Fuel Cells – Futuristic Battery

Student Objectives
The student:
- will be able to explain the chemical reaction in the electrolysis procedure
- will be able to explain the chemical reaction occurring in the fuel cell
- will be able to calculate the efficiency of the fuel cell system
- will understand how conservation of energy relates to the electrolysis/fuel cell procedure
- will be able to explain the benefits and disadvantages of using fuel cells to generate electricity and power vehicles.

Key Words:
anode
catalyst
cathode
nafion
PEM
platinum

Time: 1-2 class periods

Materials
- PEM reversible fuel cell with gas storage tanks (1 per group)
  Note: fuel cell used for this lesson was #544008 from Fuel Cell Store
- photovoltaic panel or transformer .5 amps or less (1 per group)
- wires with alligator clips (4 per group)
- multimeter (1 per group)
- small motor and propeller (1 per group)
- distilled water
- stopwatch

Background

A fuel cell produces electricity. Similar to a battery, a fuel cell converts energy produced by a chemical reaction directly into usable electric power. But, unlike a battery, a fuel cell does not get ‘used up’; it can generate electricity as long as it is supplied with hydrogen. Inside a fuel cell, hydrogen and oxygen combine to produce electricity and water. As a simple electrochemical device, a fuel cell does not actually ‘burn’ fuel, so it operates pollution-free. This also makes it quiet, dependable and fuel-efficient.

Inside most fuel cells, a selectively permeable membrane is sandwiched between two electrodes. Hydrogen gas feeds into the negative chamber (the anode), and oxygen enters the other side in the positive chamber (the cathode). As the hydrogen atoms flow through the anode, a platinum-based catalyst separates the hydrogen protons from their electron. The charged protons are attracted to the oxygen on the other side and pass through the membrane. The electrons cannot pass through the membrane, and instead must get to the cathode via an electrical wire–creating electricity! When the electrons arrive at the cathode they recombine with the hydrogen protons and the oxygen atoms to make water. This process also generates some heat which can be used for other purposes.

An individual fuel cell produces low voltage DC electricity. To meet other power needs, fuel cells are put together in a 'stack', to create any voltage needed.

This experiment demonstrates the decomposition of water in aa ratio of 2 volumes of hydrogen gas to 1 volume of oxygen.

$$2H_2O \rightarrow 2H_2 + O_2$$

In the fuel cell, the reverse of electrolysis takes place; the gases stored during electrolysis are reconverted into water.

$$2H_2 + O_2 \rightarrow 2H_2O$$

This proves that this electrochemical reaction is reversible.

The first reaction (electrolysis) requires electrical energy, whereas the second reaction releases electrical energy. In any such energy cycle there will be losses. The conversion of one form of energy to another is never 100% efficient. The fuel cell, however, is about twice as efficient as the internal combustion engine.

Procedure

1. Divide the students into lab groups of 3 - 5 students per group.
2. Show the class the reverse PEM fuel cell.
3. Demonstrate how to fill the chambers for the electrolysis procedure:
   - Flip the fuel cell over so the bottom caps are up.
   - Remove the caps.
   - Fill one chamber completely with distilled water. (Remind the students that only distilled water is used, any other kind of water or any other liquid will ruin the membrane in the cell.) Make sure you fill the chamber until some water runs down the center tube.
   - Push the cap on from the center–this pushes out as much ambient air as possible.
   - Repeat with the second chamber.
4. Demonstrate how to attach the fuel cell to the photovoltaic panel (or transformer):
   - Attach the red wire to the red terminal on the fuel cell and the positive post on the photovoltaic cell. Repeat with the black wire to the black terminal and the negative post on the PV cell.
   - If using a transformer, connect the red to red, and the black to black.
   - Tell the students not to reverse the wires (polarity) as this will foul the fuel cell.
5. If the students are unfamiliar with a multi-meter or it has been awhile since they have worked with one, review its usage: Demonstrate with your particular multi-meter:

- Put the black lead in the common plug.
- Show the students where to plug the red lead in for voltage and amperage readings.
- Show them which setting to use for amperage and voltage (the voltage in this experiment will be in the .5 to 2.0V range and the amperage will be in the .3 to 1A range)

6. Pass out the equipment and have the students complete the experiment in their lab manuals.
7. Assist students as necessary.
8 After the students finish the lab, show them the animation of a fuel cell (listed in Internet Sites below).
9 Discuss the lab or the fuel cell information. Questions you may wish to pose to your class:
   - How are fuel cells and batteries alike? *(batteries and fuel cells both produce electricity, they both have anodes and cathodes)*
   - How are fuel cells and batteries different? *(their chemicals are different, batteries run out and need recharged while fuel cells will continue as long as they have a supply of hydrogen)*
   - How could we use fuel cells in the future?
   - What are the advantages of using fuel cells to produce electricity? *(non-polluting, no moving parts, quiet)*
   - What are the disadvantages of using fuel cells? *(no hydrogen infrastructure at the present time, cost)*

Further Research

1. Research NASA's use of fuel cells on the space shuttle and the space station.
2. Providing a reliable supply of hydrogen and an infrastructure for mobile uses such as cars, poses a host of transportation and storage problems. Have students pick a fuel cell application (a car, train, home, apartment complex or factory), and work up a plan to make this application a reality.

Internet Sites

http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html

US Department of Energy, Energy Efficiency and Renewable Energy. Fuel Cell animation

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1. Answers will vary depending upon the particular energy source used, however the answers should be consistent within the class.
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5 Answers will vary depending upon the particular energy source used, however the answers should be consistent within the class, and students should have recorded their answers in Watts (volts x amps).

6 The amount of hydrogen produced is twice the volume of oxygen.

7 $2H_2O \rightarrow 2H_2 + O_2$

9 Answers will vary depending upon the particular fuel cell used, however the answers should be consistent within the class, and students should have recorded their answers in Watts (volts x amps).

10 $2H_2 + O_2 \rightarrow 2H_2O$

11 Students should notice that the fuel cell essentially reverses the reaction of the electrolysis.

12 Answers will vary, but the method of calculation should follow the same procedure. The watt units should be changed to watt hours by dividing the watts that were recorded in minutes by 60. Then efficiency should be calculated by dividing the energy output by the energy put into the system. This number should then be written as a percentage.

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			.1	.2	.3	.4	.5	.6	.7	.8
Nature of Matter	**Standard 1**	**SC.A.1.4-**	X				X			
	Standard 2	**SC.A.2.4-**	X							
Energy	**Standard 1**	**SC.B.1.4-**		X			X	X	X	
	Standard 2	**SC.B.2.4-**								

Benchmark SC.A.1.4.1 - The student knows that the electron configuration in atoms determines how a substance reacts and how much energy is involved in its reaction.

Benchmark SC.A.1.4.5 - The student knows that connections form between substances when outer shell electrons are either transferred or shared between their atoms, changing the properties of substances.

Benchmark SC.A.2.4.1 - The student knows that the number and configuration of electrons will equal the number of protons in an electrically neutral atom and when an atom gains or loses electrons, the charge is unbalanced.

Benchmark SC.B.1.4.2 - The student understands that there is conservation of mass and energy when matter is transformed.

Benchmark SC.B.1.4.5 - The student knows that each source of energy presents advantages and disadvantages to its use in society.

Benchmark SC.B.1.4.6 - The student knows that the first law of thermodynamics relates to the transfer of energy to the work done and the heat transferred.

Benchmark SC.B.1.4.7 - The student knows that the total amount of usable energy always decreases, even though the total amount of energy is conserved in any transfer.

Fuel Cells – Futuristic Battery

anode - the negative terminal or chamber, as in a fuel cell

cathode - the positive terminal or chamber, as in a fuel cell

catalyst - a substance that modifies and increases the rate of a reaction without being consumed in the process

Nafion - Nafion® is DuPont's trademark of a sulfonated tetrafluorethylene polymer modified from Teflon®. Nafion is used as an ion-exchange membrane for applications such as PEM fuel cells

PEM - Proton Exchange Membrane–refers to the most common type of fuel cell

platinum - a heavy precious grayish white noncorroding malleable metallic element that fuses with difficulty and is used especially in chemical ware and apparatus, as a catalyst, and in dental and jewelry alloys

Fuel Cells – Futuristic Battery

1. Take a voltage reading from your photovoltaic (PV) cell (or transformer) to find out how much energy you will be putting into the electrolysis procedure. Take your PV cell out into the sunshine to take your reading. Write the voltage below.

   ________ voltage of the photovoltaic cell (or) ________voltage from the transformer

2. Take an amperage reading of your charging device (PV panel or transformer). To do this, make a circuit that includes the charging device, the motor, and the multi-meter (in the circuit). Write the amperage below.

   ________ amperage of the PV cell (or) ________ amperage from the transformer

3. Fill the water tanks of the fuel cell. Remember:
   - Flip the fuel cell over so the bottom caps are up.
   - Remove the caps.
   - Fill one chamber completely with distilled water. (Use only distilled water, any other kind of water or any other liquid will ruin the membrane in the cell.) Make sure you fill the chamber until some water runs down the center tube.
   - Push the cap on from the center–this pushes out as much ambient air as possible.
   - Repeat with the second chamber.

4. Attach the PV cell (or transformer) using wires with alligator clips:
   - Attach the red wire to the red terminal on the fuel cell and the positive post on the photovoltaic cell. Repeat with the black wire to the black terminal and the negative post on the PV cell.
   - If using a transformer, connect the red to red, and the black to black.
   - Remember, do not reverse the wires (polarity) as this will foul the fuel cell.

   Begin timing with a stopwatch as soon as you make the second connection. Record the level of gases at one minute intervals until the hydrogen tank is completely filled and begins to bubble up.

5. When the hydrogen tank is completely filled, record the time and disconnect the fuel cell from the PV cell (or transformer).

   ________ time it took to fill the H_2 chamber with ________ Watts of electricity
   (Remember to convert your volts and amps to watts!)

6. What did you notice about the ratio of hydrogen and oxygen produced during the electrolysis procedure?

7. Write a balanced equation for the electrolysis procedure.

8. Attach the fuel cell to a motor and propeller. (This time it doesn't matter which wire goes to which terminal on the motor–reversing the wires will only reverse the spin of the motor.) Begin timing with a stopwatch as soon as you make the second connection, and record the level of gases at one minute intervals.

   During the first few minutes take a voltage reading with your multi-meter by placing the probes on the connections from the fuel cell to the motor (these can be held in place on top of the existing connections without disconnecting the motor). Record the voltage.

   Next, take an amperage reading by breaking the circuit briefly to add in the multi-meter. After you take the reading, you may leave the multi-meter in the circuit.

9. When the motor stops or the hydrogen tank is almost empty (only one bubble of hydrogen left), remove the wires and record the time.

   ________ time it took to use the H_2 in the chamber with ________ Watts of electricity.

10. Write a balanced equation for the fuel cell procedure.

11. What did you observe about the electrolysis reaction and the fuel cell reaction? Compare and contrast the two.

12. Calculate how much energy is lost to heat in the sum of these reactions. (Hint: Convert both measurements to standard units–watts per hour--and calculate efficiency by dividing the energy out by the energy in. Express the efficiency as a percentage.)