Fermentation factories

Focus questions	How can we create ethanol? What does the process of fermentation produce?
Vocabulary	Renewable fuels, nonrenewable fuels, energy positive, glucose, distillers grain
Learning target	Students will develop a model of a fermentation factory and be able to explain how ethanol is made.

MS-LS2: Ecosystems: Interactions, Energy, and Dynamics

Performance expectation MS-LS2-3	**Classroom connection:** Students will create a model to produce ethanol in the largest volume.

Science and engineering practices

Developing and Using Models	**Classroom connection:** Students will create a model of a fermentation factory to produce ethanol in the largest volume.

Disciplinary core ideas

MS-LS2.B: Cycle of Matter and Energy Transfer in Ecosystems	**Classroom connection:** Students will develop experimental models to make sense of the phenomenon by identifying the relevant components of a fermentation system.

Cross-cutting concepts

Energy & Matter	**Classroom connection:** Students use the model to track energy transfer and matter cycling in the fermentation bag ecosystem.

This lesson focuses on Developing and Using Models as a means to make sense of the phenomenon below. Students will develop experimental models to describe the relationships between the components of the fermentation ecosystem and predict how those relationships can be manipulated to produce carbon dioxide and ethanol in equal amounts.

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 (ethanol plus gasoline) 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 takes to make it, and helps to reduce greenhouse gas emissions.

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

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

Materials

- Yeast
- Warm water (95° F/35° C)
- Liquid glucose or crushed glucose tablets
- Corn flour
- Amylase
- Glucoamylase
- Snack-sized bags

Possible materials for student challenge:

- 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

Prior knowledge

Students should be familiar with the concept of respiration: release of energy requiring the use of oxygen, and **fermentation:** an anaerobic process that releases energy. Yeast are used in this model to show fermentation. 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.

Teacher preparation

Notice the phenomenon: More cars are on the road than ever before, so we need to be able to produce high quality ethanol quickly and efficiently to provide fuel for the increase of active automobiles. (Notice that there are a couple of directions to go with this statement. Why does the sentence refer to producing high quality ethanol for all cars? Do all cars need ethanol? This is a good way to start a conversation about what additives there are in petroleum based gasoline. (Most gasoline contains 5-15% ethanol as an additive to help to increase octane ratings (`motorbiscuit.com/why-is-ethanol-added-to-gas/`). In addition, students can research the benefits of using ethanol over gasoline (fewer pollutants from those additional cars).

1. Create the 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) such as an incubator, 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	¼ tsp. amylase	
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. 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. Next, 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 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. Read the challenge to the students: **Create the greatest volume of ethanol (measured by the volume of CO_2 generated) in the fastest time possible.**
5. Students should work in groups of 2–3 individuals for this challenge. Review the following criteria and constraints for the challenge.
   - Plan an (several) experiment(s) to produce ethanol in a small bag environment.
   - You can only use the following materials/amounts provided.
   - You have 1 or more class period(s) to experiment on your initial design(s) based on your plan.
   - Data must be collected and analyzed to provide evidence for your conclusion.
   - Report back to the class and provide future experimental designs as a result of your current data/conclusion.
6. Provide some, all, or additional material items to the students that are listed above.
7. Discuss the engineering design process with your students. Encourage 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.
8. 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.
9. 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.
10. Students should create a model of their fermentation ecosystem. The students can draw what is happening in the anaerobic process of fermentation based on the data collected in their experimental models.
11. Create a discussion with your students to determine if they could improve upon their

experimental design based upon the evidence presented. What could they improve upon? Materials used? Experimental conditions? What research could they do to make their design as efficient as possible?

- Can you create a more efficient design using different materials?
- Can you predict the outcome of other experimental designs?
- How can you change you 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 make the most CO_2 over time.

Differentiation

- **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?)
- **Students with special needs (auditory/visual/language/reading):** See the extra support below.
- **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 can research the use of ethanol as a fuel alternative and current gasohol blends available to the public.

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Develop and refine models to explain, predict, and investigate the natural and designed world.	Develop and/ or use models to describe and/or predict phenomena.	Student develops and/ or uses models to describe and/or predict phenomena and show relationships among variables that are not observable but predict observable phenomena.	Student develops, uses and/ or revises models based on evidence to describe and/or predict phenomena and show relationships among variables that are not observable but predict observable phenomena. Student model illustrates and/or predicts the relationships between systems or components of a system.
Develop and/or use a model to generate data.	Student model generates data to to compare between models.	Student model generates data to to compare between models and uses data to test ideas about phenomena within the system including inputs and outputs and those at unobservable scales.	Student model generates data to to compare between models and uses data to test ideas about phenomena within the system including inputs and outputs and those at unobservable scales. Student data is used to support explanations, predict additional phenomena, analyze system components and/or solve problems.

Rubric for self-assessment

Skill	Yes	No	Unsure
I developed a model that shows fermentation.			
I can explain how my model demonstrates the relationships between components of the fermentation factory.			
I developed a model that generated data to enable a prediction of outcomes from components in a fermentation factory.			