ENERGY AND BIOFUELS (HS)

Corn mash and distillation

Focus question	How can the production of ethanol help to create both a sustainable fuel and quality animal feed?
Learning target	Students will investigate the production of ethanol and design solutions for coproduct use.
Vocabulary	Starch, glucose, fermentation, ethanol, coproducts, distillers grains, corn oil, carbon dioxide

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

Performance expectation HS-LS2-3	**Classroom connection:** Students create a corn mash for the fermentation of sugars then distill ethanol. Students test ethanol to determine the concentration of ethanol produced.

Science and engineering practices

Constructing Explanations and Designing Solutions	**Classroom connection:** Students construct an explanation for the process of commercial ethanol production based on evidence from student investigations and design logical solutions for the coproducts that are produced.

Disciplinary core ideas

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems	**Classroom connection:** Students investigate the breakdown of starch to provide energy for the anaerobic respiration of yeast.

Cross-cutting concepts

Energy & Matter	**Classroom connection:** Students create an explanation for the fermentation reaction of glucose to demonstrate the cycling of matter into carbon dioxide and ethanol.

This lesson is designed to follow Lesson 1, Fermentation Factories; Lesson 2, Ticketase; Lesson 3, Biomass to Sugars; and Lesson 4, Macromolecules and Fuel; where students utilize different components (enzymes, yeast, feedstocks, and water) to produce ethanol and carbon dioxide through the process of fermentation, model enzyme action on starch to produce simple sugars, and analyze macromolecule content in available ethanol feedstocks and coproducts. This lesson focuses on Constructing Explanations and Designing Solutions for using corn in the process of commercial ethanol production based on evidence from student investigations and figure out that the amount of starch available in ethanol can be fermented by yeast and easily obtainable enzymes to make energy.

Background

Commercial production of fuel ethanol in the United States involves breaking down the **starch** present in corn into simple sugars **(glucose),** feeding these sugars to yeast **(fermentation),** and then recovering the main product **(ethanol)** and **coproducts (distillers grains, corn oil, and carbon dioxide).** Ethanol is an alcohol produced by yeast from sugars. Fuel ethanol is ethanol that has been highly concentrated and blended with other compounds (gasoline) to render the alcohol undrinkable. For each pound of simple sugars, yeast can produce approximately .5 pounds (0.15 gallons) of ethanol and an equivalent amount of carbon dioxide. The value of corn as a feedstock for ethanol production is due to its large volume of carbohydrates, specifically starch. Starch can be easily processed to break down into simple sugars, which can then be fed to yeast to produce ethanol. Modern ethanol production can produce approximately 2.8-3 gallons of fuel ethanol per bushel of corn. Dry-milled ethanol production uses only the starch portion of the corn, which is about 62% of the kernel. All the remaining nutrients—protein, fat, minerals, and vitamins—are concentrated into dried distillers grains (DDGs), a valuable feed for livestock. Some ethanol plants also remove the corn oil from DDGs to create renewable diesel. Approximately 40% of the United States' corn crop is used to produce ethanol and distillers grains.

Materials

Students should have access to the following materials at their group lab table.

- Hot plate
- 110V heating mantle
- 100 or 1000 mL distillation apparatus
- Condenser tube
- Dial thermometer
- Graduated cylinders (10, 100 mL)
- Large watch glass covers
- Beakers (100, 250, 600, 1000 mL)
- Deionized water
- Hammered dent corn
- Scale or triple beam balance
- Glass vials with caps (or a small beaker)
- Buffer solution (pH 5)
- Yeast solution
  (20 g yeast/100 mL water, 49–55° C)
- Amylase solution (3 tsp/100 mL water)
- Glucoamylase solution (3 tsp/100 mL water)
- Funnel
- Thermal gloves
- Glass stir rod
- Cheesecloth/plastic sieve
- Safety glasses
- Hot gloves
- Optional: pipette pump
- Optional: 10 mL serological pipettes
- Optional: aluminum foil
- Optional: paper towels

Teacher preparation

1. Prepare materials ahead of time for students. Make sure to create the amylase and glucoamylase solutions before the lab.
2. Students should work in groups of 3-4 to create a corn mash and distill the filtrate into ethanol. Carefully observe safety procedures during the lab!
3. See student lesson for detailed instructions of the corn mash preparation and ethanol distillation. This lesson will take one day to prepare the corn mash, three days in between to allow for complete fermentation (this could be shorter if samples are kept warm in an incubator set to 32° C/90° F (optimal temperature for yeast metabolism). Distillation will take longer than a class period, so a demo could be prepared so that students can test the final product in the following class period.
   Safety note: Do not use any flames in the room during ethanol distillation. Students should make sure that the joints of the distillation equipment are tightly sealed in order to capture the distilled ethanol and prohibit it from being released into the atmosphere.

Alcohol flame test

Safety note: This test should only be done in an active fume hood on a watch glass after the ethanol distillation is complete and there is no vapor in the air.

Students will be testing the ethanol distillate for alcohol concentration by lighting it on fire. The longer the flame burns, the greater the alcohol concentration. If the distillate does not burn, the water concentration is too high (over 50%).

Salt wash (optional)

Students can separate remaining water from the ethanol distillate by adding a small amount of potassium carbonate, K_2CO_3, which is soluble in water but not in ethanol, to the distillate. The K_2CO_3 and water will form an alkaline solution and separate from the ethanol to form a dense, bottom layer with the ethanol remaining in the top layer. This can be seen more easily if a drop of food coloring is added to the distillate at the same time as the K_2CO_3. Students can then remove the ethanol and test it either by flame test in the fume hood, with an ethanol probe, alcohol refractometer, or in a stirling engine.

Questions you might want to ask students

- How can we modify dent corn to make glucose available for fermentation?
- What role does anaerobic respiration play as yeast consume glucose to create ethanol and carbon dioxide?
- What change does glucose undergo to become ethanol and carbon dioxide?

Student handout

Reflection

1. What effect does the physical heating have on the corn mash?

Possible answers: The heating helps to break down the fiber and complex carbohydrates in the corn.

2. Explain how each enzyme (amylase and glucoamylase) change the corn mash mixture in preparation for fermentation.

Possible answers: The enzymes help to deconstruct the starch into glucose. If students completed the Ticketase lab, they should be able to explain how each enzyme works to break starch into smaller saccharides.

3. What is the function of the yeast during the fermentation process? How did the consistency of the corn mash change during the 3 day fermentation process?

Possible answers: The yeast will continue to consume sugars over the 3-day fermentation process. As time continues, the sugar percentage will decrease, making contact with the yeast more difficult. The corn mash will become less dense due to the consumption of sugars by yeast. Students might also mention the bubbling that occurs during the fermentation and should be able to explain that it is a result of fermentation; yeast waste products.

4. What are other ways you can experiment to make the fermentation process more efficient?

Possible answers: The corn was broken down both mechanically and chemically into smaller and smaller polysaccharides until reduced to single glucose molecules. Glucose was removed and consumed by yeast, leaving a higher concentration of proteins and lipids in the final product.

6. What byproducts result from ethanol production?

Possible answers: Ethanol production also creates distillers grains (solid product), water, oil, and carbon dioxide.

7. What are efficient and economical uses for the coproducts (carbon dioxide and distillers grains) that are generated during ethanol production?

Possible answers: Carbon dioxide is captured to be used as a carbonate in beverages. Distillers grains are currently used in animal feed as a protein source.

8. Construct an explanation for using corn in the process of commercial ethanol production based on evidence from student investigations and design logical solutions for the coproducts that are produced.

Student responses will vary according to their lab results and research.

Differentiation

Other ways to connect with students with various needs:

- **Local community:** Students may investigate the use of dent corn in their local area. If it is not apparent that corn is being used, students might bring in packages of food products (or pet food) that include corn. (The corn used in food products is a different type of corn than dent corn, but it is grown as a commodity and sold to food processing plants i.e. Frito Lay, etc.) Students may also investigate the use of ethanol by visiting their local gas station for the amount of ethanol used in gasoline.
- **Students with special needs (auditory/visual/language/reading):** Students may be paired with other students to investigate corn and corn uses. See World of Corn (`worldofcorn.com`).
- **Extra Support:** Video: How ethanol is made (`youtu.be/59R-NqykoXs`). This video helps demonstrate relationships between the components of the ethanol fermentation ecosystem. Infographic: `vitalbypoet.com/infographics/ethanol-process-2`
  This infographic represents the process of corn flour breakdown into glucose for fermentation.
- **Extensions:** Students may research the current commercial process of ethanol production and uses of the generated coproducts. Students may also research additional future uses for ethanol coproducts to make ethanol production more efficient and sustainable.

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Construct an explanation for using corn in commercial ethanol production.	The student collects data but does not use the data to construct and explanation for using corn in commercial ethanol production	The student independently constructs an explanation based on data for using corn in commercial ethanol production and analyzes data to support their explanation.	The student independently constructs an explanation based on data for using corn in commercial ethanol production, analyzes data to support their explanation and suggests future solutions for coproduct usage.

Rubric for self-assessment

Skill	Yes	No	Unsure
I generated data and constructed an explanation for the use of corn in commercial ethanol production.			
I suggested viable solutions for the industrial application of the remaining coproducts produced in the commercial ethanol production.			