discuss the engineering design process with your students. Encourage the student groups to create two or more experimental designs based upon their knowledge of what occurs in the phenomena bags. Why are they investigating their design? What is their reasoning for their materials? What patterns do they expect to see? They will also need to create a method for measuring their CO_2 gas. We suggest that they measure volume by height displacement using a clipboard and ruler to demonstrate their volume change in CO_2 gas.

   Students should be able to predict the outcome of some of their experimental designs based upon previous background knowledge and their observations of the anchoring phenomena.
8. Encourage the students to create charts and graphs to show the volume change within their bags over time. Students should create their own experimental procedure to collect and record data.
   - What are some physical ways your group can measure carbon dioxide production and/or ethanol production?
   - How can your group predict the amount of carbon dioxide and ethanol that is generated from your fermentation bags?
9. Have students complete the reflection questions on the student document.
10. Give students an opportunity to redesign their experiment. Assign research to determine what food sources might be best for yeast, if there are other organisms that are more efficient at fermentation and/or other enzymes that might be used.

    Following the research, ask students to discuss improvements of their experimental design based upon the research presented. What could they improve upon: Materials used? Experimental conditions? Sample questions might be used to fuel the discussion
    - Can you create a more efficient design using different materials?
    - Can you predict the outcome of other experimental designs?
    - How can you change your original design to become more efficient by changing the experimental conditions?
    - Make predictions using all of the available feedstocks in separate designs to determine which one will generate the most carbon dioxide and ethanol over time.
11. Assign assessment: Write two to three paragraphs to construct an explanation of the fermentation process of corn into ethanol. Include what you learned about fermentation by using the evidence collected in your experiments.

Student handout

Reflection

Create an explanation of the fermentation process of corn into ethanol. Reflect on the following questions while creating your explanation.

1. What is the purpose/role of each component in your group's fermentation bag design(s)? How did each component act upon another? Write/draw your most efficient design below.

Possible answers: glucose, honey, other sugars provide food source for yeast, enzymes help to speed up fermentation, yeast are necessary to breakdown/metabolize food source into CO_2 and ethanol.

2. What evidence did your group generate to clarify the role of each component in your group's design?

Possible answers: controlled variables, made comparisons between bags, left out components to see results.

3. What are the reactants and products of your fermentation reaction?

Possible answers: reactants include sugar type and enzymes; products include CO_2 and ethanol.

Differentiation

Other ways to connect with students with various needs:

- **Local community:** Students may investigate the use of ethanol in their community. (i.e. Do any fuel stations offer gasohol blends? What gasohol blend/percentages are available? Which type of gas/fuel do your parents use and why)?
- **Students with special needs (auditory/visual/language/reading):** Pair students together to engineer the bag they create.
- **Extra Support:** Video: How ethanol is made (`youtu.be/59R-NqykoXs`) This video helps demonstrate relationships between the components of the ethanol fermentation ecosystem.
- **Extensions:** Students may determine how they might scale this process and/or research the history of ethanol as a fuel alternative and current gasohol blends available to the public.

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Constructing explanations	The student is able to use the data generated to construct an explanation for what is occuring in the bag, but does not make the connection to fermentation.	The student is able to independently develop explanations based on data to describe the fermentation process; provide evidence to support the explanation; design future solutions to create a more efficient fermentation process; analyze explanations of the fermentation process as it relates to the cycling of matter and energy in aerobic or anaerobic conditions.	The student is able to independently develop explanations based on data to describe the fermentation process; provide evidence to support the explanation; design future solutions to create a more efficient fermentation process; analyze explanations of the fermentation process as it relates to the cycling of matter and energy in aerobic or anaerobic conditions; and determine how one might scale the experiment so that ethanol can be made in large quantities.

Rubric for self-assessment

Skill	Yes	No	Unsure
I was able to construct an explanation for the fermentation process based on evidence.			
I provided possible future solutions for a more efficient fermentation design based on evidence.			