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 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
cathode
catalyst
PEM
platinum

Time: 1 hour

Materials
- PEM reversible fuel cell with gas storage tanks (1 per group)
  Note: This activity uses fuel cell #544008 from Fuel Cell Store
- photovoltaic panel or transformer .5 amps or less (1 per group)
- wires with alligator clips (2 per group)
- small motor and propeller (1 per group)
- distilled water
- stopwatch (or watch with second hand)

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 a 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. Pass out the equipment and have the students complete the experiment in their lab manuals.
6. Assist students as necessary.

7. After the students finish the lab, show them the animation of a fuel cell (listed in Internet Sites below).
8. Discuss the lab or the fuel cell information. Questions you may wish to pose to your class:
   - Since we know that no energy transformation is 100% efficient, we know that the electricity produced by the fuel cell is less than the energy needed for the electrolysis procedure. We also know that energy cannot be created or destroyed, so what happens to the 'missing' energy? *(it turns into heat as a by-product of the reaction)*
   - 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.
3. Have students create an advertising poster that promotes the use of fuel cells as an energy source.

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	.2	.3	.4	.5	.6	.7
Nature of Matter	Standard 1	SC.A.1.3-					X		
	Standard 2	SC.A.2.3-	X	X					
Energy	Standard 1	SC.B.1.3-	X	X		X			
	Standard 2	SC.B.2.3-	X						
How Living Things Interact With Their Environment	Standard 1	SC.G.1.3-							
	Standard 2	SC.G.2.3-	X						

Benchmark SC.A.1.3.5 - The student knows the difference between a physical change in a substance and a chemical change.
Grade Level Expectations
The student:
Sixth
- knows the difference between a physical and chemical change

Seventh
- knows that chemical changes result in new substances with different characteristics.

Benchmark SC.A.2.3.1 - The student describes and compares the properties of particles and waves.
Grade Level Expectations
The student:
Sixth
- understands that particles may be either neutral or have a positive or negative charge

Seventh
- knows that charged particles will attract or repel each other

Eighth
- knows that matter is mostly neutral, but that particles can attain a charge by the gain or loss of electrons.

Benchmark SC.A.2.3.2 - The student knows the general properties of the atom and accepts that single atoms are not visible.
Grade Level Expectations

The student:
Sixth
Seventh
- understands that protons and neutrons are located in the nucleus of the atom while electrons exist in areas of probability outside of the nucleus

Eighth
- knows that when electrons are transferred from one substance to another, the general properties of both substances change.

Benchmark SC.B.1.3.1 - The student identifies forms of energy and explains that they can be measured and compared.
Grade Level Expectations
The student:
Sixth
- knows different types of energy and the units used to quantify the energy
- understands that energy can be converted from one form to another

Eighth
- knows examples of natural and man-made systems in which energy is transferred from one form to another.

Benchmark SC.B.1.3.2 - The student knows that energy cannot be created or destroyed, but only changed from one form to another.
Grade Level Expectations
The student:
Sixth
- understands that energy can be changed in form
- uses examples to demonstrate common energy transformations

Eighth
- understands how the principle of conservation of energy is applied during an energy transfer.

Benchmark SC.B.1.3.4 - The student knows that energy conversions are never 100% efficient.
Grade Level Expectations
The student:
Seventh
- knows that useful energy is lost as heat energy in every energy conversion

Eighth
- knows that energy conversions are never 100% efficient and that some energy is transformed to heat and is unavailable for further useful work
- knows that a transfer of thermal energy occurs in chemical reactions.

Benchmark SC.B.2.3.1 - The student knows that most events in the universe involve some form of energy transfer and that these changes almost always increase the total disorder of the system and its surroundings, reducing the amount of useful energy.
Grade Level Expectations

The student:

Sixth

- understands that energy moves through systems

Eighth

- understands that as energy is transferred from one system to another there is a reduction in the amount of useful energy.
- knows that energy transfer is not efficient.

Benchmark SC.G.2.3.1 - The student knows that some resources are renewable and others are nonrenewable.

Grade Level Expectations

The student:

Sixth

- knows renewable and nonrenewable energy sources

Eighth

- knows that some resources are renewable and others are nonrenewable.

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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

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

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1. 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.

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

Time Interval	Hydrogen level	Oxygen level

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

4. Why did the electrolysis procedure produce this ratio of hydrogen to oxygen?

5. 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. 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 Interval	Hydrogen level	Oxygen level

6. What did you notice about the ratio of hydrogen and oxygen consumed by the fuel cell to produce electricity?

7. Why did the fuel cell consume this ratio of hydrogen to oxygen?

8. Write a balanced equation for the electrolysis procedure.

9. Write a balanced equation for the chemical reaction occurring in the fuel cell.

10. Compare and contrast the electrolysis procedure and the fuel cell procedure.

11. In the electrolyser, electrical energy is converted into chemical energy. The energy is stored as hydrogen gas. In the fuel cell, chemical energy is converted into electrical energy. For a given volume of hydrogen produced and used, will the fuel cell generate as much electrical energy as was needed to produce the hydrogen in the electrolyser? If not, why not?