Ethanol Combustion

Next Generation Science Standards

NGSS Science and Engineering Practices:

- ☐ Asking questions and defining problems
- ☐ Developing and using models
- ☑ Planning and carrying out investigations
- ☑ Analyzing and interpreting data
- ☑ Using mathematics and computational thinking
- ☑ Constructing explanations and designing solutions
- ☐ Engaging in argument from evidence
- ☑ Obtaining, evaluating, and communicating information

NGSS Cross-cutting Concepts:

- ☐ Patterns
- ☑ Cause and effect
- ☐ Scale, proportion, and quantity
- ☐ Systems and system models
- ☐ Energy and matter
- ☐ Structure and function
- ☑ Stability and change

NGSS Disciplinary Core Ideas:

- ☑ PS1.B: Chemical Reactions

Initial Prep Time

Less than 5 min. per apparatus, plus about 15 minutes to mix solutions, if necessary

Lesson Time

1 – 2 class periods, depending on experiments completed

Assembly Requirements

- Scissors
- Hot plate or other heating element
- Various beakers or other containers for solution

Materials (for each lab group):

- Horizon Ethanol Fuel Cell Science Kit
- Distilled water
- Ethanol
- Stopwatch
- Celsius thermometer
- Hairdryer or small space heater
- Horizon Renewable Energy Monitor or multimeter (optional)

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Lab Setup

- Before the lab starts, you should assemble the fan motor, and complete steps 1-3 of the assembly guide. This should take no more than a few minutes for each kit.
- Attach a small length of tubing to each syringe to make cleaning out the fuel cell much easier.
- If you prefer to prepare the different concentrations of ethanol solutions beforehand instead of having your students prepare their own, you can omit the first portion of Experiment 1.
- If you only have one hot plate or hair dryer/heater you can rotate groups into the solution temperature and air temperature experiments, respectively, at different times or have groups work together on those experiments.
- pH paper is included, but any other pH paper can be used as well if you run out.
- If you're using the Measurement section, you'll need a multimeter or the Horizon Renewable Energy Monitor.
- Lab includes small parts that can go missing easily. Set up a resource area for each lab table or for the entire class to minimize lost pieces.

Safety

- Do not use greater than 15% ethanol mixtures in the fuel cell or it will be irreparably damaged.
- Do not mix pure ethanol with water inside the fuel tank. Instead, use the container with the milliliter markings or a graduated cylinder first and then transfer the mixture to the fuel tank.
- Ethanol is volatile and the solutions should never be heated to more than 60ºC (140ºF).
- Keep ethanol away from open flames, and be sure to keep any containers of pure ethanol sealed when not in use.
- Safety goggles should be worn at all times.

Notes on the Ethanol Fuel Cell Science Kit:

- It's recommended that you mix your ethanol beforehand in a large batch, to prevent you from having to continue mixing ethanol throughout the activity. As a guide for how much to make, please note that students will go through about 60mL per experiment per group.

Common Problems

- If no electricity is flowing, check that all connections are properly wired and try again.
- The fan motor sometimes needs a quick tap or flick to get it to start spinning.
- If the fuel level in the tank drops too low, ethanol will not flow into the fuel cell. Keep the level of ethanol higher than the fuel cell's inlet nozzle.

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- If the fan slows, purge the fuel cell with distilled water and air as described in the Procedure section then wait 5-10 minutes before attaching the fan again.

Goals

- ✓ Use an ethanol fuel cell to produce an electric current
- ✓ Conduct experiments to study its performance
- ✓ Make calculations based on data

Background

Any organic molecule with an –OH group attached to a carbon atom is an alcohol. The common term "alcohol," as in the substance found in alcoholic beverages, refers to the alkane with the chemical name ethanol (CH_3CH_2OH).

Ethanol is a naturally-occurring product of fermentation reactions, one of the many ways in which microorganisms break down organic matter. Ancient humans harnessed this natural process and fermented many different types of grains and fruits to create the different alcoholic beverages we still have today.

Today, ethanol has uses beyond drinking: it is a source of fuel for heating homes and powering cars and trucks. Most gas stations today have up to 10% ethanol mixed in with the fossil fuels they distribute at the pump. This not only reduces the amount of oil needed to fuel conventional cars, but also decreases pollution since ethanol can be "recycled" by growing plants that pull carbon out of the atmosphere.

Ethanol fuel cells combust ethanol as well, but unlike in gasoline engines they do it without actually setting it on fire. When exposed to the catalyst inside the fuel cell, ethanol reacts in one of two ways. If the ethanol is completely combusted, the reaction is:

$$C_2H_5OH + 3O_2 \rightarrow 3H_2O + 2CO_2$$

But under certain conditions, the ethanol oxidizes to form acetic acid:

$$C_2H_5OH + O_2 \rightarrow CH_3OOH + H_2O$$

During this activity, we will use an ethanol fuel cell to generate an electric current and decompose ethanol using both of the above reactions. We will manipulate the conditions of the reaction to see if we can change the output.

Procedure

1. Your fuel cell is attached to a fuel tank, which will be moving the ethanol solution into the fuel cell when you remove the clamp on the tube. For now, leave it there and look at your fuel cell.
2. Where do you think you'd find the products of your chemical reaction exiting the fuel cell?
3. Attach the red and black wires to the fuel cell. Then attach the other ends of the wires to the fan. Why do you think we need two wires?

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4. Open the clamp on the fuel tank tube to let ethanol solution into the fuel cell.
5. Once liquid flows out of the unclamped tube, replace the clamp on the fuel tank tube. What happens to the fuel cell and fan? Record your observations below.
6. To clean out your fuel cell after use, fill the syringe with distilled water and disconnect the fuel tank tube from the fuel cell.
7. Attach the syringe to the fuel cell and push the distilled water into the fuel cell.
8. Disconnect the syringe and its tube from the fuel cell and fill the syringe with air.
9. Use the syringe to push air into the fuel cell. Your fuel cell is now ready to be used again.

Observations

Experimentation

1. How does the concentration of the ethanol solution affect the ethanol reaction? You'll test multiple concentrations. First, calculate how much ethanol and distilled water you'll need to prepare solutions of the following concentrations:

Concentration:	mL Ethanol:	mL H2O:	Solution Total mL:
5%	3	57	60mL
7%	4.2	55.8	60mL
10%	6	54	60mL
12%	7.2	52.8	60mL
15%	9	51	60mL

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2. Now follow the procedure described above with the different concentrations. Be sure to clean out your fuel cell and fuel tank between each trial. Record your observations below:

Concentration:	Time until fan starts (sec):	pH paper color when placed under exhaust tube:	Other observations:
5%			
7%			
10%			
12%			
15%			

3. How does the temperature of the solution affect the ethanol reaction? Using ethanol solutions of different temperatures, run your fuel cell as described in the procedure section. Be sure to clean out your fuel cell and fuel tank between each trial. Record your observations below:

Temperature:	Time until fan starts (sec):	pH paper color when placed under exhaust tube:	Other observations:

4. What happens if we change the temperature of the air around the fuel cell? Using a hair dryer or other heating device, run your fuel cell as described in the procedure section. IMPORTANT: Use the heating device on a low setting, as ethanol can be dangerous at temperatures above 60°C. Use your thermometer to make sure your heater isn't heating the air beyond that temperature before you begin. Record your observations below:

Trial	Time until fan starts (sec):	pH paper color when placed under exhaust tube:	Other observations:
Unheated air			
Heated air			

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Measurement

For this section, you will need a multimeter or the Horizon Renewable Energy Monitor. For an introduction to using a multimeter, click here.

1. Using the conditions that started the fan the fastest according to your experiments, record the current in Amps and highest voltage in Volts produced while the fuel cell is powering the fan motor. Record your answers below:

(Answers in this section will vary, but check that they are within reason, i.e. not >1A.)

Time:	Current (A):	Voltage (V):
0 min		
2 min		
4 min		
6 min		
8 min		
10 min		

2. Voltage is equal to the current in amps multiplied by the resistance in ohms (V = IR), so according to your data what is the resistance of the motor in ohms?

Resistance: _____ Ω

3. Power is the current in amps multiplied by the voltage in volts (P = IV), so according to your data how much power in watts is your fuel cell producing?

Power: _____W

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Analysis

1. Make a scientific claim about what you observed while running your ethanol fuel cell.

Claim should reference the reaction rate or products.
Example: "Increasing the air temperature caused the reaction to create more water and carbon dioxide."

2. What evidence do you have to back up your scientific claim?

Evidence should cite data in Observations and/or Experimentation sections.
Example: "The pH paper showed that the product was less acidic when we used the hair dryer to heat the air around the fuel cell."

3. **What reasoning did you use to support your claim?**

Reasoning can draw from Background section and/or other materials used in class.
Example: "The only ways that ethanol can react in the fuel cell is to create acetic acid, which would turn the paper red, or water and carbon dioxide, which aren't acidic."

4. Design an experiment that would test what conditions allow the fuel cell to run for the longest period of time. Describe your experiment below:

Though answers may differ, students should include what parameters they would change, how they would know which configurations performed best, and describe the control and experimental groups in their experiment.

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Conclusions

1. Based on your experiments, what conditions created the most efficient reactions of ethanol?

Students should reference their data from the Experimentation and/or Measurement sections and mention both the specific changes that improved the efficiency of the ethanol reactions and how they know those changes were successful.

2. In the human body, ethanol is converted into acetic acid. Why do you think the human body doesn't convert it into carbon dioxide and water?

Some possibilities students could propose: there might not be enough oxygen, acetic acid is a necessary product that the body needs, there's no need for carbon dioxide and water to be formed, it may require too much energy, and other answers.

3. What do you think could be done to increase the rate of this reaction?

Some possible answers: increase the amount of catalyst, increase the pressure of the ethanol fuel, increase the size of the area of the fuel cell where the reaction happens, and others.