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)
- photovoltaic panel (1 per group) 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 proton from its electron. The charged protons are attracted to the oxygen's negative ions on the other side and pass through the electrolyte membrane. The electrons cannot pass through this 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 molecules 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. Large stacks may contain hundreds of fuel cells to get the desired voltage. Spacecraft have been using fuel cells as a support power source for decades.

This investigation demonstrates the decomposition of water in an oxidation-reduction (redox) reaction producing a ratio of 2 volumes of hydrogen gas to 1 volume of oxygen during the electrolysis phase. Electric energy is used to produce a chemical reaction.

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

More specifically:

Anode: $6\ H_2O\ (l) \longrightarrow 4\ e^- + O_2\ (g) + 4\ H_3O^+\ (aq)$; oxidation

Cathode: $4\ H_2O\ (l) + 4e^- \longrightarrow 2\ H_2\ (g) + 4\ OH^-\ (aq)$; reduction

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

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

More specifically:

Anode: $2H_2\ (g) + 4\ OH^-\ (aq) \longrightarrow 4\ e^- + 4\ H_2O\ (l)$; oxidation

Cathode: $O_2\ (g) + 2\ H_2O + 4\ e^- \longrightarrow 4\ OH^-\ (aq)$; reduction

This proves that this electrochemical reaction is reversible. Fuel cells directly change chemical energy into electric energy.

The first reaction (electrolysis) requires electrical energy, whereas the second reaction releases electrical energy. In any such energy cycle 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 team.
2. **Engage:** Show the class the reversible PEM fuel cell. Ask the students to identify it and accept all answers.
3. Demonstrate how to fill its 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 permeable membrane in the cell.) Make sure you fill the chamber until some water runs down the center tube, removing all air.

- Push the cap on from the center–this pushes out as much ambient air as possible.
- Repeat this procedure 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 short the fuel cell.
5. If the students are unfamiliar with a multi-meter or it has been awhile since they have worked with one, demonstrate its use with your particular multi-meter:
   - Put the black lead in the common plug.
   - Show the students where to plug the red lead in for readings of voltage and current (amperage) readings.
   - Show students which setting to use for amperage and voltage (the voltage in this experiment will be in the range of .5 to 2.0V range and the current will be in the .3 to 1A range)
6. **Explore:** Pass out the equipment and have the students complete the exploratory 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 to help evaluate what students learned. 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, and they requre an electrolyte material)*
   - How are fuel cells and batteries different? *(their chemical energy sources are different, batteries are less efficient and need to be recharged or replaced while fuel cells are more efficient and will continue as long as they have a supply of hydrogen)*
   - How could we use fuel cells in the future? *Student generated answers.*
   - What are the advantages of using fuel cells to produce electricity? *(non-polluting, no moving parts, quiet, uses a renewable energy source, water)*
   - What are the disadvantages of using fuel cells? *(no hydrogen infrastructure at the present time, cost, needs purified, distilled, water)*
10. **Explain and Elaborate:** The Fuel Cell Advertisement activity may be used solely as a homework project or a classroom project and then presented to the class. This project was designed to evaluate student knowledge and provide an avenue for students to use their creative or technical skills. Encourage students to add more independent research using a reliable source before finalizing their project plans.

Evaluation and Student Assessment

Evaluate the Fuel Cell Advertisement assignment using the following rubric with the scale 5 - exemplary, 4 - above average, 3 - average, 2 - needs improvement

TV or Radio Commercial / Tri-fold Brochure	Teacher's Evaluation
Clear science and fuel cell theme	
Information is accurate and flows together	
Fuel cell benefits are purposeful and persuasive	
Overall: interesting and creative (or entertaining)	
Overall: correct use of language and grammar skills	
Overall: purpose is effective and appropriate	

Use the rubric's value and total grade percentage as desired. The other adult's scores may be included in your overall assessment or it can act as a means for sharing classroom knowledge with others and showcasing the talents of the student, or as a way of perfecting the quality of the student's work.

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. Research the different types of fuel cells such as the PEM fuel cell, the alkaline fuel cell, the phosphoric acid fuel cell, the solid oxide fuel cell and the molten carbonate fuel cell. Include their function, efficiency, and information on their current and future use.
4. Research Sir William Robert Grove who is given credit for building the first fuel cell in 1839.

Related Reading

- ***Hydrogen: Hot Stuff Cool Science–Jouney to a World of Hydrogen Energy and Fuel Cells at the Wasserstoff Farm*** by Rex Ewing (Pixyjack Press, 2004)
  This book is a clever, innovative meld of "Harry Potter makes contact with the Hydrogen Wizard and together they travel Back to the Future." At least, those are the images I saw while reading. Science teachers will love "technistoff," the technical notes and references following each chapter. Armed with these, teachers can enrich their own knowledge and understanding of some incredible new technologies of hydrogen generation, storage, and delivery, as well as visiting some very instructive web sites with their students.

Internet Sites

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

US Department of Energy, Energy Efficiency and Renewable Energy. The basics of hydrogen fuel cells, includes a fuel cell animation

Fuel Cells – Futuristic Battery

1. Answers will vary depending upon the particular energy source used, however the answers should be consistent within the class.
2. Answers will vary depending upon the particular energy source used, however the answers should be consistent within the class.
3. Students should have recorded their data neatly and thoroughly.
4. 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).
5. The amount of hydrogen produced is twice the volume of oxygen.
6. O_2
7. $2H_2O \rightarrow 2H_2 + O_2$
8. Students should have recorded their data neatly and thoroughly.
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 power units of Watts (volts x amps). Power is work or energy per unit of time.
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 and the quotient is multiplied by 100. This number should then be written as a percentage.

$$\% \text{ Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100$$

13. Evidence that a chemical reaction is taking place includes the transformation of energy, a change in temperature, and a gas being produced.
14. The Law of Conservation of Energy states that energy can not be created or destroyed. Energy provided by the power source was transformed to chemical energy to produce a chemical reaction which in turn transformed into electric energy. Water was changed chemically into its components, hydrogen and oxygen gas; same elements, same proportions and the fuel cell combined the components back into water molecules to increase the efficiency of the fuel cell as a power source. Laws describe a natural event without providing explanations.
15. Advantages of using fuel cell: non-polluting, no moving parts, quiet, uses water not petroleum as an energy source. Disadvantages: no hydrogen infrastructure at the present time, cost, some types of fuel cells use scarce elements (platinum)

Fuel Cells – Futuristic Battery

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nature of Science																					
Standard 1	**SC.912.N.1.**	**X**																			
Physical Science																					
Standard 8	**SC.912.P.8.**	**X**	**X**		**X**			**X**	**X**		**X**										
Standard 10	**SC.912.P.10.**	**X**	**X**	**X**												**X**					
Language Arts Standards		**LA.910.3.5.1, LA.910.3.5.3, LA.910.5.2.4, LA.910.5.2.5, LA.910.6.3.3, LA.910.6.4.1, LA.910.6.4.2, LA.1112.3.5.1, LA.1112.3.5.3, LA.1112.5.2.4, LA.1112.5.2.5, LA.1112.6.3.3, LA.1112.6.4.1, LA.1112.6.4.2,**																			
Mathematics Standards		**MA.912.A.1.4**																			

Science Standards

Standard 1: The Practice of Science

- SC.912.N.1.1- Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science, and do the following:
  1. pose questions about the natural world
  2. conduct systematic observations
  3. examine books and other sources of information to see what is already known
  4. review what is known in light of empirical evidence
  5. plan investigations
  6. use tools to gather, analyze, and interpret data (this includes the use of measurement in metric and other systems, and also the generation and interpretation of graphical representations of data, including data tables and graphs)
  7. pose answers, explanations, or descriptions of events
  8. generate explanations that explicate or describe natural phenomena (inferences)
  9. use appropriate evidence and reasoning to justify these explanations to others
  10. communicate results of scientific investigations, and
  11. evaluate the merits of the explanations produced by others.

Standard 3: The Role of Theories, Laws, Hypothesis, and Models

- **SC.912.N.3.3 -** Explain that scientific laws are descriptions of specific relationships under given conditions in nature, but do not offer explanations for those relationships.

Standard 8: Matter

- SC.912.P.8.1 - Differentiate among the four states of matter.
- SC.912.P.8.2 - Differentiate between physical and chemical properties and physical and chemical changes in matter
- SC.912.P.8.4 - Explore the scientific theory of atoms (also known as the atomic theory) by describing the structure of atoms in terms of protons, neutrons, and electrons, and differentiate among these particles in terms of the mass, electrical charges and locations within the atom.
- SC.912.P.8.7 - Interpret formula representations of molecules and compounds in terms of composition and structure..
- SC.912.P.8.8 - Characterize types of chemical reactions, for example: redox, acid-base-synthesis, and single and double replacements.
- SC.912.P.8.10 - Describe oxidation-reduction reactions in living and non-living systems.

Standard 10: Energy

- SC.912.P.10.1 - Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.
- SC.912.P.10.2 - Explore the Conservation of Energy by differentiating among open, closed, and isolated systems and explain that the total energy in an isolated system is a conserved quantity.
- SC.912.P.10.3 - Compare and contrast work and power qualitatively and quantitatively.
- SC.912.P.10.15 - Investigate and explain the relationship among current, voltage, resistance and power.

Language Arts Standards

Writing Process - Standard 5: Publishing

- LA.910.3.5.1 and LA.1112.3.5.1 - The student will prepare writing using technology in a format appropriate to the purpose.
- LA.910.3.5.3 and LA.1112.3.5.3 - The student will share with others or submit for publication.

Communication - Standard 2: Listening and Speaking

- LA.910.5.2.4 - The student will use an engaging introduction and conclusion and use figurative language to reinforce the intended message
- LA.1112.5.2.4 - The student will use appropriate eye contact, body movements, and voice register for audience engagement informal and informal speaking situations.
- LA.910.5.2.5 and LA.1112.5.2.5 - The student will research and organize the information that integrates appropriate media into presentations for oral communication (e.g. digital presentation, charts, photos, primary sources, webcasts)

Information and Media Literacy - Standard 3: Media Literacy

- LA.910.6.3.3 and LA.1112.6.3.3 - The student will demonstrate the ability to select print and nonprint media appropriate for the purpose, occasion, and audience to develop into a formal presentation.

Information and Media Literacy - Standard 4: Technology

- LA.910.6.4.1 and LA.1112.6.4.1 - The student will use appropriate available technologies to enhance communication and achieve a purpose (e.g. video, digital technology)
- LA.910.6.4.2 and LA.1112.6.4.2 - The student will routinely use digital tools for

publication, communication, and productivity.

Mathematics Standards

Algebra - Standard 1: Real and Complex Number Systems

- MA.912.A.1.4 - Perform operations on real numbers (including integer exponents, radicals, percent, scientific notation, absolute value, rational numbers, irrational numbers) using multi-step and real-world problems

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 valuable, heavy, precious metal: grayish white colored; noncorroding malleable and ductile element. Its symbol is Pt and its atomic number is 78. It is generally unreactive and has stable electrical properties. It is used as an alloy in electrodes, electrical contacts, dental and medical equipment, chemical lab ware and equipment; used as a catalyst in chemical reactions including the catalytic converter, and in making jewelry

Fuel Cells – Futuristic Battery

1. To find how much voltage you will be putting into the electrolysis procedure, connect the multimeter in a parallel circuit with the photovoltaic cell or transformer. Your PV panel must be out in the sunlight to take your reading. Read and record the voltage (in volts) below.

   _____ voltage of the photovoltaic cell (or) _____voltage from the transformer

2. To find the value of the current (or charge per second) flowing through the system, connect the PV panel or transformer, the fuel cell motor, and the multi-meter in a series circuit. Read and record the current in amps below.

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

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.

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.

3. Use a stopwatch to begin timing as soon as you make the second connection. Read and record in the table below, the level of gases in one minute intervals by observing the markings on the cell's until the gas chambers until the hydrogen tank is completely filled and begins to bubble up.

Time (minutes)	H_2 level	O_2 level
0		
1		
2		
3		
4		
5		

4. When the hydrogen tank is completely filled, record the time and disconnect the fuel cell from the PV cell (or transformer). Energy or work done within the system perunit of time is Power and the unit of measurement is watts.

   _____ time it took to fill the H_2 chamber with _____ Watts of electrical energy *(Remember watts = volts x amps!)*

5. Reducing the water molecule into its components is a decomposition or redox type of chemical reaction. What did you notice about the ratio of hydrogen and oxygen produced during the electrolysis procedure?

6. What gas was collected at the positive or cathode terminal?

7. Write a balanced chemical 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 in the table below.
   - 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.

Time (minutes)	H_2 level	O_2 level
0		
1		
2		
3		
4		
5		

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 chemical 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 and multiply the quotient by 100. Express the efficiency as a percentage.)

    $$\% \text{ Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100$$

13. How do you know a chemical reaction was taking place?

14. Briefly defend the Law of Conservation of Energy during the fuel cell process.

15. Based on your observations, what are the benefits and disadvantages of using fuel cells to generate electricity?

Fuel Cell Advertisement

Prepare and produce either:

- a TV or radio commercial with a poetic song or jingle OR
- design a tri-fold brochure using all sides of the paper (front and back) to be presented to the public

The purpose of your commercial or brochures is to explain fuel cell technology–how it works and its present and future benefits. Decide on a main theme, use accurate scientific information, connect your message to your audience (the general public), and use effective communication skills.

Present this project to your parents, guardian, or another adult for critiquing. Use their advice, modify if necessary, and present to your classmates and teacher.

Due date _____

Performance Rubric

Use the scale: 5 - exemplary 4 - above average 3 - average 2 - needs improving

TV or Radio Commercial / Tri-fold Brochure	Adult's Evaluation	Teacher's Evaluation
Clear science and fuel cell theme		
Information is accurate and flows together		
Fuel cell benefits are purposeful and persuasive		
Overall: interesting and creative (or entertaining)		
Overall: correct use of language and grammar skills		
Overall: purpose is effective and appropriate		

Comments:

Adult Evaluator's Name and Signature; _____