

Fuel Cell Technology An Alternative Energy System For the Future

**Created by Teachers,
Engineers, and Scientists**

**Lesson Plan Created by: Daniel
Arnold (Grades 9 - 12) Nancy Hazuka
(Grades 9 - 12) David L. Herring
(Grades 9 - 12) David L. Murray
(Grades 6 - 8) Sherri Williamson
(Grades 9 - 12)**

*In Collaboration With:
Dr. Robert James, Process Engineer
United States Department of Energy
Federal Energy Technology Center*

FUEL CELL TECHNOLOGY: ALTERNATIVE ENERGY SYSTEM FOR THE FUTURE Grades 9 - 12

Duration: 5 Days

WHAT IS A FUEL CELL?

A fuel cell is a device that converts chemical energy into electrical energy. It works on the same principle as a battery but is continually fed with fuel, usually hydrogen. Fuel cells are silent and reliable (no moving parts) but are expensive to produce.

WHAT IS ITS PURPOSE?

The purpose of a fuel cell is to generate electricity through an alternative, non-polluting electrochemical process. Output voltage is increased by adding fuel cells in series called stacking.

WHY IS IT IMPORTANT?

Fuel cell technology (FCT) is receiving attention to address the depletion of natural resources and global environmental concerns such as global warming and the greenhouse effect. FCT is also being proposed to move away from non-renewable natural resources such as fossil fuels and move towards renewables such as hydroelectric and solar power. Fuel cells also promise greater operating efficiency with lower emissions over conventional power sources used today.

HOW DOES IT WORK?

In a typical fuel cell, gaseous fuels (typically hydrogen-based) are fed continuously to the anode (negative electrode) compartment and an oxidant (i.e., oxygen from air) is fed continuously to the cathode (positive electrode) compartment; the electrochemical reactions take place at the electrodes to produce an electrical current. A fuel cell, although having components and characteristics similar to those of a battery, differs in several respects. A battery is an energy storage device and its maximum energy storage is determined by the amount of chemical reactant stored within the battery package. A battery will cease to produce electrical energy when the chemical reactants are consumed (i.e., discharged). The fuel cell, on the other hand, is an energy conversion device that theoretically has the capacity of producing electrical energy for as long as the fuel and oxidant are supplied to the electrodes. The transfer of ions is the fundamental chemical process that creates the electrical energy within the fuel cell stack. There are several types of fuel cells currently in development. They primarily differ in input fuels used and operational temperatures. A PEM (Proton Exchange Membrane) is a hydrogen fueled fuel cell that will be the focus of this lesson plan. See “How a PEM Fuel Cell Works” (later in this plan) for a more detailed description.

WHAT ARE ITS APPLICATIONS?

. Stationary (A.C. Applications)

- Power plants
- Home use
- Hospitals
- Hotels
- Isolated rural areas
- Military applications

Enclosed Environments (D.C. Applications)

- Space Station
- Space vehicles (space shuttle)
- Underwater vehicles (submarine)

Motive Transportation (D.C. Applications)

- Personal Vehicles (ZEV's -Zero Emission Vehicles)
- Public Transportation
- Commercial and Military Vehicles

BENEFITS AND DISADVANTAGES

Current power generation at 33% Fuel cell power generation at 50% - 80%	Expensive to produce.
Non polluting	Technology needs to expand.
Supply of hydrogen and air.	Extreme heat in some models.

Use all energy	
No moving parts	
Silent	

History:

Sir William Grove first discovered fuel cell technology in 1839. Sir William Grove is recognized as the “Father of the Fuel Cell.” Grove’s insights were developed from his experiments of the electrolysis of water. He reasoned it should be possible to reverse the process reacting oxygen with hydrogen producing electricity. Fuel Cell was a term coined in 1889 by Ludwig Mond and Charles Langer. They attempted to build the first practical device using air and industrial coal gas. The first successful cell devices resulted from inventions in 1932 by engineer Francis Bacon. He improved on the expensive platinum catalysts employed by Mond and Langer. Harry Karl Ihrig of Allis-Chalmers Manufacturing Company demonstrated his famous 20-horsepower fuel cell-powered tractor. In the late 1950’s NASA began experimenting with the technology to develop a power source for space travel. Fuel cell technology is also used in NASA’s space shuttle program and is projected for use in the new international space station.

Objectives:

1. Define fuel cell and its purpose.
2. Label fuel cell parts.
3. Describe the process of how a fuel cell operates.
4. Define fuel cell terminology and chemical processes.
5. List and compare in the advantages and disadvantages of fuel cells.

Skills and Knowledge You Need:

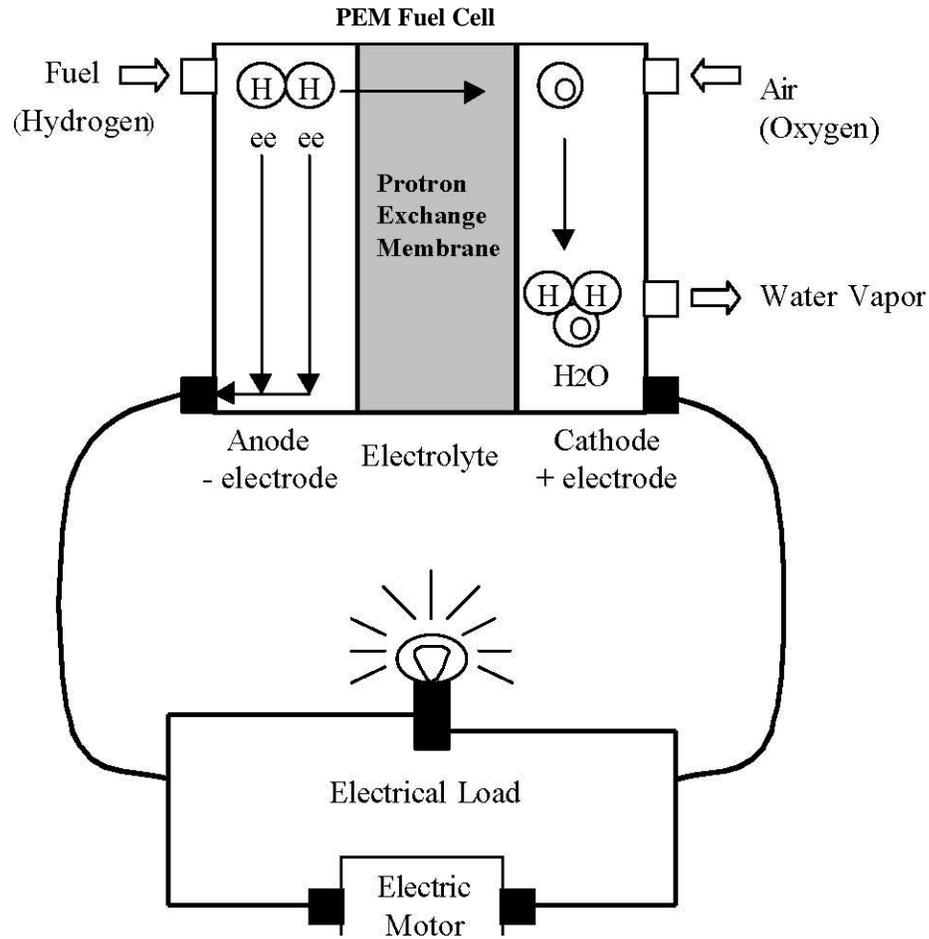
- Basic electricity.
- Basic chemistry.
- Electron flow within a simple circuit.

Words you will learn:

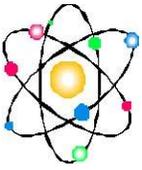
- alternating current** – (AC) a continual pulsating electrical force
- anode** – the negative electrode
- cathode**– the positive electrode
- direct current** – (DC) a direct electrical force that does not vary
- electrochemical** – converts chemical energy to electrical energy
- electricity** – flow of electrons in a circuit
- electrolysis** – a process of chemical changes by passing an electric current through a solution resulting in a transfer of ions (electrons) to the electrodes
- electrolyte** – in a Proton Exchange Fuel Cell this material is between the Cathode and the Anode and is primarily made of Nafion which is a Dupont Polymer
- fuel cell** – an electrochemical/self generating power source
- hydrogen** – chemical fuel of a fuel cell flowing through the anode
- ionization** – process of loss or gain of electrons to form positive or negative ions

- **membrane** – substance allowing hydrogen and oxygen to pass through
- **oxidation** – change of chemical composition due to exposure to oxygen
- **oxygen** – chemical fuel flowing through the cathode
- **PEM** – proton exchange membrane
- **prototype** – experimental model
- **stacking** – method of adding fuel cells to increase voltage output
- **voltage** – a measure of electrical potential of an electrical circuit or device
- **ZEV** – zero emission vehicle

How a PEM Fuel Cell Works



Hydrogen enters the anode side of the fuel cell. At the same time Oxygen is applied to the cathode side. The hydrogen protons pass through PEM (Proton Exchange Membrane) while the electrons of the hydrogen cannot penetrate the membrane. The PEM is the electrolyte that passes the protons but not the electrons. The electrons seeking the least path of resistance will flow from the anode of the fuel cell through an electrical circuit to power electrical devices or loads and return to the fuel cell via the cathode. The electrons will join with the hydrogen and oxygen within the cell to form a water molecule which is the water vapor byproduct of the fuel cell. In reality billions of water molecules are produced. This rapid combination of elements also creates heat. A PEM fuel cell has an average operational temperature of 80 degrees C or 176 degrees F. The combining of hydrogen and oxygen elements creates free electrons which is the desired energy output. Electricity!

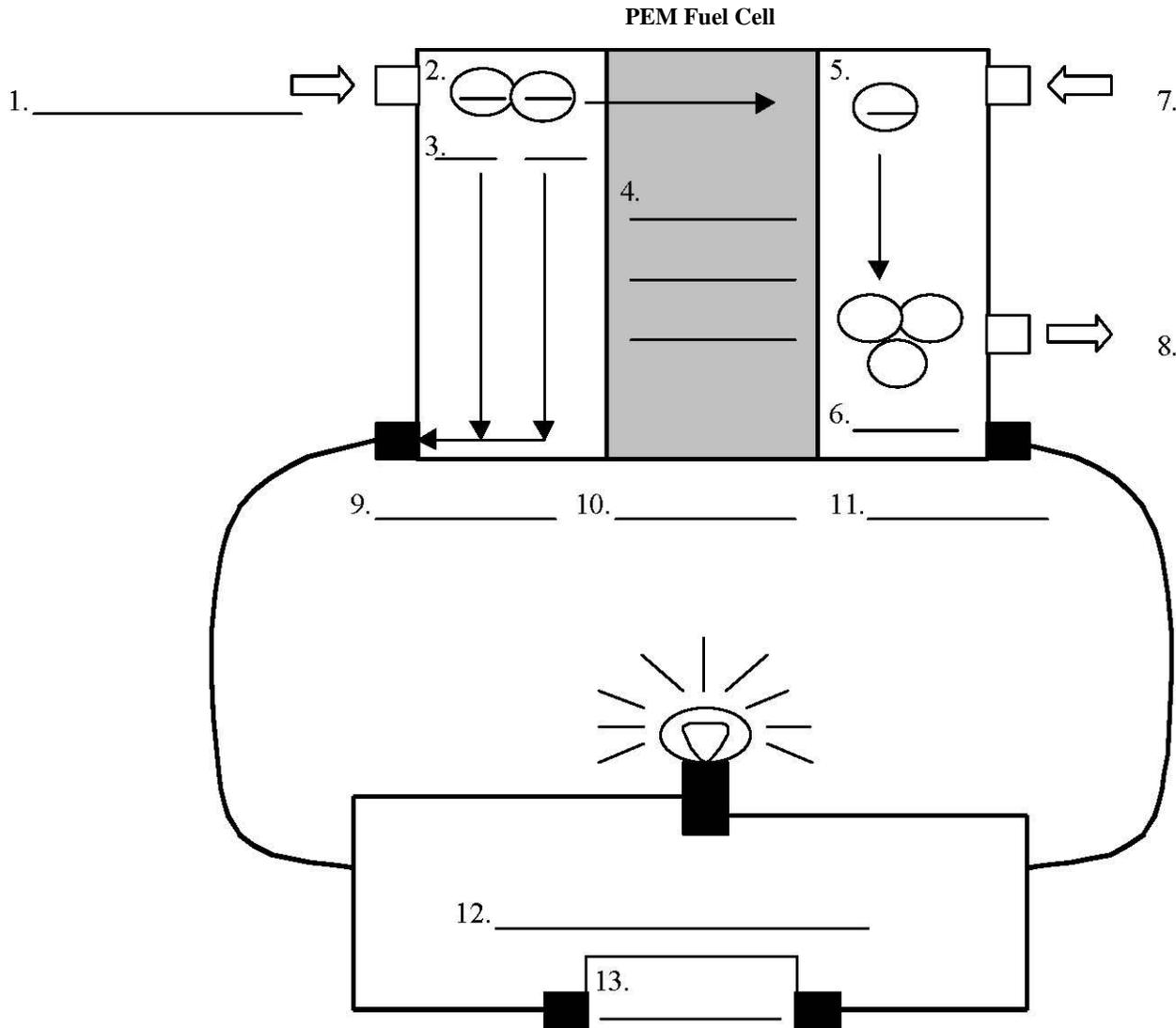


PEM Fuel Cell Student Worksheet

Name: _____

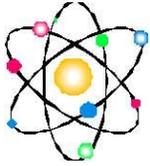
Date: Pd: _____

List the parts of the PEM Fuel Cell in the spaces provided in the illustration.



14. Explain the flow of electrons within this fuel cell example?

15. Explain the benefits of using a fuel cell over other fossil fueled and alternative energy sources?



Simple Electrolysis Experiment

Fuel Cell Preparatory Experiment: Part A

This is an easy experiment that uses basic electrical and common science materials to demonstrate how water (H_2O) can be broken down into separate hydrogen and oxygen elements by applying an electrical current to the water.

Purpose:

To observe that water can be divided into separate components of hydrogen and oxygen gases and associate that hydrogen and oxygen are used as input fuels within a fuel cell.

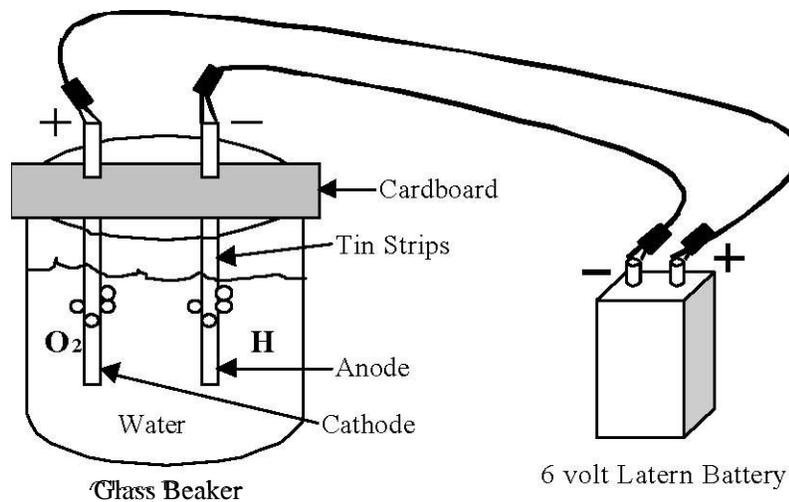
Materials:

1 – (400 – 1000) ml clear beaker
2 – 20 cm or longer test leads (wires) with double-ended alligator clips
1 – 6 volt lantern battery
1 – strip of cardboard
2 – electric conducting tin strips

Set Up:

See the diagram below and assemble the experiment as illustrated

Electrolysis Experiment



Procedure:

- 1 Fill the beaker $\frac{3}{4}$ full with common tap water.
- 2 Cut two small slits into the cardboard. The cardboard will serve as a holder and insulator for the tin strips electrodes.
- 3 Slide the tin strips into the cardboard and place the strips into the water.
- 4 Attach the double ended alligator clipped wires to the battery terminals as illustrated.
- 5 Observe the results after the battery is connected to the tin strips.

Observations:

When the battery is connected to the tin strips, a path for electron flow is completed. The water will conduct the electricity to some degree and also decompose. The decomposition of water can be observed by bubbles forming around the tin strip electrodes. Hydrogen gas bubbles will form around the negative electrode, which is called the anode. Oxygen gas bubbles will form around the positive electrode, which is called the cathode.

Conclusion:

Tap water, while not a good conductor, will transfer electrons within its liquid state. When electricity is passed through the water, it causes it to decompose as witnessed by the formation of oxygen and hydrogen gas bubbles around the anode and cathode electrodes. This is the process of electrolysis. Electrolysis is the production of chemical changes by a passage of an electric current through an electrolyte. The electrolyte in this experiment is the tap water. We applied an electrical current to the water to observe the separation of hydrogen and oxygen elements.

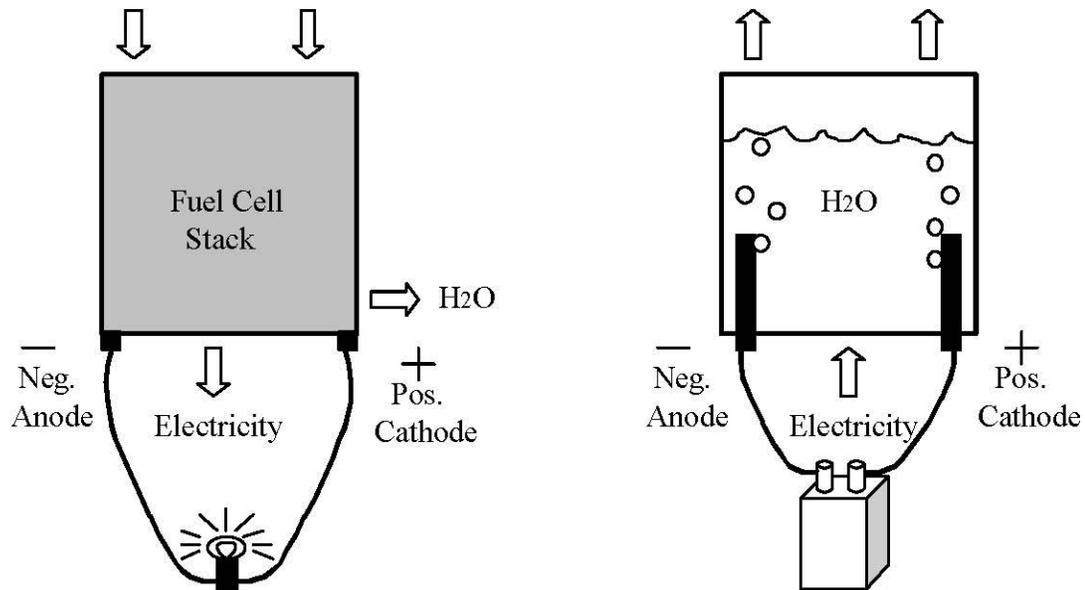
In a fuel cell, a similar but reverse process happens. Separate hydrogen and oxygen elements are supplied to the fuel cell and are combined to create electricity.

Free electrons are formed by the combination of hydrogen and oxygen elements which creates usable electricity to power devices. The electrons then flow back to the cell and join the hydrogen and oxygen to create a stable water molecule. In reality, the rate of combining the oxygen and hydrogen is very rapid which creates many molecules to form water vapor and heat.

Simplified Diagram of Fuel Cell and Experiment

Comparisons Fuel Cell Electrolysis Experiment Hydrogen Oxygen

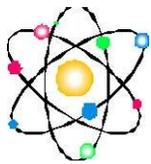
Hydrogen Oxygen



In the **fuel cell**, hydrogen and oxygen are supplied to the fuel cell stack. The elements combine within the fuel cell and in the process produce free electrons. These electrons create the electrical energy which travels from the anode side of the fuel cell, through an electrical circuit to power an electrical device, and returns to the cathode of the cell.

In our **electrolysis experiment**, we created the reverse process of the fuel cell. In this experiment we supplied the electrons from the battery and “energized” the water. The electrical energy caused the chemical composition of the water (H₂O) to decompose into individual oxygen and hydrogen gases. The results of this experiment can be observed by hydrogen bubbles which formed around the anode electrode and oxygen bubbles which formed around the cathode electrode.

Although the processes of the fuel cell and the electrolysis experiment chemically operate in reverse, the electrochemical process and the transfer of electrons flow in a similar manner between the anodes and cathodes. The electrolysis experiment divides water into hydrogen and oxygen components. Whereas the fuel cell combines hydrogen and oxygen to produce electrical energy.



Simple Ionization Experiment

Fuel Cell Preparatory Experiment: Part B

This is an easy experiment that uses basic electrical and common science materials to demonstrate how electricity can flow through an electrolytic solution (saltwater) to complete an electrical circuit.

Purpose:

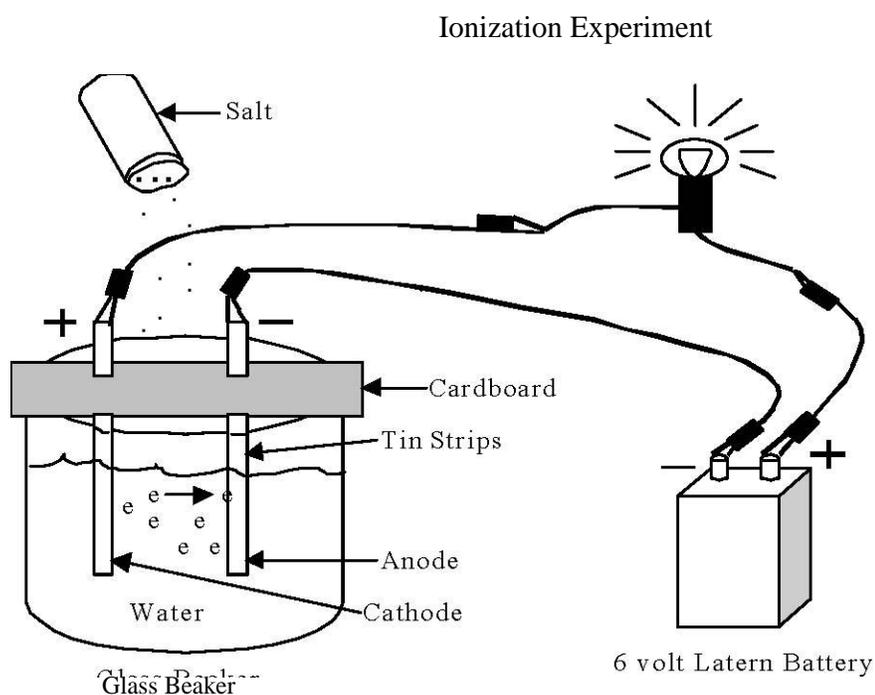
To observe that an electrolyte can complete an electrical path in which free electrons (ions) can flow. When salt is dissolved into water, the ions of the salt can freely conduct electricity. Similarly, the ionization of hydrogen and oxygen is the fundamental chemical process that enables a fuel cell to produce electricity.

Materials:

1 – (400 – 1000) ml clear beaker
3 – 20 cm or longer test leads (wires) with double-ended alligator clips
1 - 6 volt lantern battery
1 – 6 volt incandescent light bulb and bulb holder
1 – strip of cardboard
2 – electric conducting tin strips
1 – container of iodized table salt (approx. 100 grams)

Set Up:

See the diagram below and assemble the experiment as illustrated



Procedure:

1. Fill the beaker $\frac{3}{4}$ full with common tap water.
2. Cut two small slits into the cardboard. The cardboard will serve as a holder and insulator for the tin strips electrodes.
3. Slide the tin strips into the cardboard and place the strips into the water.
4. Attach the double ended alligator clipped wires to the battery terminals and attach the light bulb and holder as illustrated.
5. Slowly pour the table salt into the water. When the concentration increases the light should illuminate. Stirring the saltwater solution will speed up the dilution of salt and create a more thorough electrolytic solution.
6. Observe the result of the experiment. As the salt content in the water increases, the solution becomes more conductive to the electrical current and illuminates the light bulb.

Observations:

When the experiment is assembled, prior to adding the salt, the light does not illuminate. This is due to an absence of conductivity within the water. However when salt is added to the water, the saltwater solution becomes electrically conductive and the light will now illuminate.

Conclusions:

Prior to adding salt to the water, the chemical composition of the water is not a good conductor of electricity therefore the light will not illuminate. The chemical makeup of the salt (Sodium Chloride) contains negative and positive charged ions. When diluted in water the ions are free to move about and transfer electrons. The salt in its solid state will not transfer electrons because the ions are bonded within the crystal. But when the salt is diluted in water the ions are free to move in the solution and can transfer electrons easily. When the electrons from the battery flow into the solution the ions can transfer the electrical energy and complete the circuit. The result of adding salt to the water makes the saltwater solution conductive to electricity which allows electrons flow to pass through it. The conductive solution now becomes part of the electrical circuit and when an electrical current is applied the bulb will illuminate.

In comparing this experiment to the operation of a fuel cell, the fuel cell produces electricity by ionizing hydrogen and oxygen. The atomic structure of the hydrogen and oxygen are changed due to the process of ionization that occurs within the fuel cell. Electrons separate from the hydrogen atoms, which create usable electrical energy to power an electrical device. The electrons flow through the circuit and rejoin the hydrogen and oxygen molecules within the cell to form water. The process of ionization to transfer electrons in this experiment is a simple demonstration of how electrons flow in a chemical solution. Similarly, a fuel cell creates electricity through a chemical means.

Expand your view:

Further Areas of Study

The electrochemical processes that occurs within a dry cell or rechargeable batteries would be good introductory lessons for students understand the chemical creation of electricity. The primary advantage of the fuel cell in comparison to batteries is that fuel cells will continue produce electricity as long as fuel and oxidant are supplied to the cell. Batteries, however, lose their ability to produce power as the chemical reactants are consumed, or discharges within a battery-powered circuit. A variety of applications are being considered for fuel cell technology to replace traditional fossil fueled, polluting power sources. Emphasis is being placed on home electrical distribution (i.e., replacing coal fired power plants) and automobile applications, since the EPA is adopting tighter vehicle emissions standards in the US.

Other interesting activities you may wish to do based on the experiments illustrated in this lesson plan is an experiment in electroplating. Using the materials from electrolysis experiment, you can add salt to the beaker to create an electrolyte and change the metal strips to different metal types. An easy method to use to replace tin strips would be to clip a penny (copper) to the alligator clip leading to the positive terminal (cathode) of battery. Attach a nickel to the (anode) negative side of the battery. When the salt is added to the water, the electrical energy from the battery will flow from the anode side to the cathode side and the ions in the electrolyte will carry the nickel metal particles to the penny. You will be able to observe the penny gaining a silver appearance. You are now witnessing electroplating in the process! If you cannot reproduce this result try moving the coins closer together to stimulate the reaction. A discoloration of the water will also occur.

Teacher Resources

We have compiled a list of web sites and resources that you can further explore for more information about fuel cells.

Fuel Cell Web Sites and Additional Teacher Resources:

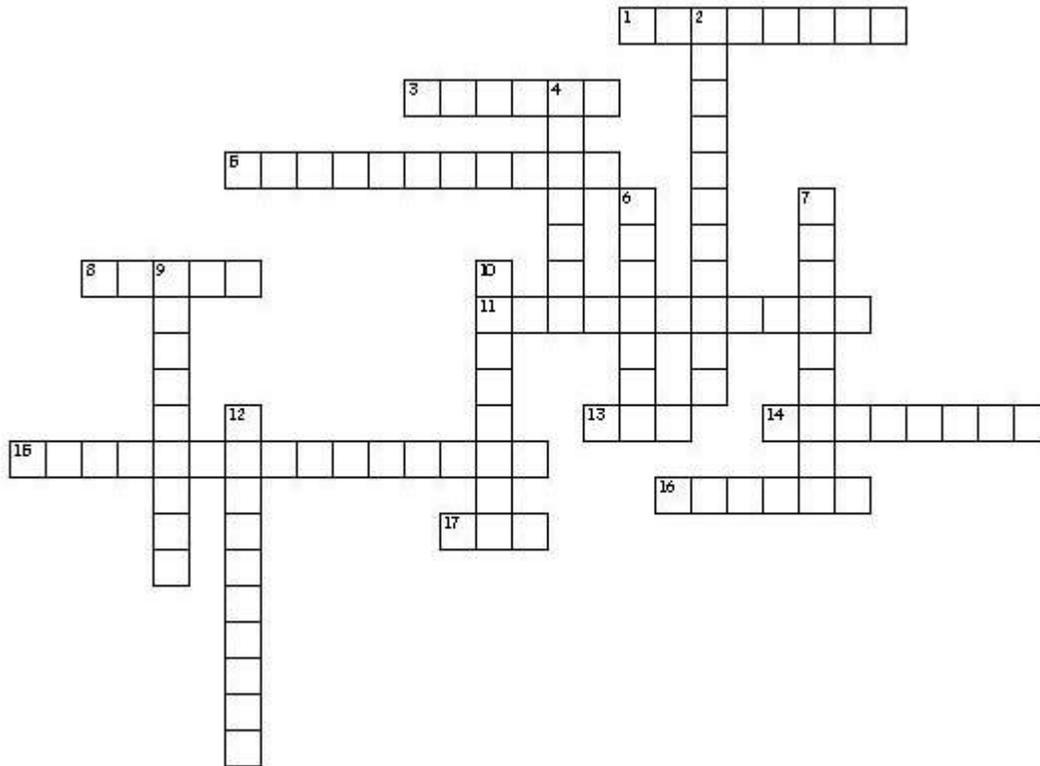
- <http://www.fetc.doe.gov> – Department of Energy-Federal Energy Technology Center
- <http://www.fe.gov> – Department of Energy Fossil Energy
- <http://www.doe.gov/rnd/dbhome> – Department of Energy R&D Project Summaries
- <http://www.dodfuelcell.com> – Department of Defense
- <http://www.anl.gov> – Argonne National Labs
- <http://www.sandia.gov> – Sandia National Labs
- <http://www.ornl.gov> – Oak Ridge National Labs
- <http://www.lanl.gov> – Los Alamos National Labs
- <http://www.Nfcrc.uci.edu> – National Fuel Cell Research Center
- <http://www.fuelcells.org> – Fuel Cell 2000
- <http://www.uscar.org> – US Car
- <http://www.ta.doc.gov/pngv> – Partnership for a New Generation of Vehicles
- <http://www.alliedsignal.com> –Allied Signal
- <http://www.ballard.com> – Ballard Power Systems
- <http://www.fuelcell.com> – ElectroChem, Inc.
- <http://www.ercc.com> – Energy Resource Corporation
- <http://www.hpower.com> – H-Power, Inc.
- <http://www.stc.westinghouse.com> – Siemens Westinghouse S&T Center
- <http://www.infotch.com/avista.htm> – fuel cell education kit you may purchase

Videos about Fuel Cell Technology is available from the Federal Energy Technology Center (FETC) for you to borrow. Contact them at <http://www.fetc.doe.gov>.

A demonstration of a working Proton Exchange Membrane (PEM) Fuel Cell is also available upon request from FETC at <http://www.fetc.doe.gov>.

Crossword Puzzle Name: _____

FUEL CELL



Across

1. method of combining fuel cells to increase voltage output
3. current DC-a stored energy source
5. material between the anode and cathode
8. the negative electrode
11. flow of electrons in a circuit
13. proton exchange membrane
14. chemical fuel flowing through the anode
15. convert chemical energy to electrical energy
16. chemical fuel flowing through the cathode
17. zero emission vehicle

Down

2. current AC-a continuing pulsating force
4. the positive electrode
6. force of energy
7. experimental model
9. change of chemical composition due to exposure to oxygen
10. substance allowing hydrogen and oxygen to pass through
12. process of loss or gain of electrons fo form positive or negative icons

Word Search Name: _____

FUEL CELL

L Q E B X R P H E G A M V N H N
A B L N O I T A D I X O O Y E Z
C B E R C E F O O N L I D G P P
I E C N A N G O N T T R O Q Y T
M A T I T I N O A A O R X A T R
E Z R T H X Z G Z C D W R B O A
H A I Y O Y E I A Y I M F T T R
C G C Z D Z N R H E H I U E O E
O E I I E A B M I O M N E N R V
R K T M V O P N T E X G L X P Z
T X Y L N E J G S T A C K I N G
C D A O M O Y G R E N E R A Z B
E G G C S T E A M H H C P C S T
L I Y W A G E L E C T R O L Y T
E

ANODE	MEMBRANE
CATHODE	OXIDATION
COGENERATION	OXYGEN
ELECTRICITY	PEM
ELECTROCHEMICAL	PROTOTYPE
ELECTROLYTE	STACKING
ENERGY	STEAM
FUEL	VOLTAGE
HYDROCARBON	WATER
HYDROGEN	ZEV
IONIZATION	

22 of 22 words were placed into the uzzle.

Solution



This puzzle was created at www.puzzlemaker.com by Network Solution Developers, Inc.

Name: _____
Period: _____ Date: _____

Fuel Cell Terms Study Sheet

1. A device used to produce electricity through a chemical process and is a self-generating power source is a fuel cell.
2. Oxygen is fed to the positive electrode in the fuel cell called the cathode.
3. Hydrogen is fed to the negative electrode in the fuel cell called the node.
4. Electrical energy is supplied at a steady current is called D.C.
5. The process of losing or gaining electrons to form positive or negative ions is called ionization.
6. Fuel cells are used in experimental models. These models are commonly called prototypes.
7. Electrolyte is a chemical means in the transfer of ions from one medium to another.
8. A measure of potential in an electrical circuit or device is called voltage.
9. Electricity is transferred to homes and institutions via power lines at 60 cycles per second is called alternating current.
10. An anode is the negative electrode in an electrical device.
11. A cathode is the positive electrode in an electrical device.
12. The method of adding fuel cells to increase electrical voltage is called stacking.
13. Electrochemical is the term given to a fuel cell where chemical energy is converted to electrical energy.
14. ZEV is the abbreviation for zero emission vehicle which the EPA hopes to achieve in the near future.
15. PEM is the abbreviation for a hydrogen fuel cell that transfers hydrogen protons to create electricity.

Name: _____

Period: _____ Date: _____

Fuel Cell Vocabulary Quiz

1. A device used to produce electricity through a chemical process and is a self-generating power source is a _____.
2. Oxygen is fed the positive electrode in the fuel cell called the _____.
3. Hydrogen is fed the negative electrode in the fuel cell called the _____.
4. Electrical energy is supplied at a steady current is called _____.
5. The process of losing or gaining electrons to form positive or negative ions is called _____.
6. Fuel cells are used in experimental models. These models are commonly called _____.
7. _____ is chemical means in the transfer of ions from one medium to another.
8. A measure of potential in an electrical circuit or device is called _____.
9. Electricity is transferred to homes and institutions via power lines at 60 cycles per second is called _____.
10. An anode is the _____ electrode in an electrical device.
11. A cathode is the _____ electrode in an electrical device.
12. The method of adding fuel cells to increase electrical voltage is called _____.
13. _____ is the term given to a fuel cell where chemical energy is converted to electrical energy.
14. _____ is the abbreviation for zero emission vehicle which the EPA hopes to achieve in the near future.
15. _____ is the abbreviation for a hydrogen fuel cell that transfers hydrogen protons to create electricity.