Spotlight on Photovoltaics & Fuel Cells

(A Web-based Study & Comparison)

Suggested Grade Level 9-12

Standard Statements

- 3.1.10 A Discriminate among the concepts of systems, subsystems, feedback and control in solving technological problems.
- 3.2.10 B Apply process knowledge and organize scientific and technological phenomena in varied ways.
- 3.4.12 A Apply concepts about the structure and properties of matter.
- 3.4.12 B Apply and analyze energy sources and conversions and their relationship to heat and temperature.
- 3.8.12 A Synthesize and evaluate the interactions and constraints of science and technology on society.
- 3.8.10 C Evaluate the possibilities, consequences, and impacts of scientific and technological solutions.
- 4.2.12 A Analyze the use of renewable and nonrenewable resources.

Content Objectives

Students will know that

1. A fuel cell is an electrolytic cell.
2. The four main parts of a fuel cell are the anode, catalyst, cathode, and electrolyte.
3. A fuel cell uses hydrogen and oxygen to produce an electrical current.
4. The main parts of a photovoltaic cell are the n-layer, p-layer, covers and junction.
5. A photovoltaic cells coverts sunlight into electricity.
6. The flow of electrons creates a direct electric current in both fuel cells and photovoltaic cells. (DC voltage)
7. Scientific research on fuel cells and photovoltaic cells has been heavily influenced over the years by societal and economic factors.
8. There are both similarities and difference with the technology behind fuel cells and photovoltaics.

Process Objectives

Students will be able to

1. Describe how energy is created from the flow of electrons.
2. Compare and contrast fuel cells and photovoltaics.
3. Generate ideas about why these technologies can be considered clean energy sources.

Assessment Strategies

1. Completion of the entire student handout.
2. Class discussions on material and web simulations.

Materials

Per class:

- Student computers with Internet access
- Teacher computer
- Projection equipment
- Student handouts – one per student
- Images of photovoltaic layers and fuel cells (Teacher Notes)
- Chemistry model kits or toothpicks and gum drops

Multimedia Resources

- PowerPoint presentation, "PV Presentation FSEC"
- QuickTime movie, Photovoltaics (pv4) (1:11).
- Websites:
  - http://www.greenspec.co.uk/html/design/materials/pvcells.html
  - http://www.pbs.org/newshour/science/hydrogen/images/interactive.swf
  - http://www.dsireusa.org/

Procedures

Part 1 *(1, 50-min Class Period)*

1. Show students photos of a Photovoltaic (PV) array and a fuel cell and ask them what they know about the chemistry that makes each technology produce electricity.
   a. PV array: http://www1.eere.energy.gov/solar/pv_use.html
   b. Fuel cell: http://www.nrel.gov/data/pix/Jpegs/12508.jpg
2. Review the chemistry terms: electron, photon, cathode, and anode.
3. Have the students work in pairs to create the following models: hydrogen, oxygen, water, silicon. Students may use molecular modeling kits if available, pipe cleaners and gum drops or drawings to model the molecules.
4. Give a short lecture using the "PV Presentation FSEC.ppt." Students will need to be able to make a general comparison between a PV system and a fossil-fueled one in a discussion at the end of the section. The "PV Presentation FSEC" content may be edited to suit the needs and skills of your students.
5. Discuss the questions on the last slide of the presentation as a class.

Part 2 *(1, 50-min Class Period)*

1. Have the students watch the web simulation on fuel cells at: *http://www.pbs.org/newshour/science/hydrogen/images/interactive.swf* After viewing the simulation on fuel cells, have the students spend a few minutes working in groups to fill out the differences and similarities charts on their student handout.
2. Have the students watch and take notes on the following simulations on a photovoltaic cell at their computer:
   - QuickTime movie on how photovoltaics work: Photovoltaics (pv4) (1:11)
   - http://www.greenspec.co.uk/html/design/materials/pvcells.html
   - *http://eagle.chimacum.wednet.edu/middle/jss/Course_SolarPanel.htm*
3. Have the students fill in the schematic of the n-layer, p-layer and junction on the student handout and explain the chemistry behind how they function.

4. Invite students to share what they think are the differences between photovoltaic and fuel cells. Record the student responses on the board, or assign a student to this task.

Part 3 *(1, 50-min Class Period)*

1. Review how both the fuel cell and photovoltaic function to reinforce the differences in the chemistry between the two systems.
2. Ask the students to explain why and how both systems produce electricity.
3. Review and discuss how electron flow creates a current.
4. Review how both the fuel cell and photovoltaic function to reinforce the differences in the chemistry between the two systems using the diagrams of the photovoltaic and the fuel cell provided in the Teacher Notes or multimedia links provided on the E-21 website.
5. For homework have the students find a source that awards either a tax incentive or grant for using renewable energy. Have them write a paragraph about how their family might benefit from such an award. A great site for students to refer to is: http://www.dsireusa.org/.

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General Lesson Notes

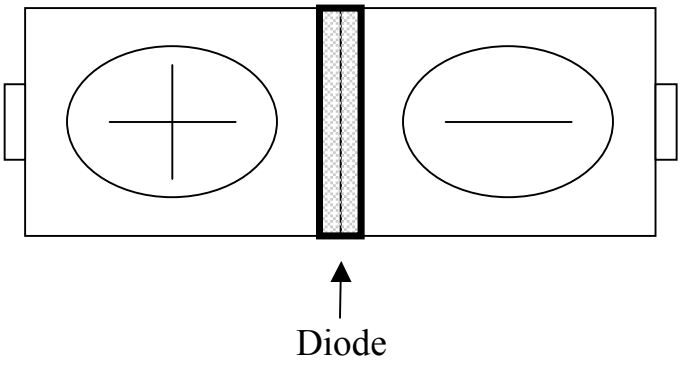
Electrochemistry is defined as the branch of chemistry that deals with oxidation-reduction reactions that transfer electrons to form electrical energy rather than heat energy. An **electrode** is a conductor used to establish electrical contact with a nonmetallic part of a circuit such as an electrolyte. There are two types of **electrodes**, a **cathode** is an electrode where reduction takes place and an **anode** is an electrode where oxidation takes place. Both the cathode and anode together make up an electrochemical cell. There are two types of electrochemical cells: voltaic (galvanic) cells and electrolytic cells.

An electrolytic cell can be seen as an electron pump which simultaneously supplies electrons to the cathode and recovers electrons from the anode. The anode and cathode of an electrolytic cell are connected directly to a power source; this causes *nonspontaneous* redox reactions which produce electricity**. Electrolytic cells** convert electrical energy into chemical energy as is seen in a **fuel cell**. Hydrogen enters the **fuel cell** at the **anode** has a positive (+) polarity; this separates electrons from the hydrogen molecules. A **catalyst** assists in the separation of the hydrogen's electrons from its protons. The Polymer **Electrolyte** Barrier (semi-permeable barrier) allows protons to pass through the **electrolyte** but not electrons. The electrons flow past the **electrolyte** causing a current (electricity). The **cathode** has negative (-) polarity in electrolytic systems because electrons are continuously being pumped into the system; here the protons combine with Oxygen from the air and electrons. A second **catalyst** platinum speeds up the reaction of hydrogen, oxygen and the electrons which produces the by products out of the exhaust in the form of heat and water vapor (H_20). See overhead 2 below.

Voltaic cells (i.e., batteries) serve as a source of electrical power which is produced by *spontaneous* redox reactions. Voltaic cells convert chemical energy into electrical energy. Photovoltaics, as the word implies (photo = light, voltaic = electricity), convert sunlight directly into electricity. However, this is not a chemical reaction like that of a voltaic cell. Sunlight hits the PV cell which is made of both a **p-layer** and **n-layer** both of which are semiconductors. The **n-layer** contains silicon which contains an impurity that allows it to contain an excess amount of electrons. This layer is considered the **anode (**negative (-) polarity) because electrons are continuously being generated there. The **p-layer** also referred to as the **cathode** has a positive (+) polarity which absorbs photons and contains excess holes. Between the two layers lies a **p/n junction** which allows the two layers to act as a battery, thus creating an electric field where they meet. The junction forces the electrons to move out towards the ends of the PV cell towards the back cover and the glass cover thus creating the electric current. A photovoltaic only creates energy during the daylight hours due to sunlight, at night due to lack of sunlight it needs a secondary source of energy. Also the amount of energy produced depends on the orientation of the PV cell in relation to the sunlight.

How a fuel cell differs from a battery. Fuel cells and voltaic batteries (AA, for example) operate on the same principles. Also sometimes referred to as a "flow battery," a fuel cell differs from a regular voltaic battery because a continuous flow of reactants must be supplied to the fuel cell in order for it to generate electrical current. Voltaic batteries have the reactants stored within the system. A fuel cell can therefore theoretically operate indefinitely as long as fuel is supplied; whereas a battery eventually goes dead.[1] (Reference: GREATT Project)

Photovoltaic as a Semiconductor: A PV cell **semiconductor** typically is made of silicon. Silicon is a common element in the periodic table. When it binds to itself it creates a crystal lattice network without any free electrons, thus this silicon crystal is nearly an **insulator**, and little electricity will flow through it. In order for silicon to have **semiconductor** properties which will create electricity it must be able to have free electrons available to produce a current. This is done by doping the silicon with an impurity so that the lattice structure will allow free electrons to be readily available, thus producing a current. This creates a **diode,** defined as a device that blocks current in one direction while letting current flow in another direction. An example of a **diode** is a battery. One end of the battery has a positive (+) end and the other a negative (-) end. There is a zone in the middle that doesn't allow the positive and negative charges to meet, this zone is a **diode**.



[1] The Penn State GREATT Project. "Fuel Cells." http://csats.psu.edu/files/GREATT/FuelCells/FuelCells.doc.

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The following charts compare differences and similarities between these two technologies.

Chart 1- Differences:

Photovoltaic	*Fuel Cell*
Energy created by the PV cell can be stored in a battery.	Fuel cells were invented to replace batteries and engines.
Main parts are Photovoltaic cell: N-Layer, Junction and P-layer	Four main parts of a fuel cell: Anode, Catalyst ,Cathode, and Electrolyte
Voltaic cell	Electrolytic cell

Chart 2- Similarities:

Photovoltaic	*Fuel Cell*
Clean Energy" Pollution reduction No by products.	Clean Energy" Pollution reduction Release of water vapor and heat which are non pollutants.
Produce Electricity in the form of direct current (DC) voltage	
Renewable Technology but high initial cost	
Challenges: 1. Only produce electricity during the daylight hours. 2. Producing and installing solar cell is expensive for their current energy payback.	Challenges: 1. There is a lot of energy required to make and distribute hydrogen. 2. Hydrogen's elemental nature makes it a difficult fuel to transport and store.

Additional Resources:

Visit the following websites for more information:

- http://www.rps.psu.edu/hydrogen/microbial.html
- http://www.eere.energy.gov/hydrogenandfuelcells/
- http://science.howstuffworks.com/fuel-cell1.htm
- http://science.howstuffworks.com/solar-cell.htm

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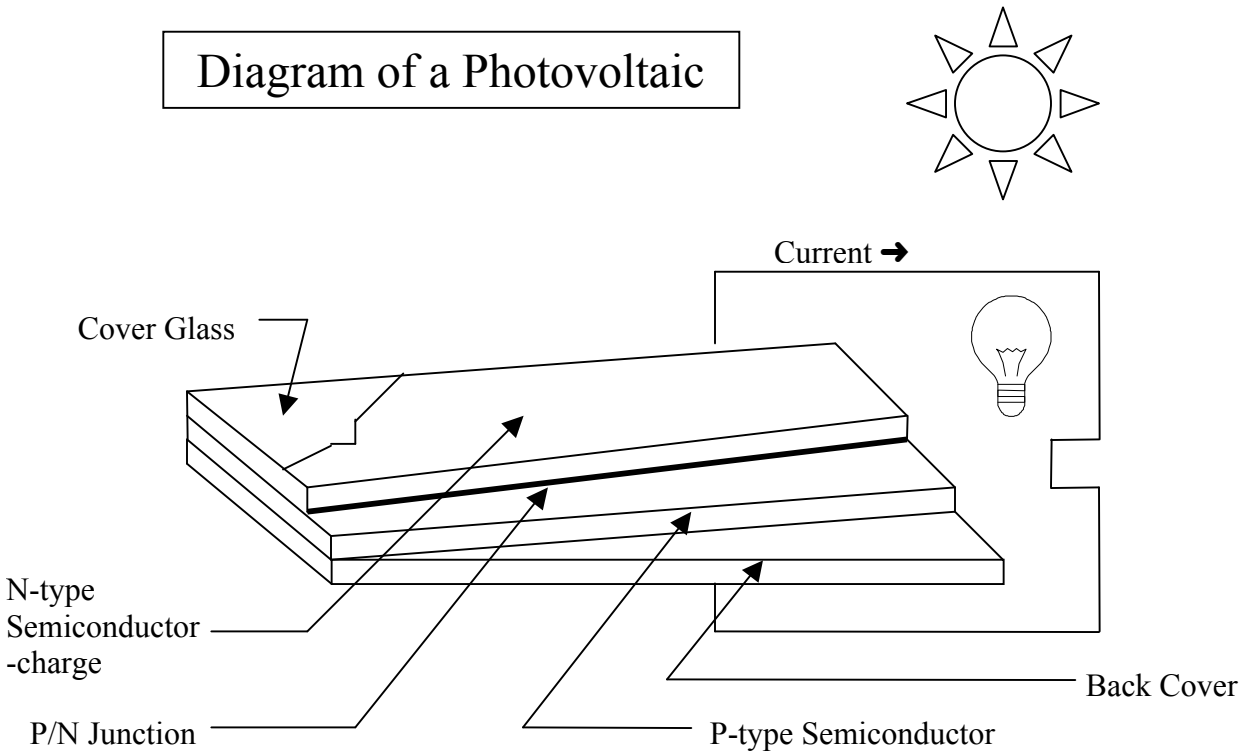

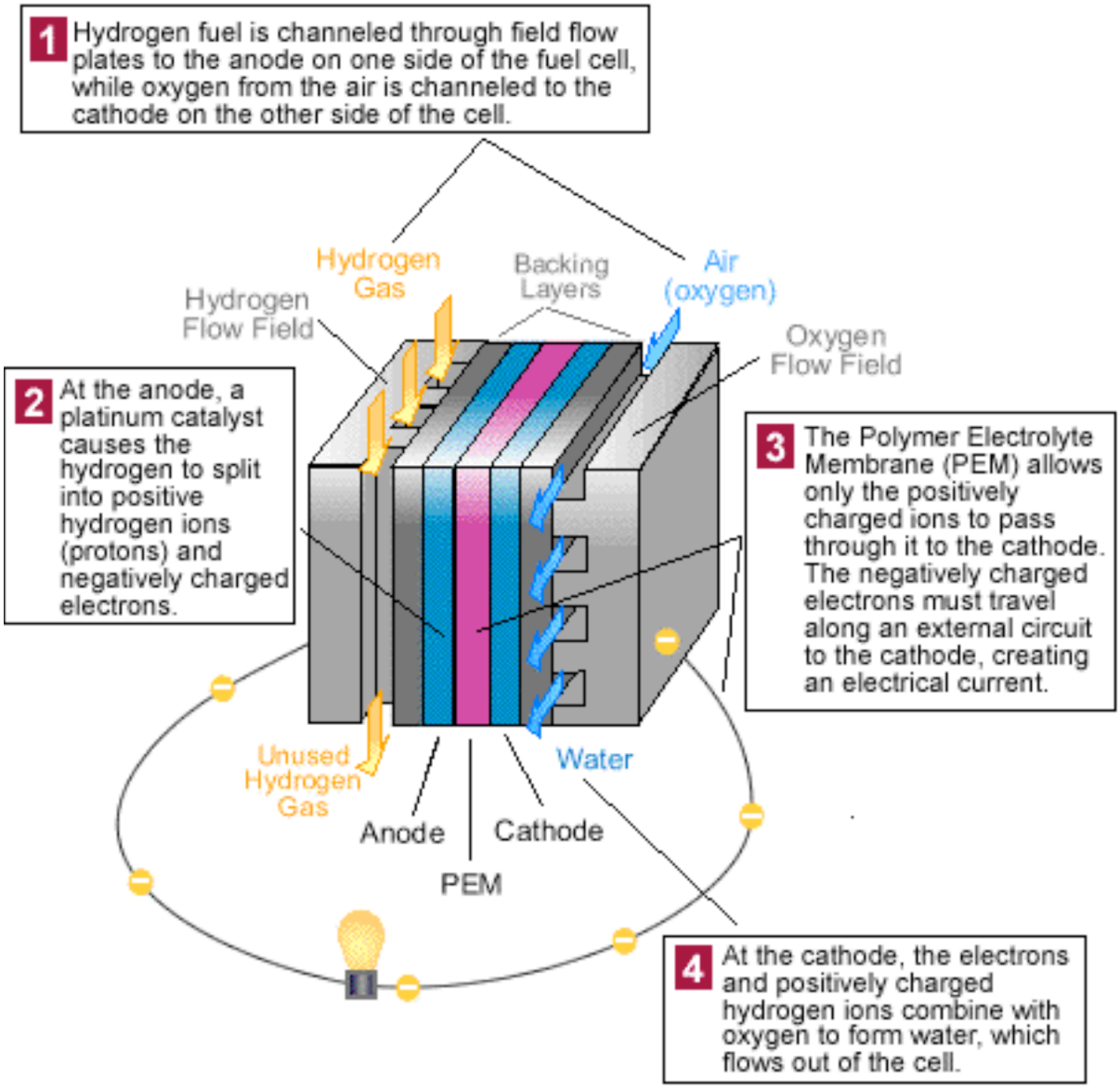

Source: http://www.fueleconomy.gov/feg/fc_pics/fuel_cell_still.gif

Name:_____

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Student Handout

1. Fill in the chart below on the *differences* between Fuel Cell versus a Photovoltaic Cell.

Differences	
Fuel Cell	Photovoltaic Cell

2. Fill in the chart below on the *similarities* between a Fuel Cell versus a Photovoltaic Cell.

Similarities	
Fuel Cell	Photovoltaic Cell

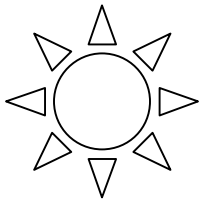
3. Fill in the charges in the following chart with Charge (+ or -) :

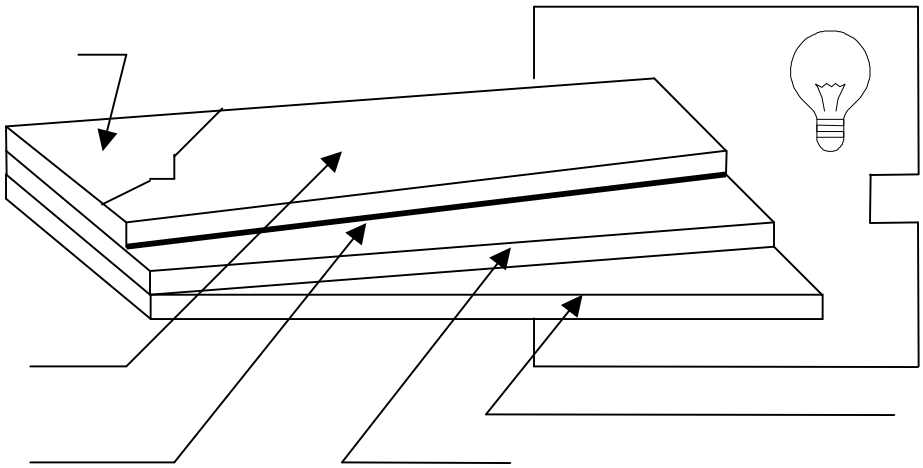
	Fuel Cell	Photovoltaic
Electron		
Proton		
Cathode		
Anode		

4. What are the biggest differences in how a fuel cell and a photovoltaic cell work?

5. Label the following schematic of a photovoltaic. Please include charges where they are needed. Label the current also and use an arrow to show which way the current is following.

Diagram of a Photovoltaic





6. Give examples of why these two technologies are considered types of "clean energy." What are the limitations of using the two technologies?

7. The United States government offers tax incentives and federal funding for people who utilize "clean energy" sources. For homework find a source that awards either a tax incentive or grant for using renewable energy. Write a paragraph or two about how your family might benefit from such an award. (A great place to start on the Internet is: http://www.dsireusa.org/.)