ALTERNATIVE ENERGY
- FUEL CELLS -
STUDENT INFORMATION

Area of Study: Energy and Power

Objectives:

The student will investigate the relationship between current, voltage, and resistance within an electrical circuit. Students will build a circuit with a fuel cell to power an electric motor on a model car.

A hydrogen powered vehicle is fueled at a hydrogen refueling station.
- Photo courtesy of the Hydrogen Association -

Related Occupations:

Chemical Engineers

Chemical engineers apply chemical, mathematical, and scientific concepts to develop solutions to technical problems. Chemical engineers may work in research and design, testing, production, or maintenance of a product. Some chemical engineers may work in a particular field such as health care or they may concentrate on a particular chemical process such as electrolysis.

Chemists and Materials Scientists

Chemists and materials scientists study and develop new materials to improve existing products or make new ones. Research into chemicals has led to the development of improved drugs, glues, lubricants, paints, and improved oil refining. Materials scientist study applications of computer chips, graphite materials, fuel cells, and super conducting materials. Chemical and material scientists use computers and other sophisticated laboratory instruments in their job.

Natural Sciences Managers

Natural Science Managers supervise people such as biologists, chemists, geologists, or mathematicians in research and development projects and coordinate activities such as testing, quality control, and production. All managers must be specialists in the work they supervise.

Key Words and Definitions

1. **Anode** - the negative side of an electronic part.

2. **Catalyst** - a substance that alters the speed of a chemical reaction, but remains after the reaction and is not changed by the reaction itself.

ALTERNATIVE ENERGY - FUEL CELLS
Occupational Choices
Focus: Chemical Engineer

Enroll in these classes:

- Math
- Biology
- Chemistry
- Physics
- English
- Technology

After High School:

A Bachelor's degree in engineering is required. Typically this can take up to 5 years at a college or university. The first 2 years are spent on studying math, science, humanities, and general course work. The last 3 years typically lean more toward courses in engineering with a concentration of classes in chemical engineering. Some universities offer a general engineering degree and then the engineer specializes on the job or in graduate school. Engineers who graduate from an accredited program, have 4 years of work experience, and successful completion of a state exam receive the required license and are know as Professional Engineers.

Earnings:

In 2011, people employed as Chemical Engineers nationally had a median of ***salary*** of **$92,900.**

In 2011, the median wage of Chemical Engineers in Utah was lower coming in at **$87,700.**

In 2011, yearly earnings ranged nationally from **$59,400 to $146,600.** Earnings vary by experience and location.

The Work:

Engineers are employed in every state, in rural areas, as well as cities of every size. Chemical engineers may work in research and design, testing, production, or maintenance of a product. Most chemical engineers work in office buildings, laboratories, or industrial plants. Some chemical engineers may spend time outdoors at production sites, where they monitor or direct operations. Many chemical engineers work a standard 40 hour week.

Employment Opportunities

- Chemical companies
- Drug companies
- Federal government
- Scientific research & development

Personal Characteristics

- Analytical
- Creative
- Detail Oriented
- Good Communications skills
- Inquisitive
- Ability to read and write technical reports
- Must work in team situations

Source: Occupational Outlook Handbook 2012 -2013 Edition & Career One Stop

3. **Cathode** - the positive side of an electronic part.

4. **Circuit** - the complete path of an electric current including the source of electric energy.

5. **Distilled Water** - water which has been made into a vapor by boiling and then condensed into pure water so that minerals or any suspended particles are eliminated from the water.

6. **Electron** - a component of an atom. When an atom is in a state with excess electrons, the excess electrons leave the atom causing electricity to flow. Electrons have a negative electrical charge.

7. **Electrolysis** - when electricity is used to break-down a chemical compound into it's basic components.

8. **Energy** - the ability to do work.

9. **Fossil Fuels** - fuels (i.e., coal, oil, or natural gas) formed in the earth from plant remains. These fuels are finite (will eventually be used up).

10. **Fuel Cell** - a device that uses chemicals to create electricity.

11. **Power** - the amount of work done.[1]

12. **Renewable Energy** -Energy that comes from natural sources that can be replaced, such as sunlight, hydropower (water falling through a dam which turns a generator), wind power (wind turning a turbine which turns a generator) and managed forests (wood).

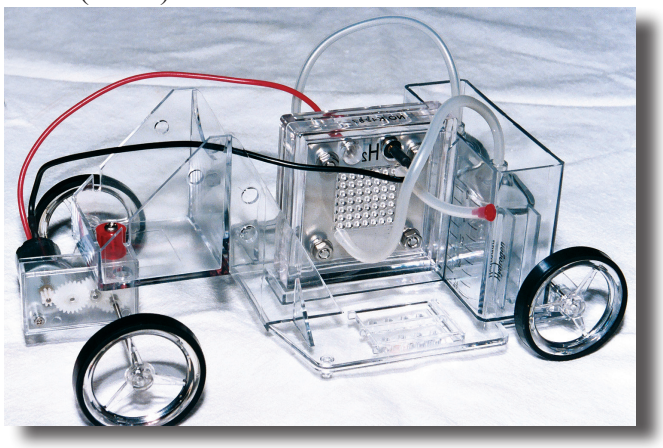
Materials Needed:

•Thames & Kosmos Fuel Cell X7 - Hydrogen powered car

•Towel •Distilled Water

•Stop Watch •Measuring Cup

•PBS DVD - "NOVA - Car of the Future"



Fuel Cell X7 - Hydrogen powered car.
Mike Breen Photo

Energy and Power:

Energy is the ability to do work. Energy comes in many different forms. Whether a light switch is turned on or a family takes a drive in a car, energy is being used. To use energy it must be able to be controlled. In either example, energy is being controlled.

Power is the amount of work done during the use of the controlled energy. It is a measurement of how much energy was used in accomplishing a certain task.

1 *Thode. B., Thode T.,*

In today's world, mention of the word "energy" and most people refer to gasoline, natural gas, heating oil, coal, and electricity. Gasoline, which is refined from oil, is used for transportation; while natural gas, heating oil, and coal are used to heat homes and produce electricity.

Petroleum refinery in Commerce City, CO
- DOE/NREL - David Parsons Photo

Fuels:

The fuels that are used for energy are classified as either fossil fuels or renewable fuels. **Fossil fuels** are fuels that are finite and will eventually be used up. Examples of fossil fuels are oil, coal and natural gas. Fossil fuels are the remains of plants that grew millions of years ago. The plants absorbed carbon dioxide from the atmosphere as part of photosynthesis. The plants eventually died and over time were buried in the soil, and the carbon dioxide in the plant was withdrawn from the atmosphere.

Fossil fuels that are used for energy today, release the carbon dioxide from millions of years ago back into the atmosphere. Burning fossil fuels for energy is a human activity that contributes to climate change. This climate change has also been called "global warming."

There is debate about how soon the world will run out of fossil fuels. For example, it may be between 20 and a 200 years before the world's supply of oil is used up. One thing is for sure, at the world's present rate of consumption, and a limited supply, the price of oil and gasoline will eventually be more expensive.

Recently, more notice has been given to renewable fuels as fossil fuel prices become more expensive and emissions have become more of an issue. **Renewable fuels** are those that can be managed or will not be used up. Examples of renewable fuels are: Biomass (i.e. managed forests, crops, alcohol fuels, garbage), hydroelectric power (i.e. dams with electrical generators), geothermal (i.e. energy from heat underground), wind power, and solar power (i.e. energy from the sun).

Many of the renewable fuels are used to produce electricity for our homes. Renewable fuels are now being thought about in other ways. One of the interesting prospects is using an alternative energy source to power a vehicle. When cars were first becoming a means of transportation, a major competitor with gasoline and the internal combustion engine were several all electric vehicles. Electric vehicles at the time, had the problem of a lack of battery capacity and gasoline powered vehicles became the standard vehicle used for transportation.

Today, with alternative fuels, other competitors are emerging. Another fuel source used with the internal combustion engine are bio-fuels. These fuel sources come from plants, and are currently on the market as bio-diesel and ethanol. While these fuels might do much to diversify the fuel market and give consumers choice; it is believed that this type of product alone can not solve this countries' oil dependence. Enough of these products can not be made to take the place of oil.

Several types of fuels will be needed as alternative sources of energy as oil supplies become smaller and gas gets more expensive.

Another possible solution that automobile manufactures have been investigating uses an internal combustion engine that burns hydrogen instead of gasoline even though the internal combustion engine is not very efficient as much of it's energy is turned into heat, vibration, and noise.

Electric Vehicles:

Many experts believe that the wave of the future will be the original competitor to the internal combustion engine which was the electric vehicle. Many of these vehicles currently have to be plugged in at night to recharge their batteries. This in of itself would use fossil fuels in the U.S. as over half of the electricity produced in the United States comes from burning coal.

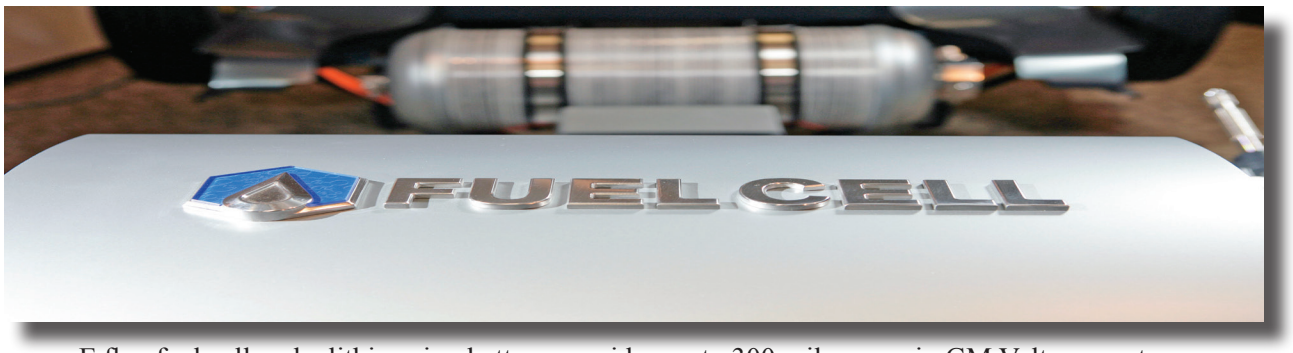
Another promising solution in vehicles is using a battery and a fuel cell. With a fuel cell, hydrogen can be converted into an electric current without combustion. A car with a fuel cell would not necessarily need to be plugged in at night to charge the electric batteries in the car. The fuel cell would keep the batteries charged.

Fuel Cells:

A fuel cell is a device that uses chemicals to create **electricity**. Think of a fuel cell as an energy source like a battery. However, a battery and a fuel cell work a little bit differently. A battery stores electrical energy, while a fuel cell produces electricity continuously as long as an external fuel source is supplied to it. They have been used for many years as a means of power. NASA uses fuel cells in all manned space craft and in some satellites. Bloom Energy currently produces the "Bloom Box." It is a stand alone solid oxide fuel cell (SOFC) power plant that has been installed and is a power source for "Google's corporate headquarters, and has also been installed as power sources for customers such as Adobe, ATT, Bank of America, EBay, Fed Ex, Staples, and The Coca-Cola Company. In Utah, fuel cell"Bloom Boxes" will soon be powering EBay in Salt Lake City[2]

There are many types of fuel cells which use different chemicals to generate electricity. However, the one that most auto makers are experimenting with functions using a proton-exchange membrane or PEM. It uses common elements, hydrogen and oxygen to promote a chemical reaction.

An electric car operating with a fuel cell would have few emissions other than **water and heat.** No harmful emissions would do much to mitigate the effects of pollution from vehicles

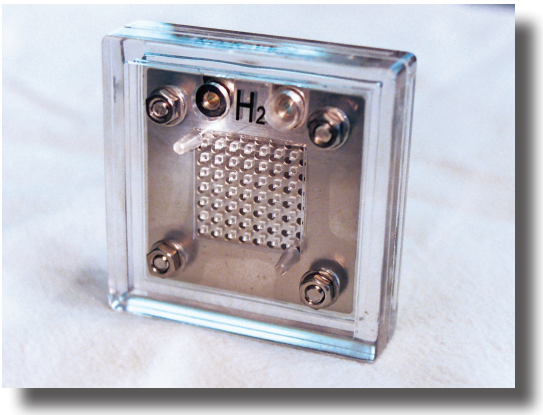


E flex fuel cell and a lithium-ion battery provides up to 300 mile range in GM Volt concept car

2 *Bloom Energy*

Electrical Systems:

The creation of electricity requires a system of power sources, paths for the electricity to follow, and devices to make use of the electricity. A system is an organized procedure for doing something which will include four parts. These parts are the input (activities and ideas that go into a system), processes (actions to produce electricity), output (use of electricity or emissions), and feedback (adjustments to the use). Generating electricity using a fuel cell will also use this organized procedure.



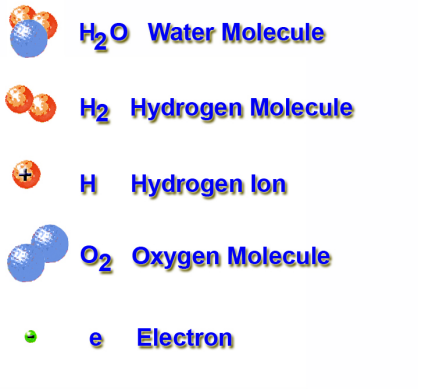
A proton-exchange membrane fuel cell
Mike Breen Photo

Fuel Cells at Work:

Input

A fuel cell system has to have a stored energy source. In the case of the PEM fuel cell, it would be hydrogen. In a fuel cell vehicle, there would be a hydrogen tank that would need to be filled periodically with hydrogen just like you would fill the gas tank in a petroleum fueled vehicle.

The hydrogen is the "gas" but unlike gasoline it is a carrier of energy. To understand this statement a closer look at hydrogen is needed. Hydrogen is one of the most abundant elements of the earth. Elements can be broken down into smaller particles called molecules, and molecules consists of smaller components called atoms. The hydrogen molecule consists of two atoms of hydrogen formed together as shown in figure 1. The hydrogen atom within a molecule, consists of a single charged proton and a negatively charged electron. A single hydrogen atom that has been broken down from the molecule is called an ion because it has a positive electrical charge (It is the proton). When a hydrogen molecule is broken down to a hydrogen ion, then it has to give up it's electron. This movement of electrons is needed to create electricity, and this is why hydrogen is a carrier of energy.



In a PEM fuel cell, hydrogen transports electrons that can be harnessed by the fuel cell.
Figure 1

The fuel cell also needs access to air. The air contains oxygen which is also an element of the earth. It also is a molecule with protons and electrons.

Processes

A PEM fuel cell is made up of three basic parts. These parts are the **anode, cathode and the proton-exchange membrane (PEM).** The PEM is sandwiched between the anode and cathode as shown in figure 2.

- The anode is on the negative side of the fuel cell. On this side of a fuel cell, hydrogen molecules come from the fuel tank to the anode. This splits the hydrogen into negatively charged electrons and positively charged hydrogen ions (protons) with the help of a catalyst of platinum.

- The proton-exchange membrane (PEM) keeps the gasses apart and separates the two sides of the fuel cell. This membrane allows only the smaller hydrogen ions (protons) to pass through it to

the cathode. It also keeps the electrons from the anode from passing through it. As the electrons try to flow to the cathode, they are forced on an external circuit which creates an electrical current. The electrons can then be used as they travel on this circuit to power and electrical load such as an electrical motor.

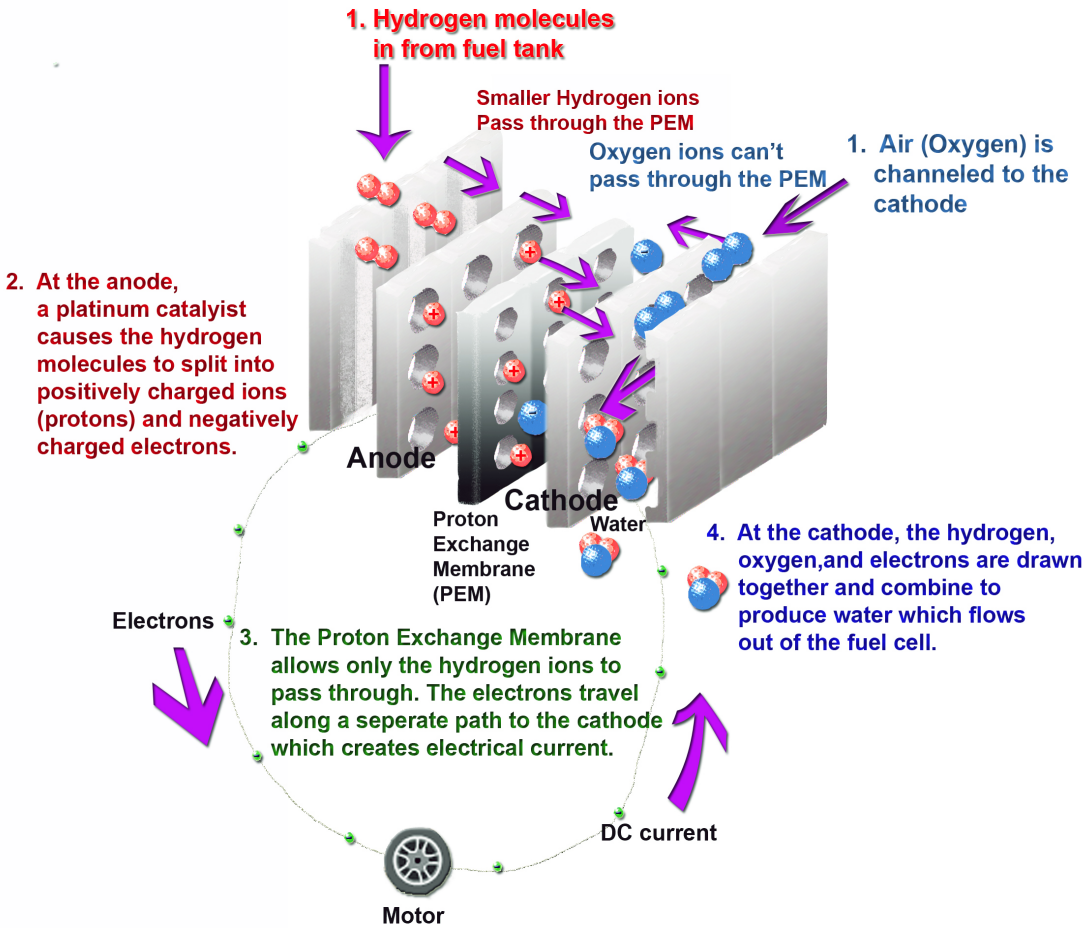
- On the cathode side, the electrons that have been traveling in the external circuit and the hydrogen ions (protons) arrive and are combined with oxygen from the air. This combination forms water molecules or H_2O which flows out of the cell.

Output

Water, electricity, and heat are the output from a fuel cell. However, the amount of electricity generated from one fuel cell is not enough to power an automobile. To actually power a electric vehicle it takes more than one fuel cell. Engineers have devised a way to group fuel cells to create the amount of electricity needed, and this connected group of fuel cells is called a fuel cell stack. A stack about the size of a suitcase is all that is needed to power a vehicle.

Feedback

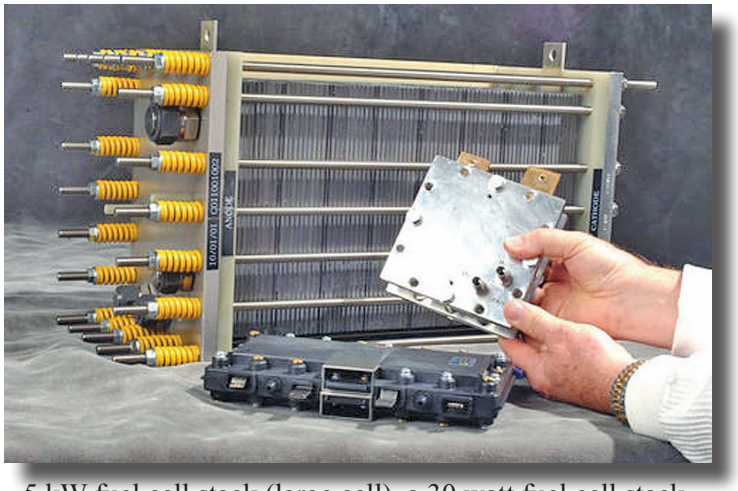
Just like an internal combustion engine, the operator would have gauges like a fuel gauge to determine if they needed to pull over to fuel up. Most fuel cell cars are being made with a battery back-up system. The operator would also know by gauges and indicator warnings in the car if the battery was not charging.



A typical proton-exchange membrane (PEM) fuel cell.

Figure 2

Electrolysis:



5 kW fuel cell stack (large cell), a 30 watt fuel cell stack, and a 25 watt fuel cell (three cell stack /smaller silver cell).
DOE/NREL Matt Stiveson Photo

As was previously stated, water is made up of molecules of oxygen and hydrogen. Often, applying energy to a molecule can break it apart. Water, called H_2O when referred to by it's elements, can be broken down to simpler units when electricity is added. This process is called electrolysis and is what occurred in Activity A. Electrolysis can be done without a fuel cell, but some fuel cells are reversible. In other words, once you have created water from a fuel cell, the water can be used to create the energy carrier hydrogen to produce electricity all over again. Fuel cells used on manned space missions are the source of water for the astronauts. In outer space, they are used to create drinking water, and electricity.

A reversible fuel cell on a car would not be able to produce enough hydrogen fast enough through electrolysis. It would also need space to store a lot of water. This would take too much room, and both processes (electrolysis and using the hydrogen for fuel) can not go on at once. A hydrogen fueling station would be needed for a fuel cell car. Hydrogen can be extracted through electrolysis, but also through thousands of compounds like, natural gas, sugar, and gas, sugar, and petroleum. Scientists are currently working to make the process of electrolysis more efficient.

Advantages Of Fuel Cells

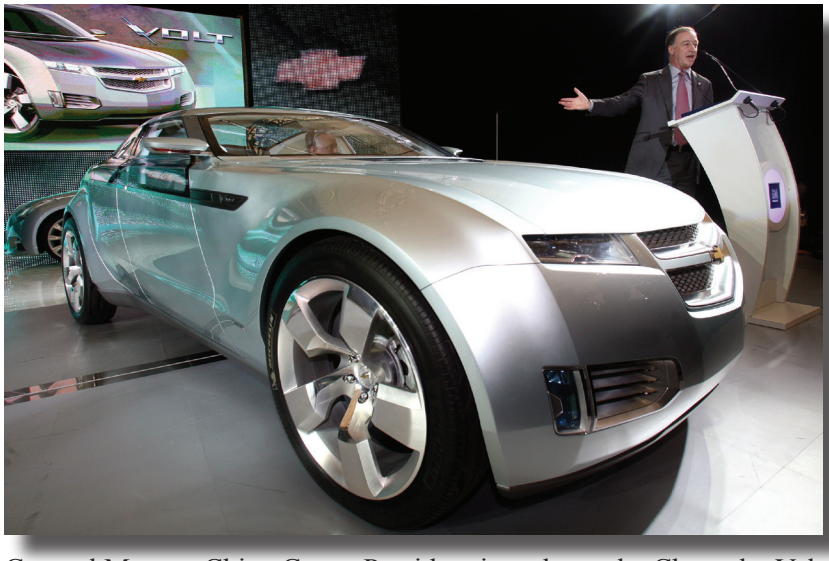
- Fuel cells can have a big positive impact on the environment as the basic emissions from a hydrogen fuel cell are water and heat. Other types of fuel cells may have other emissions.
- Fuel cells run silently cutting down on noise pollution.
- Hydrogen fuel cells have no moving parts and don't require any oil for lubrication.
- It is very reliable technology
- Hydrogen fuel cell vehicles are as safe or safer than conventional gasoline vehicles.[3]
- Fuel cells can be adapted for any electrical needs.

A Honda fuel cell car at a hydrogen fueling station that uses electrolysis to produce the hydrogen. It uses the solar panels on the ground behind the car as a means to create the electricity.
- Photo courtesy of the Hydrogen Association -

Disadvantages of Fuel Cells:

- At this time, fuel cell vehicles

3 *Office of Energy Efficiency*



General Motors China Group President introduces the Chevrolet Volt Fuel Cell concept on Friday, April 20, 2007 in Shanghai, China.
© GM Corp. - Natalie Behring Photo

are not available to most people. Fuel cell vehicles may be leased at this time only in certain parts of the USA.

- Currently, fuel cell vehicles are too expensive for most people to buy outright.

- The hydrogen **infrastructure** is not in place. Hydrogen fuel stations are not in place in most parts of the country.

- Freezing conditions have been a problem. Most fuel cells don't start instantly in cold weather as they have to warm up.

Impacts:

The creation of electricity with a fuel cell has had major impacts on everyday life, but the potential is there for even greater impact. Fuel cells used in space travel are a necessity as it produces water as well as electricity. In this one way, fuel cells have been a catalyst for allowing the manned exploration of our universe. Even though fuel cells were used by a very few astronauts, this in itself has impacted many lives as the development of items related to space travel has created many spin-off products that have become part of human life; (Velcro, cordless power tools etc.) and the missions to space have expanded human knowledge.

Fuel cells could have even greater positive impacts if used as means of power in cars. Twenty-five percent of all carbon emissions come from cars and light trucks.[4] It would also reduce this countries dependence on oil and help to lower the demand and consequently the cost of oil. If a renewable way of producing hydrogen is used in the production of hydrogen for fueling stations, it would help to curtail the effects of global warming from greenhouse gases.

The Future:

Fuel cells could be used as a "power plant" to generate electricity, power portable electrical devices, and for transportation. Experimental trains, boats, buses, and automobiles are now being tested in the transportation area.

In the immediate future, a limited production hybrid fuel cell car is here. Honda has a fuel cell vehicle that may be leased for use in Southern California called the FCX Clarity. It has a range of 270 miles per tank, the hydrogen equivalent of 74 miles to the gallon, and has capabilities of 100 mph. The FCX Clarity is two times more energy efficient than a gas-electric hybrid and three times that of an internal combustion automobile.[5] Honda's rivals Toyota, and General Motors have models in different stages of development. Fuel Cell Electric Vehicle (FCEVs) are to be introduced for commercial use by all major automakers by 2015.[6] Gas-electric hybrids are paving the way for consumers to get used to the hybrid car. Fuel Cell vehicles may be in your future by the year 2025.

4 *Seamans, J. , Smith, J. D. , Ritsko, A., & Apsell, P. S.*

5 *Omaha World-Herald*

6 *Moncayo, J & Dolan, C.*

The Honda FCX Clarity is available for lease in California.
- Photo courtesy of the Hydrogen Association -

There has to be a perceived need for people to want a product. Although fuel cell vehicles are not available to most drivers today, if production costs come down as the technology matures, (they have fallen by 80% since 2002) [7] the price of gasoline continues to climb, and if consumers continue to worry about global warming, fuel cells may very well become a reality in transportation. Currently, traveling across America in a hydrogen fuel cell car would be impossible. It will take years for hydrogen stations to be built along traveling corridors. Consumer demand and government policies will determine if fuel cells are adapted over time in this country.

Day 1 / Activity B:

Watch the DVD "NOVA: Car of the Future" (Watch only Chapter 3 - "Rush hour in Reykjavik" -segment - 10:51 - 17:55) and answer the questions to activity B of your worksheet.

Day 2 / Activity C:

The experiment will be repeated 3 times. Each time you repeat the experiment it will take about 15 minutes to complete. Make sure you have time to complete the activity before going on and have read the safety precautions.

Safety Precautions:

! Note: **Eye Protection -** is required before starting.

! Note: **Explosion -** Hydrogen is flammable. Avoid open fire.

! Note: **Shock -** Only use the components that came with the kit. The connected voltage must never exceed 3 volts.

! Note: Contamination - Use distilled water / Do not put your hands in the water.

Creating Hydrogen:

Before starting the process of electrolysis, the fuel tank at the back of the car needs to be filled with distilled water, almost to the top.

Filling the Electrolyzer:

(Note: The distilled water may be filled by a teacher's assistant.)

7 *Moncayo, J & Dolan, C.*

1. Obtain the model car kit, the measuring cup, and distilled water (If a 2.5 gallon distilled water container is used, have the tank filled at the station by the teacher or teacher's assistant).

2. Pour distilled water from the storage container into the measuring cup as shown in figure 1.

3. Use the measuring cup to fill the "fuel tank" almost to the top.

4. On the fuel cell remove the red plug from the tube on a side of the fuel cell.

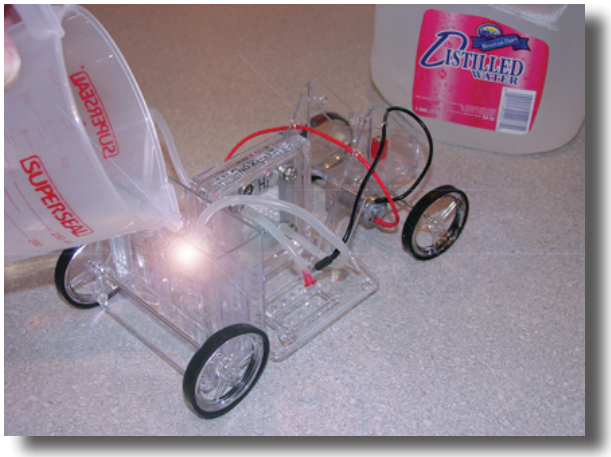
5. After removing the red plug, connect the syringe by inserting the syringe tip to the open end of the tube on the fuel cell.

6. Slowly remove the air from the fuel cell and fill with distilled water by drawing back the syringe as illustrated in figure 2. Water will be drawn up into the fuel cell. Once you have a steady flow of distilled water with no air bubbles, stop pulling on the syringe. Draw the water through slowly as this will minimize the air bubbles.

7. Now pinch the short tube tightly with your fingers and remove the syringe from the tube.

8. Without letting go of the tube, reinsert the red plug back into the tube as shown in figure 3. It may help to have a partner help with this step.

9. Repeat steps 4 - 8 for the other side of the fuel cell. Both sides of the fuel cell must be done.



The fuel tank is filled with distilled water.
Mike Breen Photo
Figure 1

1. Remove the red plug. 2. Hook up the syringe. 3. Draw into the fuel cell distilled water.
Mike Breen Photo
Figure 2

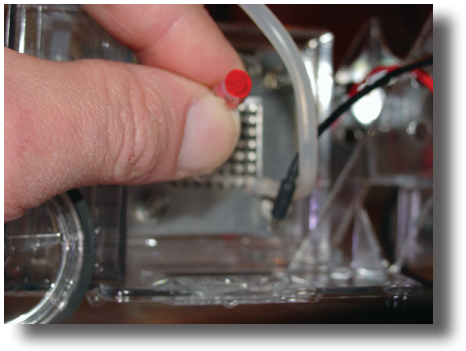
10. Extra distilled water in the syringe can be shot into the measuring cup and used later in the period.

Electrolysis:

Now a electrical current will be supplied to split the water into hydrogen and oxygen. The electrical current will be supplied by two AA batteries.

1. Plug the red battery wire into the red socket on the oxygen side of the fuel cell. Plug the black battery wire into the black socket on the hydrogen side of the fuel cell. Make sure the connectors are connected red to red and black to black.

Immediately after connecting the battery, electrolysis will begin. Gas bubbles will be observed forming in the tubes and

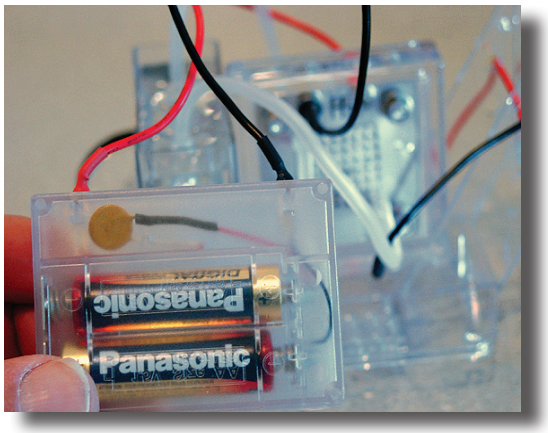


Pinch the tube and reinsert the red plug once the syringe is removed.
Mike Breen Photo
Figure 3

then in the gas collector tanks. After a few minutes, the tanks should be completely full.

2. As soon as the tanks are full of gas, disconnect the battery holder from the fuel cell.

Having completed the electrolysis process to make hydrogen, a supply of energy ready to use. The hydrogen gas is now in the inner tank. Be careful when following directions for this next step as the distilled water can now spill out of the upper part of the storage containers.



The battery holder plugged in to the fuel cell during the process of electrolysis.
Mike Breen Photo
Figure 4

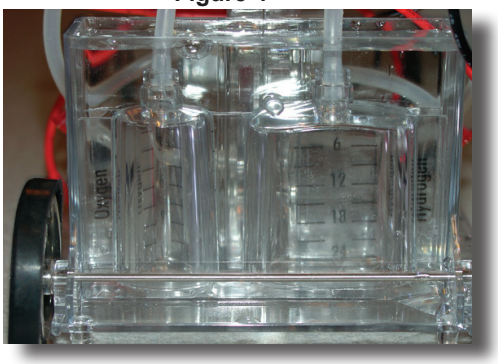
Chemical Power:

1. Place the car on the floor without spilling water, and turn the wheels slightly so that the car will run in a circle. Find a spot on the floor big enough that the car can travel in a circle (about 4 feet). The car will not run well on carpet.

2. Have a stop watch ready and set to zero as you will time how long the car runs.

3. Connect the patch cords to the fuel cell. Make sure the connectors are connected red to red and black to black. Set the car down and watch it go at the same time start the stopwatch.

4. Record the time on your worksheet.

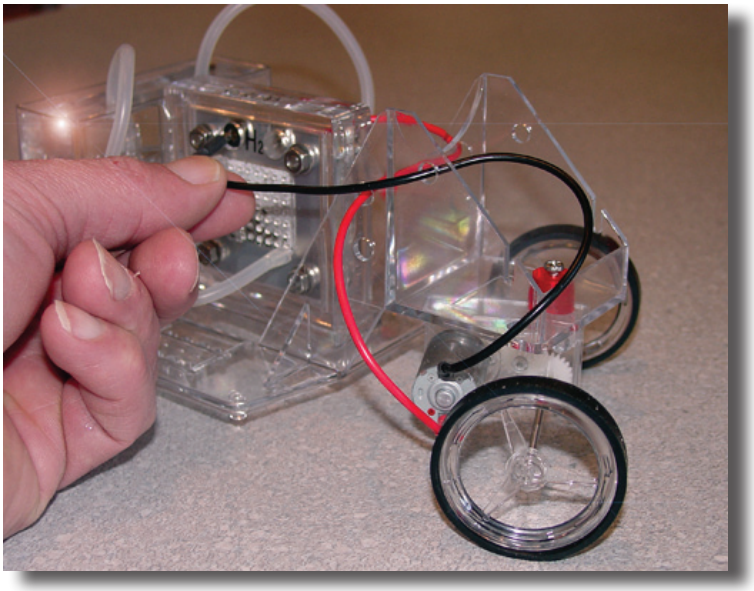


The process of Electrolysis can be observed as the water levels in the inner tanks go down and fill with hydrogen and oxygen, the water in the outer tanks go up.
Mike Breen Photo
Figure 5

5. Start the process over again. Perform the filling of the electrolyzer, electrolysis, and the chemical power headings again as illustrated on pages 11 - 12.

Once the experiment has been performed 3 times, figure the average by adding up the times and dividing by 3 with the provided calculator. Round the final answer to the hundredths place. The purpose of doing the experiment three times is to get a more accurate representation of how the fuel cell is performing.

Empty any water that is in the top of the fuel cell storage cylinders into the sink or an available garbage can. Put materials back into the storage box, and return them to where your teacher has directed previously. Turn your worksheets in for credit.



The motor being connected to the fuel cell by using patch cords.
Mike Breen Photo
Figure 6

ALTERNATIVE ENERGY
- FUEL CELLS -
STUDENT WORKSHEET

Name: _____ Period: _____ Date: _____

Directions: In the blank on the left, write the correct answer to the statement or question.

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1. _____ _____ is when electricity is used to break-down a chemical compound into it's basic components.

2. _____ _____ fuels are fuels that are finite and will eventually be used up.

3. _____ _____ fuels are those that can be managed or will not be used up.

4. _____ A fuel cell is a device that uses chemicals to create _____.

5. _____ An electric car operating with a hydrogen fuel cell would have few emissions other than _____ and heat.

6. _____ The _____, _____, and _____, make up a hydrogen fuel cells' three basic parts.

   _____

   _____

7. _____ One of the disadvantages of fuel cell technology is that the _____ _____ is not in place. This means that there are few hydrogen fueling stations.

Activity B: DVD - "NOVA: *Car of the Future" (Chapter 3 - "Rush hour in Reykjavik"*
segment 10:51 - 17:55 - 7 minutes)

8. _____ What vehicles were powered by fuel cells in this country?

9. _____ This country plans to use an alternative energy to produce hydrogen. This energy source is being developed in the country-side and comes from the ground. It is known as ____ energy.

Day 2:

10. _____ Average on 24 mil of hydrogen?	**Time Trial 1**	**Time Trial 2**	**Time Trial 3**
	10a.	10b.	10c.