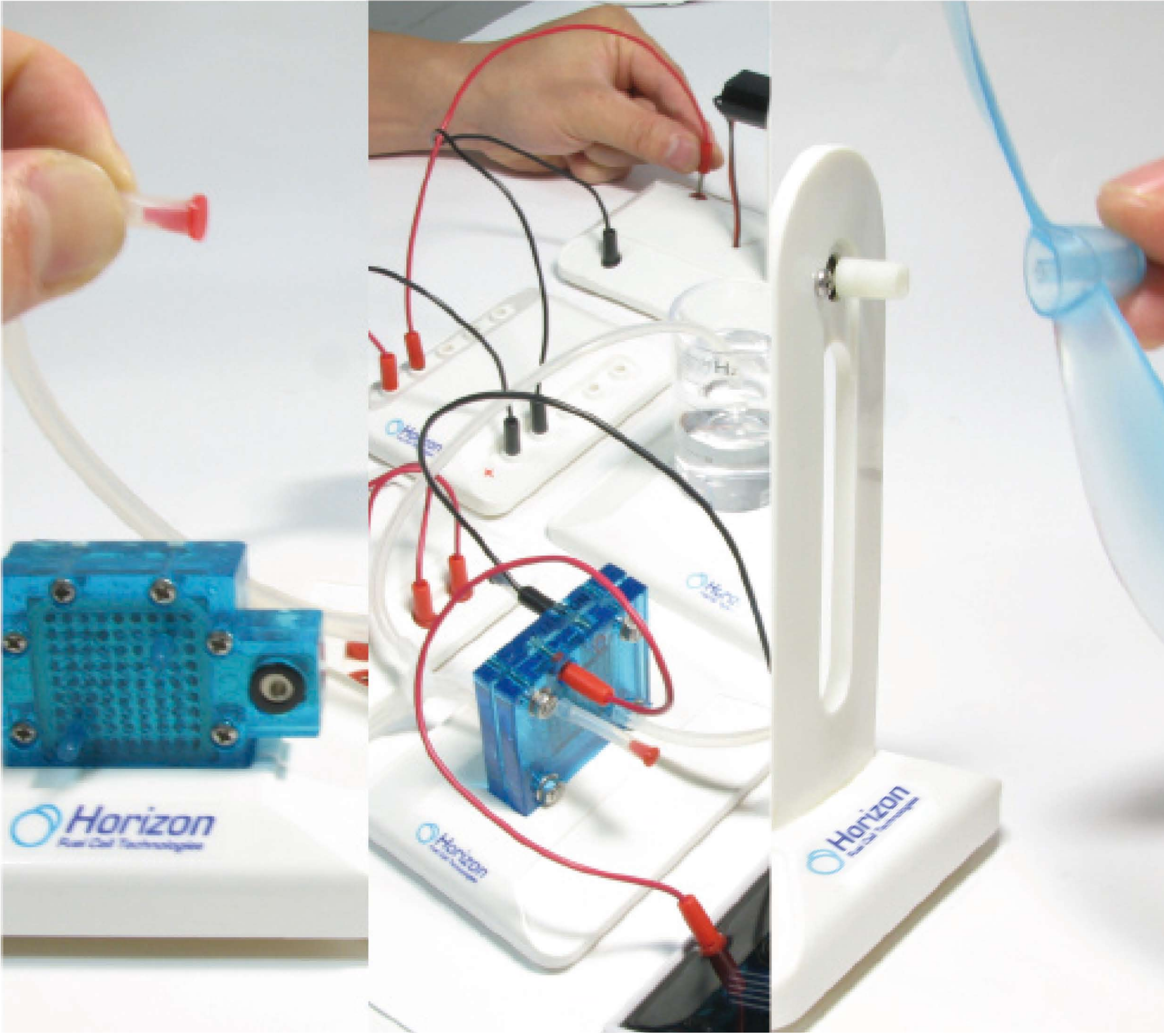

Horizon
Renewable Energy Education Experiment Manual

Horizon
Fuel Cell Technologies

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Experiment Manual

Contents

Introduction

Renewable Energy
Science Education Set

The Horizon Renewable Energy Science Education Set provides for interesting experiments with fuel cells, solar panels and wind turbines. In addition, other electrical components such as resistors, LEDs motors and propellers are used as "loads" for these devices. If you are unsure about the term "load" or what a resistor or LED really is and does, refer to the "**Electrical Components and Circuits**" section of this manual where you will find a host of useful information on basic electricity concepts and the components used in the experiments.

The experiments are sub-divided into functional sections that cover solar panels, stationary fuel cells, a wind turbine and fuel cell car experiments. You don't have to perform the experiments in any particular order, so feel free to skip around from one to the other as you and your students see fit.

In addition to the standard experiments there are some Ultra Cool ones that provide even more excitement and desire to learn on the part of students. Learning math and science using renewable energy will inspire your students to greater goals and achievements.

Adding More Depth to the Experiments

Each experiment follows a similar outline that not only provides a mechanism for easy performance and an understanding of what to do, it also gives your students the opportunity to expand on the experiment by posing "What If" questions on the experiment just performed. For example:

***What if* - you changed the tilt angle of the solar panel? Will it make any difference in the voltage, current and power outputs?**
***What if* - a wind turbine had longer blades? Will it generate more or less power compared to a wind turbine with shorter blades?**
***What if* - a fuel cell used pure oxygen instead of plain air? Will it generate more power when it mixed with pure hydrogen?**

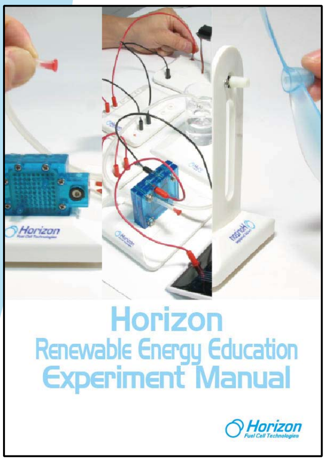
These and other practical and hypothetical questions are posed for each experiment. There are also related research questions that give students the opportunity to go beyond the experimental procedures to discover more about the renewable energy technologies they are studying.

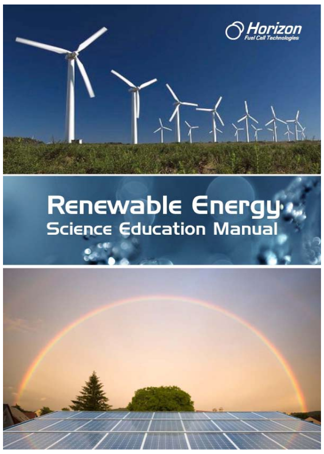
Supporting Information

The experiments are supported by additional information found in the accompanying publication "Renewable Energy Science Education Manual" that provides an exceptionally rich amount of data, photos and illustrations on the following topics:

Chapter 1: The Environment and Climate Change
Chapter 2: Solar Energy
Chapter 3: Wind Energy
Chapter 4: Electrolyzers
Chapter 5: Fuel Cells
Chapter 6: Hydrogen Storage & Transportation
Chapter 7: Basic Power Electronics

Cross reference is made between the two publications to give you and your students more complete background on the experimental processes along with sources for more research. Look for the highlighted references contained in the two publications.





Grade Level and Subject Appropriateness

The experiments are easy to follow and are designed for all middle and high school students, worldwide. Teachers will appreciate the clear, unambiguous instructions for each step of the experimental procedures along with how students are able to quickly comprehend the material.

The experiments can fit into physics, chemistry, earth science, life science, and environmental studies – virtually any subject that deals with energy and the environment.

The basis for the experiments is on basic electricity and how solar panels, wind turbines and fuel cells generate and use it. Topics such as Ohm's Law, electrical power and energy are a continuing theme throughout all of them. If first year algebra is too advanced for younger students there is our Renewable Energy Monitor that measures everything without any calculations and displays it on the classroom computer in full-color graphics (see page 4).

For more advanced studies of physics and chemistry the "Renewable Energy Science Education Manual" (at the left) contains numerous examples of advanced theory and math to support any level of technical background necessary for these subjects.

Teachers can feel confident in knowing that the experiments and the supporting information comply with the following approved standards:

National Science Education Standards (NSES)

National Science Teachers Association (NSTA)

The International Technology Education Association (ITEA)

Details of compliance to these standards are found under separate documents outside of this manual.

Getting Familiar with the Kit

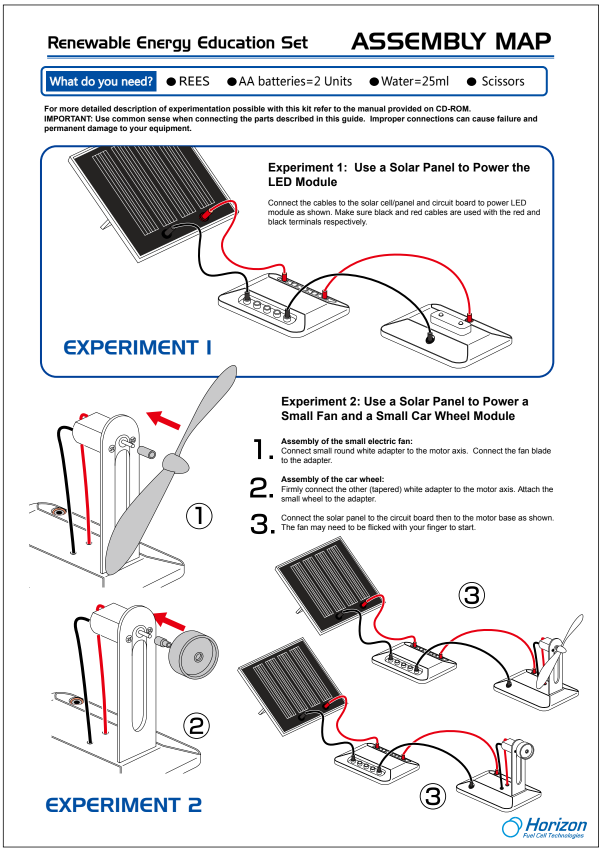
The Horizon Renewable Energy Science Education Set contains four basic devices that you will use for the experiments. These are:

- A Solar Panel
- A Wind Turbine
- PEM Fuel Cell
- PEM Electrolyzer

Experiments are designed around these three renewable energy devices. You will find complete information on the assembly and use of these devices in a separate document entitled:

Renewable Energy Education Set
ASSEMBLY GUIDE

<u>YOU ARE STRONGLY ENCOURAGED to read and understand this information before proceeding with the experiments.</u> Here are samples of the information presented.


Renewable Energy Education Set   ASSEMBLY MAP

What do you need? ● REES ● AA batteries=2 Units ● Water=25ml ● Scissors

For more detailed description of experimentation possible with this kit refer to the manual provided on CD-ROM.
IMPORTANT: Use common sense when connecting the parts described in this guide. Improper connections can cause failure and permanent damage to your equipment.

Experiment 1: Use a Solar Panel to Power the LED Module

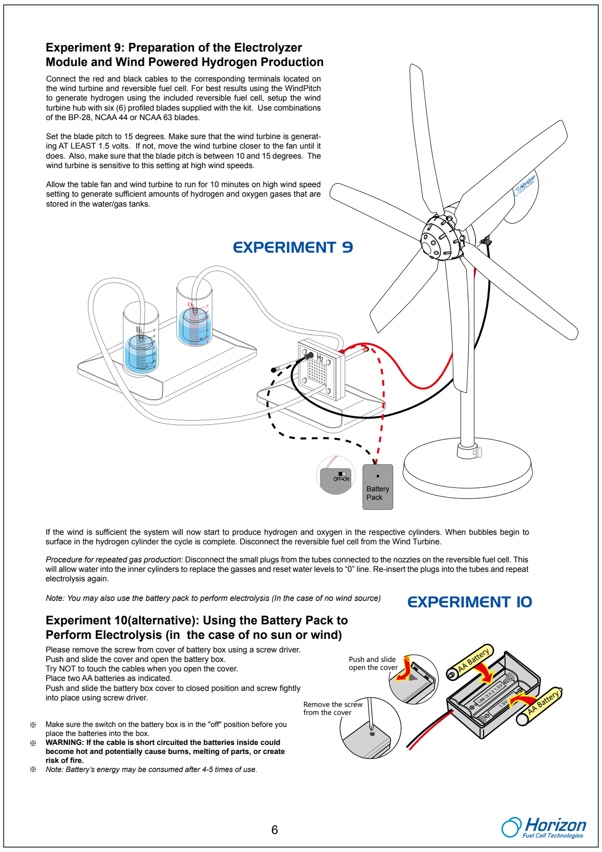
Connect the cables to the solar cell/panel and circuit board to power LED module as shown. Make sure black and red cables are used with the red and black terminals respectively.

EXPERIMENT I

Experiment 2: Use a Solar Panel to Power a Small Fan and a Small Car Wheel Module

1. **Assembly of the small electric fan:** Connect small round white adapter to the motor axis. Connect the fan blade to the adapter.
2. **Assembly of the car wheel:** Firmly connect the other (tapered) white adapter to the motor axis. Attach the small wheel to the adapter.
3. Connect the solar panel to the circuit board then to the motor base as shown. The fan may need to be flicked with your finger to start.

EXPERIMENT 2


Experiment 9: Preparation of the Electrolyzer Module and Wind Powered Hydrogen Production

Connect the red and black cables to the corresponding terminals located on the wind turbine and reversible fuel cell. For best results using the WindPitch to generate hydrogen using the included reversible fuel cell, setup the wind turbine hub with six (6) profiled blades supplied with the kit. Use combinations of the BP-28, NCAA 44 or NCAA 63 blades.

Set the blade pitch to 15 degrees. Make sure that the wind turbine is generating AT LEAST 1.5 volts. If not, move the wind turbine closer to the fan until it does. Also, make sure that the blade pitch is between 10 and 15 degrees. The wind turbine is sensitive to this setting at high wind speeds.

Allow the table fan and wind turbine to run for 10 minutes on high wind speed setting to generate sufficient amounts of hydrogen and oxygen gases that are stored in the water/gas tanks.

EXPERIMENT 9

If the wind is sufficient the system will now start to produce hydrogen and oxygen in the respective cylinders. When bubbles begin to surface in the hydrogen cylinder the cycle is complete. Disconnect the reversible fuel cell from the Wind Turbine.

Procedure for repeated gas production: Disconnect the small plugs from the tubes connected to the nozzles on the reversible fuel cell. This will allow water into the inner cylinders to replace the gasses and reset water levels to "0" line. Re-insert the plugs into the tubes and repeat electrolysis again.

Note: You may also use the battery pack to perform electrolysis (In the case of no wind source)

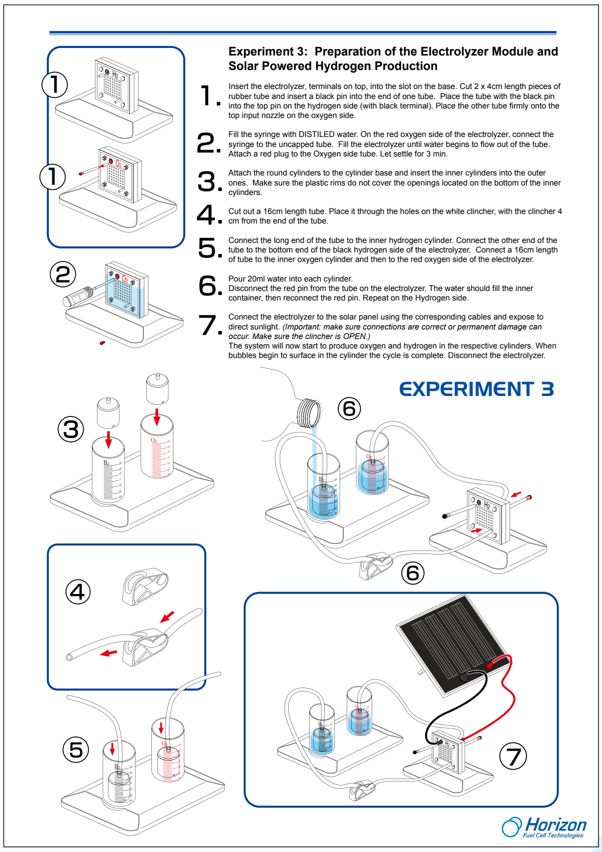
EXPERIMENT 10

Experiment 10(alternative): Using the Battery Pack to Perform Electrolysis (in the case of no sun or wind)

Please remove the screw from cover of battery box using a screw driver.
Push and slide the cover and open the battery box.
Try NOT to touch the cables when you open the cover.
Place two AA batteries as indicated.
Push and slide the battery box cover to closed position and screw fightly into place using screw driver.

※ Make sure the switch on the battery box is in the "off" position before you place the batteries into the box.
※ **WARNING: If the cable is short circuited the batteries inside could become hot and potentially cause burns, melting of parts, or create risk of fire.**
※ *Note: Battery's energy may be consumed after 4-5 times of use.*

6


Experiment 3: Preparation of the Electrolyzer Module and Solar Powered Hydrogen Production

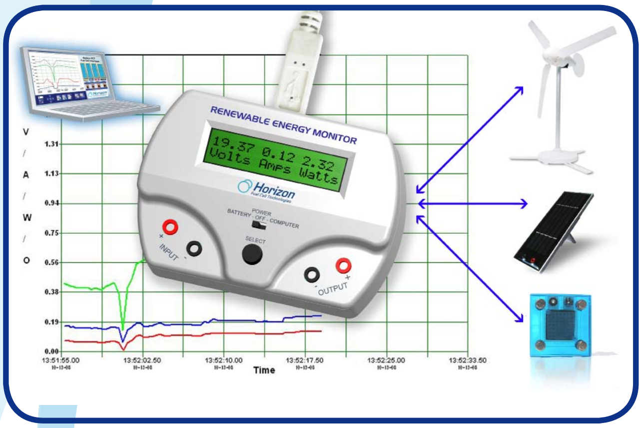
1. Insert the electrolyzer, terminals on top, into the slot on the base. Cut 2 x 4cm length pieces of rubber tube and insert a black pin into the end of one tube. Place the tube with the black pin into the top pin on the hydrogen side (with black terminal). Place the other tube firmly onto the top input nozzle on the oxygen side.
2. Fill the syringe with DISTILED water. On the red oxygen side of the electrolyzer, connect the syringe to the uncapped tube. Fill the electrolyzer until water begins to flow out of the tube. Attach a red plug to the Oxygen side tube. Let settle for 3 min.
3. Attach the round cylinders to the cylinder base and insert the inner cylinders into the outer ones. Make sure the plastic rims do not cover the openings located on the bottom of the inner cylinders.
4. Cut out a 16cm length tube. Place it through the holes on the white clincher, with the clincher 4 cm from the end of the tube.
5. Connect the long end of the tube to the inner hydrogen cylinder. Connect the other end of the tube to the bottom end of the black hydrogen side of the electrolyzer. Connect a 16cm length of tube to the inner oxygen cylinder and then to the red oxygen side of the electrolyzer.
6. Pour 20ml water into each cylinder.
   Disconnect the red pin from the tube on the electrolyzer. The water should fill the inner container, then reconnect the red pin. Repeat on the Hydrogen side.
7. Connect the electrolyzer to the solar panel using the corresponding cables and expose to direct sunlight. *(Important: make sure connections are correct or permanent damage can occur. Make sure the clincher is OPEN.)*
   The system will now start to produce oxygen and hydrogen in the respective cylinders. When bubbles begin to surface in the cylinder the cycle is complete. Disconnect the electrolyzer.

EXPERIMENT 3

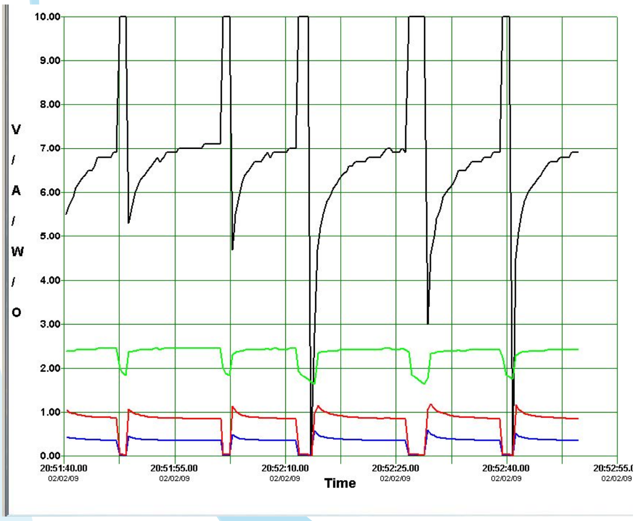
Renewable Energy Monitor
(Optional - not included)

Horizon has developed the Renewable Energy Monitor to enhance your study of renewable energy. The following is provided as a quick guide to its features and operation. For complete details refer to the Renewable Energy Monitor User Manual that comes with it.

Main Features



The Renewable Energy Monitor provides complete measurement and display functions for all the experiments; plus, it can be used as a general purpose meter instead of a multi-meter for your electrical measurements. And it does it automatically – no computations!!



Example Computer Plot of Voltage, Current, Power and Resistance

Use it with or Without a Computer

The Renewable Energy Monitor can be used with or without a computer – indoors or out – and it works with all Horizon solar, wind and fuel cell products. Do solar and wind experiments where they perform best – outdoors – and measure all the data there.

With the USB interface the Renewable Energy Monitor plugs directly into your computer. The computer displays real-time plots of actual measurements that give students a visual understanding of what's going on.

LCD Screen

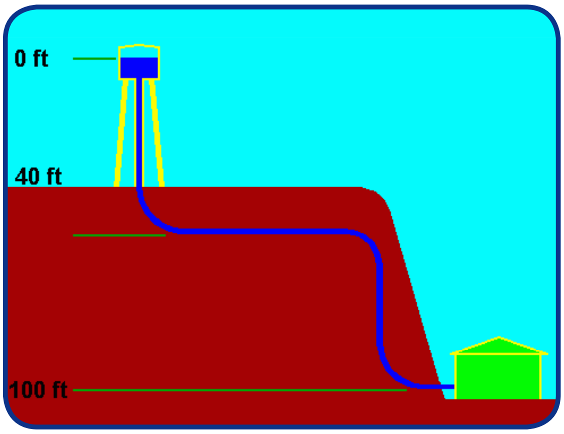
The LCD screen displays all the data at once without moving wire probes like on a multimeter. And students can switch between screens with just a push of a button. Horizon has made the complicated simple – and powerful – so that you and your students spend more time experimenting and less time figuring out how to hook things up.

Electrical Components, Circuits and Terminology

The following information will help you to understand some of the components, circuits and terminology used in the experiments. Each is presented in the form of a question.

What is Voltage?

Voltage is to electricity as pressure is to water; both are forces that move things.
Voltage is the force that moves electrons through a circuit; the greater the voltage the greater the force of electron movement.
Voltage is generated by creating a "potential difference" between positive and negative elements of the device generating it.



Like water, the higher the voltage, the more force it exerts. Water falling from a height uses gravity to create force; the higher the water falls (its potential difference), the more force or pressure it creates. Unlike water, however, voltage is not created by gravity but by chemical, optical, or magnetic forces.
Batteries use chemicals to generate voltage while common fuel cells use electrons in hydrogen gas to create voltage. Solar panels use optical means to capture the sun's photons to do the same and wind turbines use rotating magnets that are very close to coils of wire that generate voltage based on the magnetic fields created by the magnet's rotation.

Voltage is measured in units called volts

What is Current?

Electrical current is to electricity as the volume of water is to water flow. A fire hose can carry more water at higher pressure compared with a clogged shower head. So too can lager wires carry more current as compared with smaller wires.

Electrical current carries electrons along a path (called a circuit) like water carries water molecules through a hose. More electrons mean more current flow.

Water normally flows from upstream to downstream using gravity as a force. Electrical current normally flows from positive (+) to negative (-), which is called direct current or DC for short, but gravity is not involved.

Unlike water, electrical current can flow in either direction – positive to negative and negative to positive. The latter is usually called alternating current, or AC, since the current switches (alternates) between positive and negative directions. Electrical current produced by batteries are DC while electrical current coming out of the wall socket is AC. Both have their applications in electronic circuits.

Current is measured in units called amperes or amps

What is a Resistance?

A potentiometer is a variable resistor much like the knob on your car radio. You adjust it for various resistance values. The potentiometer supplied with the kit can be adjusted from 100 to 0 ohms. The two round connectors allow you to plug it into any of the experimental circuits with the supplied wires.

Larger wires can carry more electrical current as compared with smaller wires. In electrical circuit boards, components called resistors are inserted in the circuit to limit current flow.

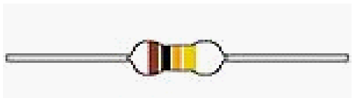
The resistance to the flow of electrons depends on the type and size of the materials used. While water flowing in a pipe does not generally produce heat by itself, electrical resistive materials produce varying degrees of heat created by the flow of electrons through the material. Heat is generally considered wasted energy (as in a hot light bulb) but not always, as in a toaster or hair dryer where heat from resistance is the desired quantity.

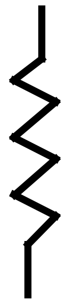
Resistance is measured in units called ohms.

What is a Resistor?

A resistor is a passive electrical device usually composed of a material like carbon that limits the flow of current from a power source. Resistors are normally considered as loads and are important components in any electrical circuit.

The physical part and electrical symbol for a resistor are shown below. This is a kind of "fixed value" resistor because it has only one resistance value.





A resistor's value is specified in ohms

What is a Potentiometer?

A potentiometer is a variable resistor much like the knob on your car radio. You adjust it for various resistance values. It has three terminals – left, center and right. Horizon has made it simple to use with a dial that shows resistance from 100 to 0 ohms.

What is a Power Source?

An electrical power source is a device that produces electrical voltage and current and power. Power sources can use chemical energy like a battery or fuel cell, solar energy like a solar panel or wind energy coupled with magnetic energy such as a wind turbine. Each of these power sources converts one kind of energy (chemical, light or mechanical) to electrical energy.

The equation for electrical power is shown below:

P = V * I   where

P = Power in watts

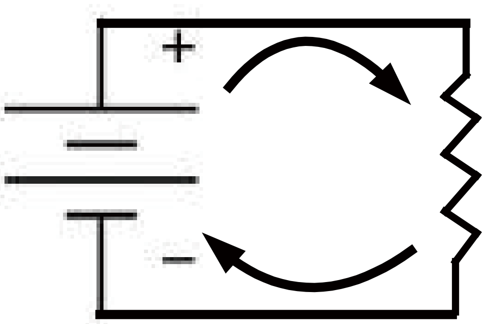
V = Voltage in volts

I = Current in amps

What is a Circuit?

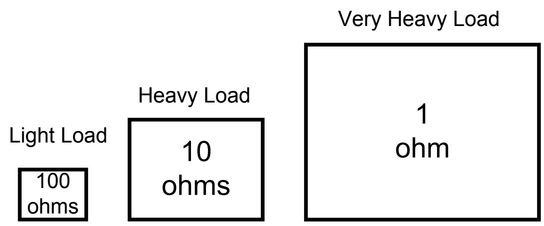
A circuit is any "unbroken" or closed connection of electrical components that form a continuous conducting path for current to flow; if the circuit is "broken" (or open as in an open circuit) no current can flow and no power or energy can be delivered.

The most basic electrical circuit is made up of a power source (like a battery shown here) attached to a load (like a resistor shown here).



What is a Load?

A load is a device that absorbs the power coming from a power source and uses the power to do work, like spin a motor, or simply dissipate the power into heat like the coils of wire in a toaster. In all cases, loads are used to both consume and regulate the power being produced. Generally speaking, a load is measured as resistance in units called ohms.

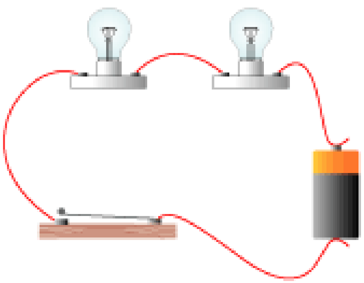


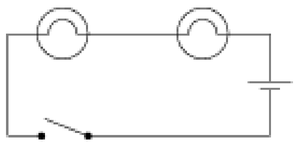
In relative terms, a "light" load has a large resistance and a "heavy" load has a small resistance. This may be counter intuitive, but it is the case, nevertheless. For example, a 100 ohm resistor presents a "lighter" load to a circuit as compared with a 10 ohm resistor. The illustration below shows the relative electrical "weight" of three typical resistor loads. The fuel cell and motor-propeller are each about 2 to 4 ohms making them a very heavy load.

What is a Series Circuit?

In an electrical circuit several devices such as light bulbs can be placed in a line - or in series - between the positive and negative poles of the battery. This is called a series circuit.

A major problem is if one light bulb burns out, then it acts like a switch and turns off the whole circuit. On the other hand a major advantage of a series circuit is that it saves wires that are needed in a parallel circuit.

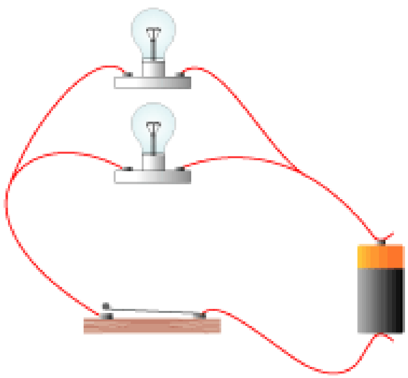


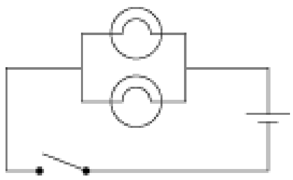


What is a Parallel Circuit?

Devices can be arranged in a parallel circuit such that if any bulbs burn out the circuit still remains intact and operates. Holiday lights are wired in parallel so that if one bulb burns out the others remain lit.

The circuit below shows two lights wired in parallel. If one light burns out the other one stays on.





What is Power?

Power is the combination of voltage and current. Voltage is the pressure component of power forcing electrons to move through a circuit, and current is the quantity component of power indicating the amount of electrons in the flow. Both voltage and current are required to produce the electrical force called power. Power is instantaneous and is not measured over time like energy. When you measure power, you measure voltage and current for a given instant of time.

This is an important distinction – time, or lack of it, is the essential difference between power and energy. Power is instantaneous while energy is power measured over time.

Electrical power is measured in units called watts.

What is Energy?

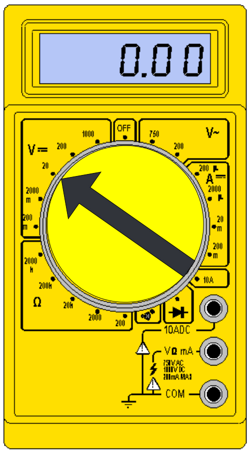
Energy is power over time. Energy is the power flowing through a circuit for a given time like one second, one minute or one hour. When we speak of energy we mean power times time. Energy is measured in units similar to power but with a time component as in watt-seconds (or Joules), watt-minutes or watt-hours.

If a circuit generates 1 watt of power for 1 hour, it is said to generate 1 Watt-Hour of energy. Your electric meter measures power in Watt-Hours (3600 Joules), but that can be converted to any other time frame by understanding how time is measured – one hour = 3600 seconds.

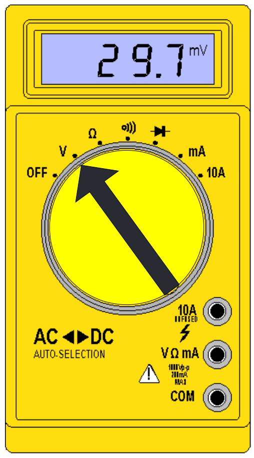
Energy is measured in Joules (watt-seconds) in the experiments.

Learning to Correctly Use A Multimeter

A multimeter combines measuring voltage, current and resistance into a single instrument. While somewhat intimidating for first time users there are a few simple and effective ways to make these measurements for the experiments. This section shows you how.



Manual



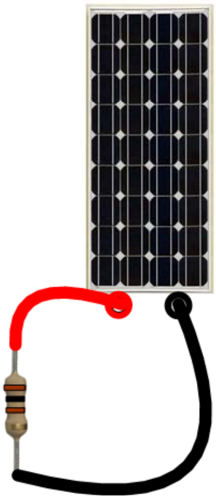
Auto

For safety reasons DO NOT connect a multimeter to the 110 VAC wall socket or to electrical appliances that are plugged in to it.

Types of Digital Multimeters

There are basically two types of digital multimeters – manual (left) and auto ranging (right). As you can see the manual model on the left has more dial positions, so you have to be careful to select the right one for your measurement. The auto ranging type on the right, which is usually more expensive, does most of the work for you. All you need to do is select the desired function like voltage, current or resistance and it makes the measurement at the proper scale. However, for both meters you need to know how to correctly attach the leads for the measurement.

A Simple Circuit



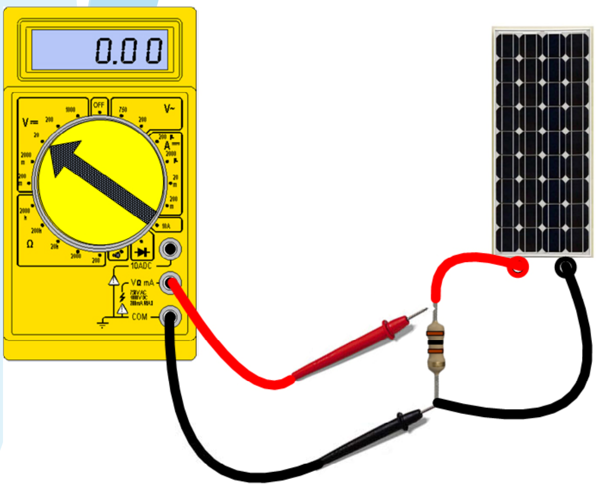
Selecting the right multimeter dial position is just the start. To correctly measure voltage, current and resistance the multimeter leads must be inserted into the circuit in the correct manner.

As an example we will start with a simple but typical circuit to see how each of these measurements is made. This one is composed of a solar panel as the voltage source and a resistor as the load. Other circuits will include fuel cells, motors and other components; however, the technique for measurement is essentially the same. Let's start with the easiest measurement and progress to the more difficult ones.

Measuring Voltage

To measure voltage:

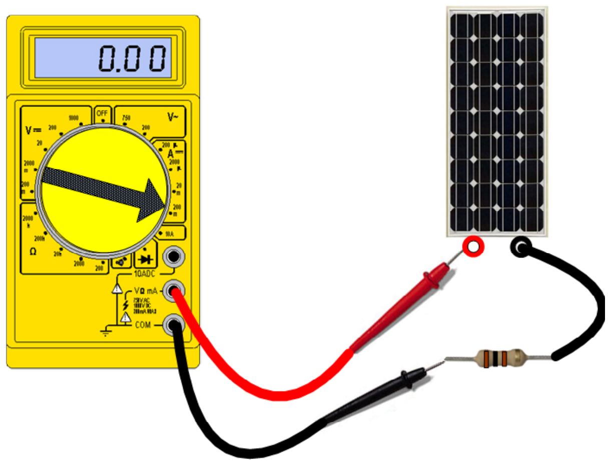
- Set the dial to the proper DC (direct current) voltage range (V)
- Connect the red lead to the positive (+) side of the part to be measured
- Connect the black COM lead to the negative (-) side to be measured
- Read the voltage on the display



Measuring Current

To measure current the circuit must be “interrupted” or “broken” and the multimeter must be placed in series with the circuit. Notice that you may need extra clip leads to attach the parts of the circuit together.

- Set the dial to the proper DC (direct current) current range usually in A or ma or milliamps
- Connect the red lead to the positive (+) side of the voltage source (the solar panel in this example)
- Connect a clip lead from the negative (-) side of the voltage source to one side of the resistor
- Connect the black COM lead to the other side of the resistor
- Read the current on the display

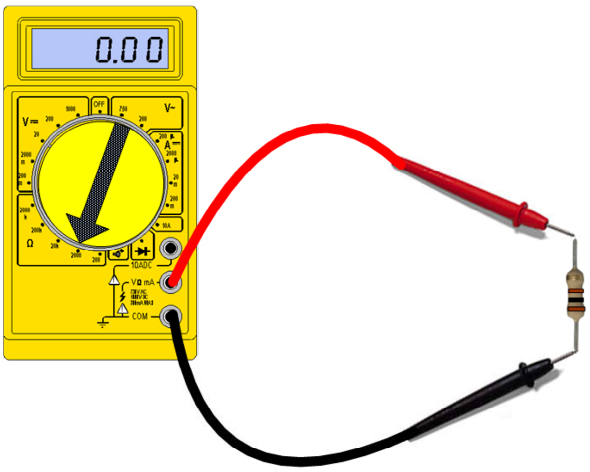


See Ohm’s Law below for an easier way to determine current without disturbing the circuit

Measuring Resistance

In order to measure the resistance of a component at least one side of the component must be free and away from the circuit. For best results both sides should be free of the circuit.

- Set the dial to resistance - normally shown with the omega ( ) symbol.
- Connect the red lead to one end of the resistor
- Connect the black COM lead to the other end of the resistor
- Read the resistance in ohms on the display



Ohm's Law

The multimeter measurements form the basis for some basic electrical computations referred to as Ohm's Law after the German physicist Georg Ohm, who, in 1827, described measuring voltage and current through simple electrical circuits containing various lengths of wire. The mathematical basis for Ohm's Law can be stated as:

V = I * R where

- **V = voltage in volts**
- **I = current in amps**
- **R = resistance in ohms**

If you have two of the three quantities already measured you can compute the third. For example if you measured current and resistance you can calculate voltage by the following equation:

V = I * R

If you have voltage and current, you can compute resistance:

R = V / I

And if you know the voltage and resistance you can compute current:

I = V / R

(see below for computing current)

Use these simple and direct equations in the experiment – especially the one for computing current with voltage and resistance, since it makes for a much easier measurement sequence without having to interrupt or break the circuit. If you know the resistance value then computing current like that shown above is a snap. If you don't know the resistance value (like using a motor for a load) you still have to use the conventional way to measure current.

Computing Current Is As Simple As 1, 2, 3

In order to quickly compute current using Ohm's Law with a known resistance and voltage see the examples below:

Examples:

1. Resistor = 100 ohms
2. Voltage = 1 volt
3. Current = 1 / 100 = 0.010 amps = 10 milliamps

1. Resistor = 10 ohms
2. Voltage = 1 volt
3. Current = 1 / 10 = 0.100 amps = 100 milliamps

1. Resistor = 50 ohms
2. Voltage = 1 volt
3. Current = 1 / 50 = 0.020 amps = 20 milliamps
1. Resistor = 5 ohms
2. Voltage = 1 volt
3. Current = 1 / 5 = 0.200 amps = 200 milliamps

Computing Power

You can compute power using voltage, current and resistance. The equation for power is:

P = V * I where

- **P = power in watts**
- **V = voltage in volts**
- **I = current in amps**

If you have the measurements for voltage and current – or if you can compute current from voltage and resistance – then use the above equation to compute power. If you have the measurements for voltage and resistance but not current, you can use the following equation by substituting the equation for resistance:

$$P = V * I$$
$$P = V * (V / R)$$
$$P = (V * V) / R$$
$$P = V^2 / R$$

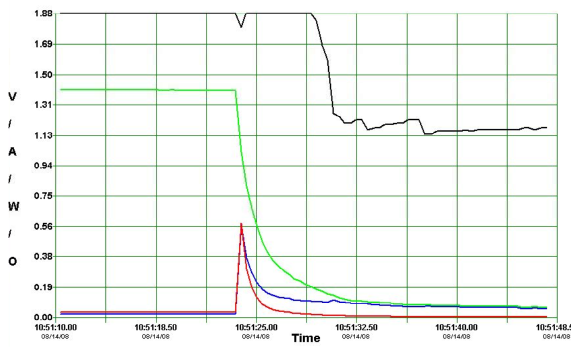
Examples:

1. Voltage = 1 volt
2. Current = 20 milliamps
3. Power = 1 x 20 = 20 milliwatts
1. Voltage = 4 volts
2. Resistance = 100 ohms
3. Power = (4 * 4) / 100 = 16 / 100 = 0.016 watts = 16 milliwatts

Measurements with the Renewable Energy Monitor - with no calculations!

Instead of using a multimeter with its complicated dial and hookups **Horizon** developed the Renewable Energy Monitor to allow you to directly measure and display voltage, current, power, resistance, energy and RPM directly and without computations. Simply attach the Renewable Energy Monitor to a solar panel, fuel cell or wind turbine and read the measurements on the large LCD screen.

That's it! There's nothing more to do…except attach it to your classroom computer for even more exciting visual measurements. And its battery powered so you can use it anywhere – indoors or out.



The WindPitch Wind Turbine

The WindPitch wind turbine is an important component of the Renewable Energy Education Set. With it you can add from two to six blades of different shapes as well as make your own. And the blades are made to aircraft standards just like real airplane propellers. You can even adjust the pitch or angle of the blades to get the most power from the wind. This is a powerful and practical experimental tool that teaches a great deal about how actual wind turbines work. An entire section of this Experiment Manual is dedicated to the WindPitch. There are experiments for:

- Measuring RPM
- Wind Turbine Efficiencies
- Tuning for Maximum Power
- Adding from Two to Six Blades
- Adjusting Blade Pitch
- And more…

Using the Right Fan

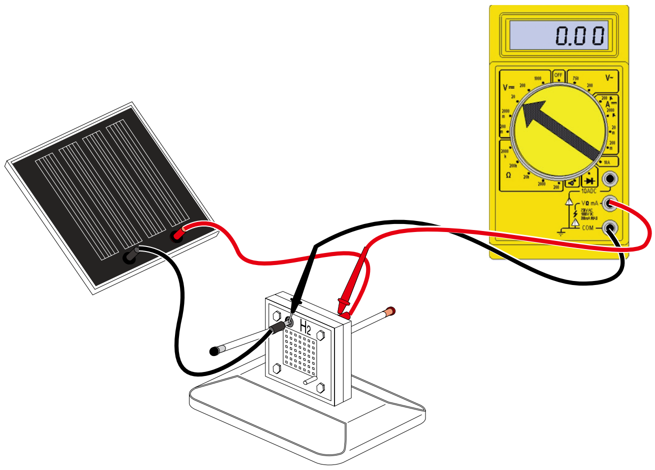
To get the best performance from the WindPitch you must use the right fan. Here is a photo of the best kind of fan to use. It's at least 20 inches in diameter with at least 3 speed settings.

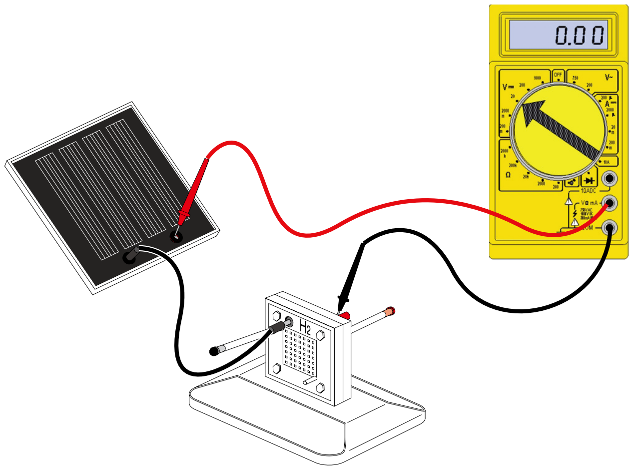
Don't skimp on a small table fan – it won't work as well and your experiments will not have the desired results. Use a big fan that produces lots of wind.

Adapting Other Horizon Products to the Experiments

Besides the Renewable Energy Science Education Set Horizon makes several other products that can benefit from the experiments presented here. These include:

- Solar Hydrogen Education Kit
- Hydro-Wind Kit
- Hydrocar Education Kit
- Fuel Cell Car Science Kit
- WindPitch Education Kit

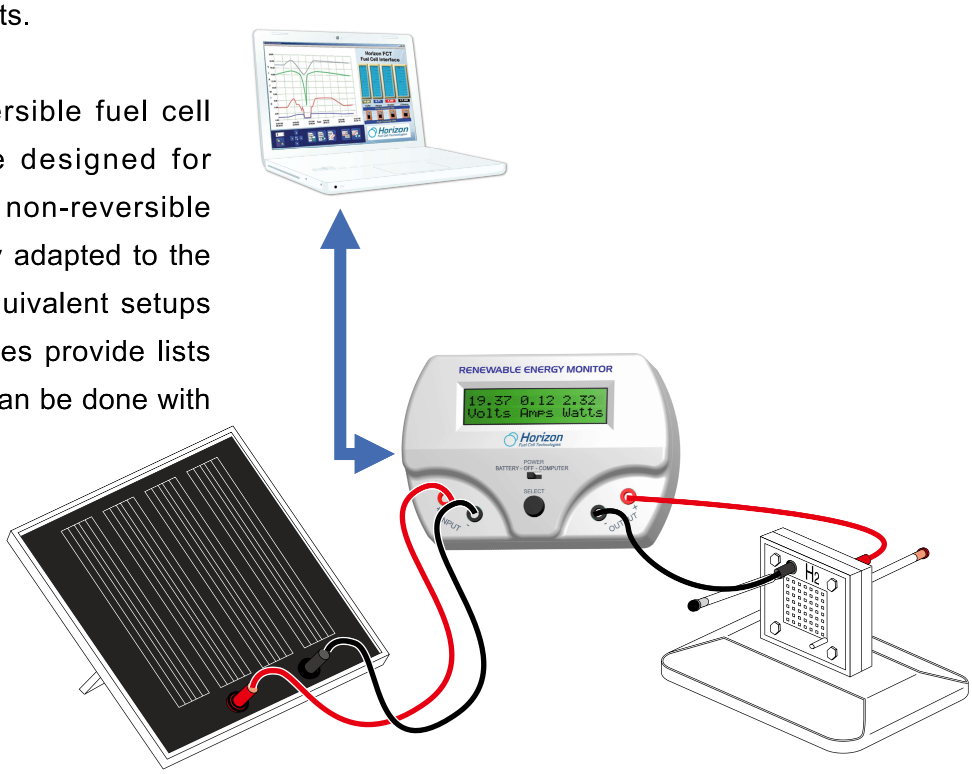




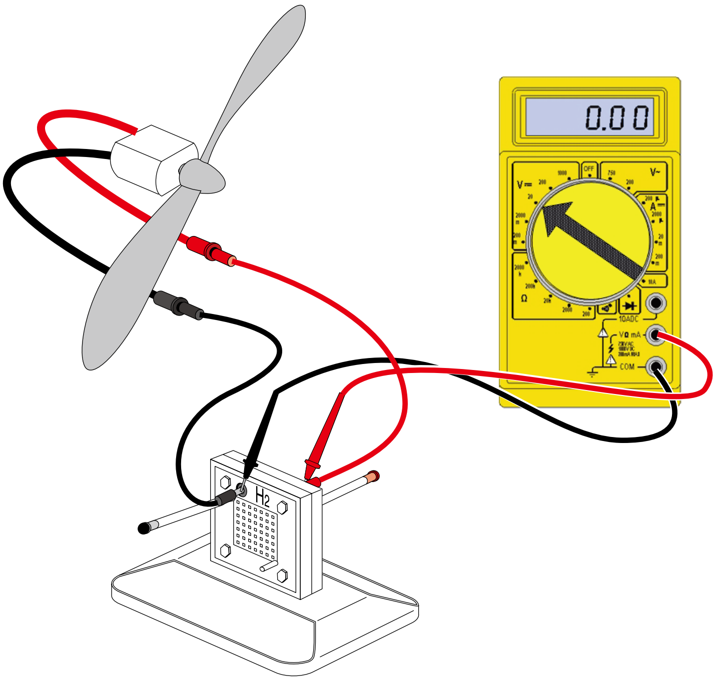
Adapting For Electrolysis

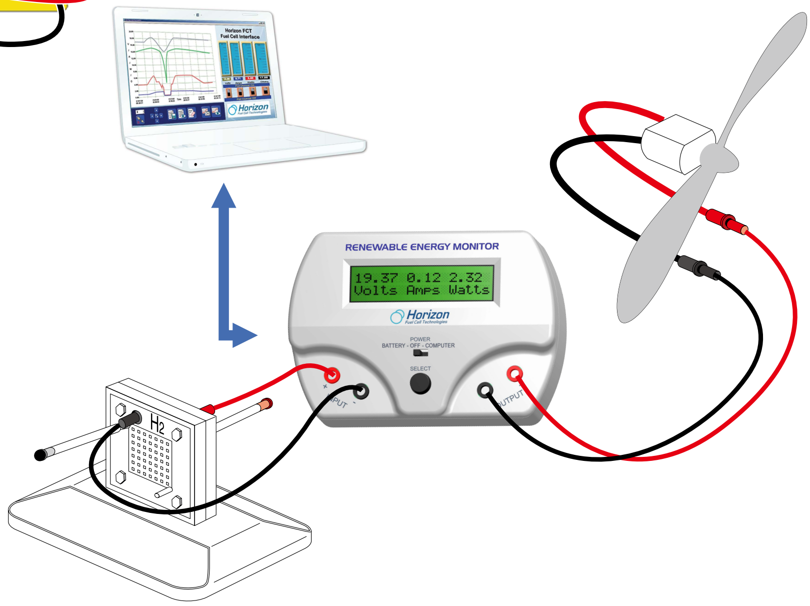
Where it is necessary to measure the voltage (V) and current (I), pull out the metal parts of both banana plugs "part way" to expose them to the multimeter leads (not necessary if using the Software Adaptor). Make sure to keep them partially plugged into the red and black terminals on the reversible fuel cell. The balance of the electrolysis cycle is essentially the same as in the experiments.

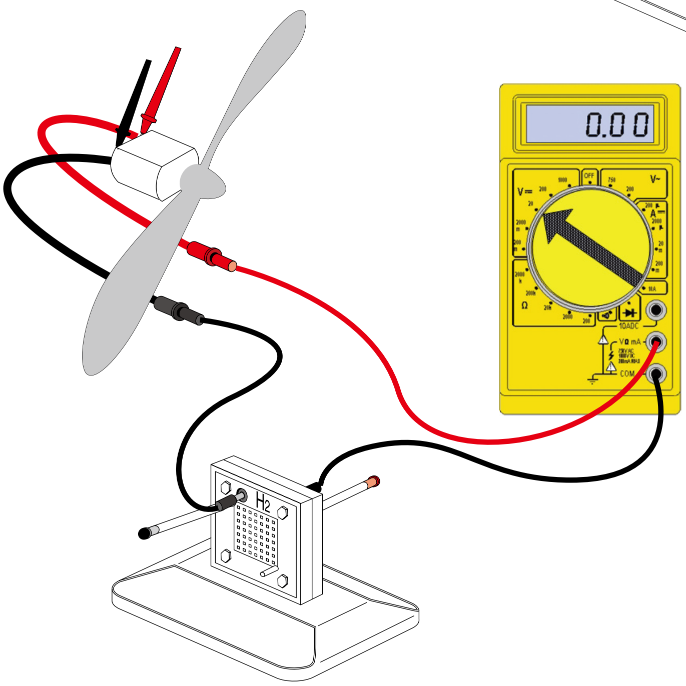
These products use a reversible fuel cell while the experiments are designed for separate electrolyzers and non-reversible fuel cells. They can be easily adapted to the experiments by using the equivalent setups shown below. The next pages provide lists of existing experiments that can be done with them.



Adapting For Fuel Cells

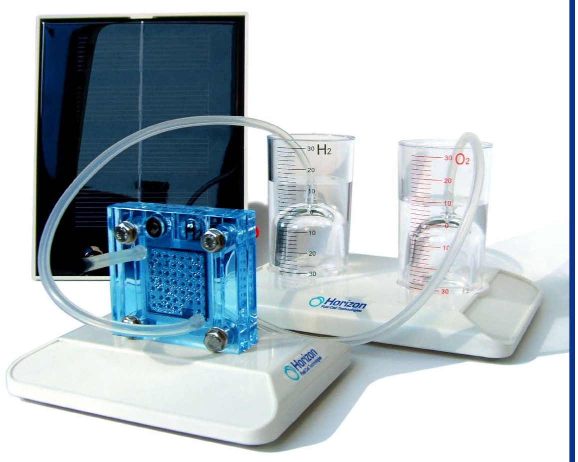






Since these products use a reversible fuel cell rather than an electrolyzer (be careful – they look alike), there is no reason to use a separate fuel cell when the experiment calls for one. Rather, the reversible fuel cell will do the same task. Follow the same general procedures for the hookup leads as in doing electrolysis. You will be substituting individual resistor for the motor-fan in some of the experiments.

Solar Hydrogen Education Kit FCJJ-16



The following experiments can be done by simply substituting the solar panel that comes with this kit for the 3-volt battery pack that is used in most of the experiments. One experiment already uses the solar panel to determine the decomposition voltage of water.

Electrolysis Mode – Generating Hydrogen and Oxygen from Water

Fuel Cell Mode – Generating Electricity from Hydrogen and Oxygen

Determining the Minimum Voltage for Water Decomposition

Polarization States for Hydrogen Fuel Cells

Hydro-Wind Education Kit FCJJ-26

The following experiments can be performed with a few additional components like resistors and clip leads and will add enormously to your understanding of wind power and how different blades make different levels of power. Contact Horizon for these extra parts.

How Many Blades Are Best - 1, 2, 3 ... More?

Using Three Different Curved Blade Shapes

Using Blades You Make Yourself

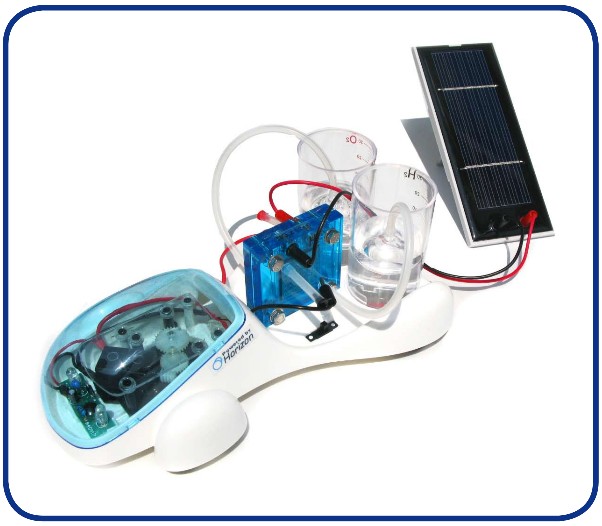
Turbine Efficiencies

Wind Power Measuring RPM

Wind Power Tuning For Maximum Power

Wind Power To Generate Hydrogen

Hydrocar Education Kit FCJJ-20



The following experiments can be done by simply substituting the solar panel that comes with this kit for the 3-volt battery pack that is used in most of the experiments. One experiment already uses the solar panel to determine the decomposition voltage of water. Simply plug the solar panel directly into the reversible fuel cell instead of using a Circuit Board Module Base.

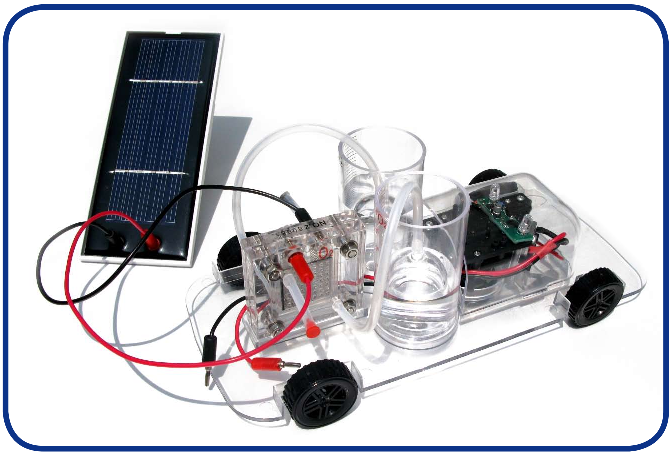
Electrolysis Mode – Generating Hydrogen and Oxygen from Water

Fuel Cell Mode – Generating Electricity from Hydrogen and Oxygen

Determining the Minimum Voltage for Water Decomposition

Polarization States for Hydrogen Fuel Cells

Fuel Cell Car Science Kit FCJJ-11



The following experiments can be done by simply substituting the solar panel that comes with this kit for the 3-volt battery pack that is used in most of the experiments. One experiment already uses the solar panel to determine the decomposition voltage of water. Simply plug the solar panel directly into the reversible fuel cell instead of using a Circuit Board Module Base.

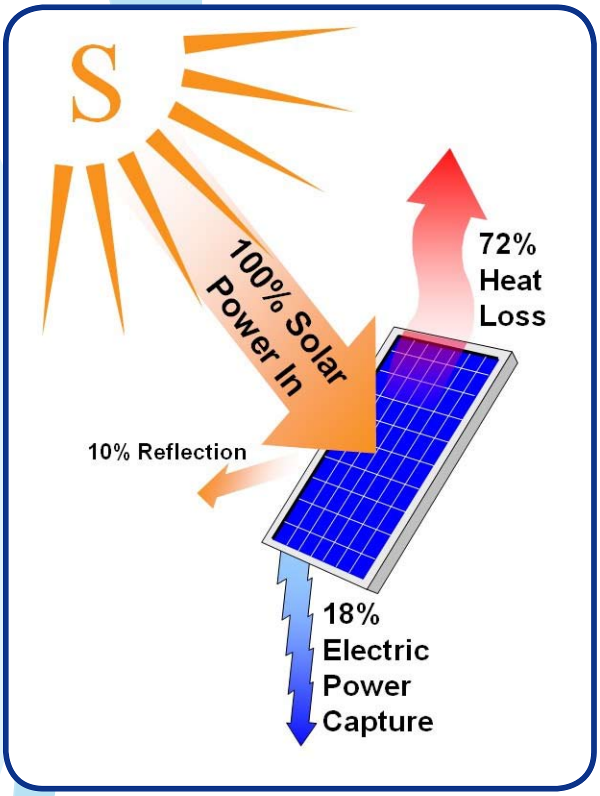
Electrolysis Mode – Generating Hydrogen and Oxygen from Water

Fuel Cell Mode – Generating Electricity from Hydrogen and Oxygen

Determining the Minimum Voltage for Water Decomposition

Polarization States for Hydrogen Fuel Cells

The Effects of Heat on a Solar Panel



LESSON OVERVIEW

This lesson demonstrates how a solar panel reacts to radiant heat from the sun or a table lamp including its diminished ability to produce electricity when it gets hot.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will observe the photovoltaic effect of sunlight and artificial light producing electricity.
- Students will learn how heat and cooling affect solar panel power output.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that heat can cause a decrease in a solar panel's power output and that wind can dissipate the heat and return the solar panel to its normal operating condition.

Students come to understand that:

1. Wind can dissipate the solar panel's heat and provide for better electrical output.
2. Solar panel efficiency (the ability to convert sunlight into electricity) is negatively affected by heat and improved with cold.
3. Solar panels operate better in colder weather as compared with warmer weather.

STUDENT ACTIVITIES

Students place a solar panel in direct sunlight or under a lamp to allow it to heat up. They record electrical data at selected times in order to determine the rate at which the solar panel looses its ability to generate electricity. Then students cool the solar panel with moving air from a table fan to remove the built-up heat and to witness how the solar panel recovers its power output. Data from cooling are also recorded. Students analyze and then explain the results of the activity.

SAFETY

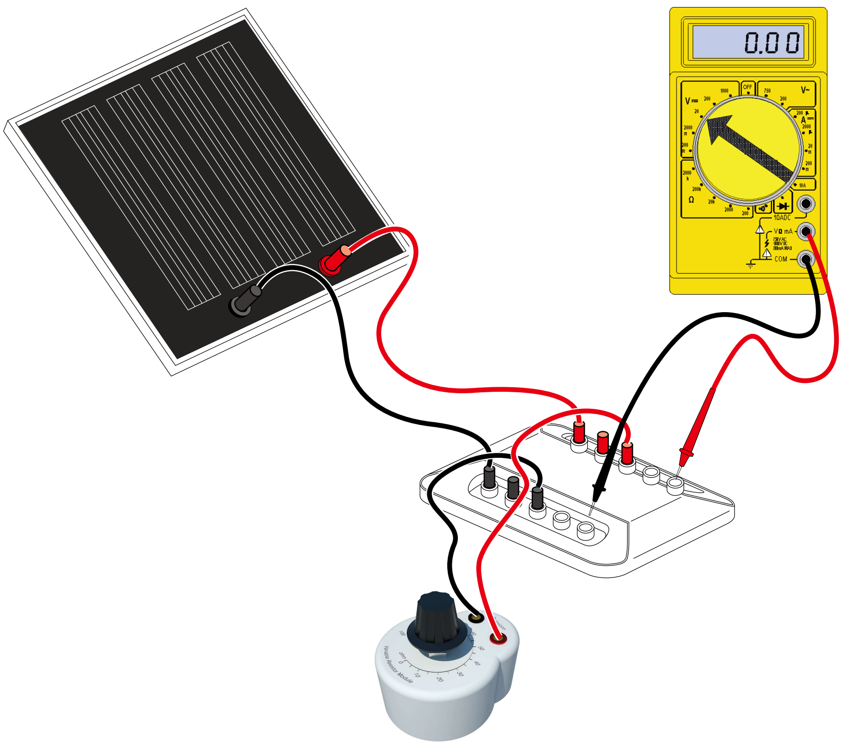
Caution must be exercised when using an artificial light source like a table lamp when heating the solar panel. Be sure NOT to overheat the solar panel as it will become HOT TO THE TOUCH and may MELT THE PLASTIC.

The Experiment with a Multimeter

Materials

1 - Solar panel
1- Goose neck table lamp
1 - Table fan
1 - 100 ohm potentiometer
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Equipment Setup



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the potentiometer to 10 ohms.
2. Set the multimeter dial to DC Volts with a range of at least 5 VDC
3. Make sure the solar panel is at room temperature to start the experiment.
4. Set the table lamp above the solar panel and turn on the light.
5. Record the voltage immediately while the panel is cool.
6. Allow 30 seconds to elapse and record the voltage again.
7. Repeat this measurement every 30 seconds for 3 minutes.
8. Aim a table fan at the solar panel and turn it on to the highest speed setting.
9. Record the voltage immediately.
10. Allow 30 seconds to elapse and record the voltage again.
11. Repeat this measurement every 30 seconds for 3 minutes.

Preparing the Data

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the 10 ohm resistor load. Refer to the **Experiment Guide** for details on how to do this.

Without Fan – Heating Up

Time	Volts	Amps	Watts
0 sec			
30 sec			
60 sec			
90 sec			
120 sec			
150 sec			
180 sec			

With Fan – Cooling Down

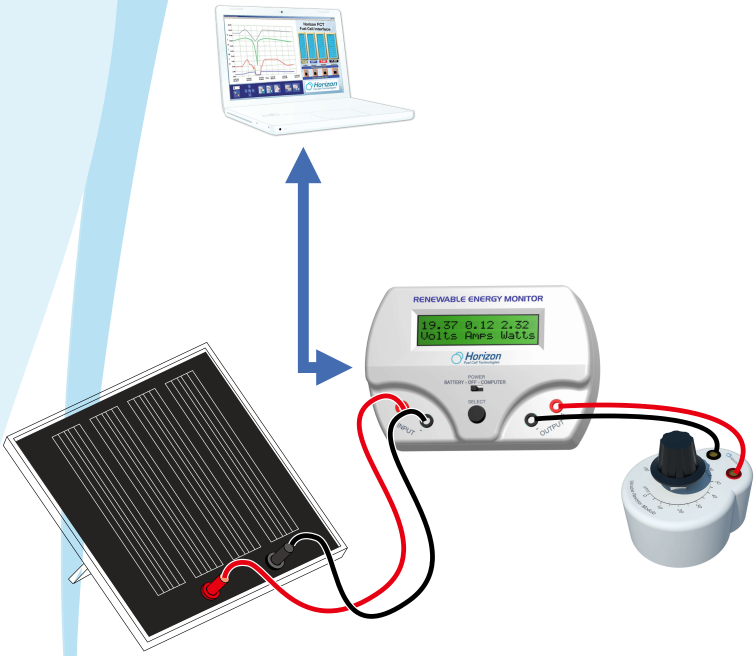
Time	Volts	Amps	Watts
0 sec			
30 sec			
60 sec			
90 sec			
120 sec			
150 sec			
180 sec			

The Experiment with the Renewable Energy Monitor

Materials

1 – Solar panel
1 – Goose neck table lamp
1 – Table fan
1 – 100 ohm potentiometer
2 – Red hookup leads
2 – Black hookup leads

Equipment Setup



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the **Renewable Energy Monitor** switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Ohms display appears.

3. Adjust the potentiometer for 10 ohms. Light must be shining on the solar panels for this to occur.
4. Push the Select Button until the Volts Amps Watts display appears. Make sure the solar panel is at room temperature to start the experiment.
5. Set the table lamp above the solar panel and turn on the light.
6. Record the voltage, current and power.
7. Repeat this measurement and recording every 30 seconds for 3 minutes.
8. Aim a table fan at the solar panel and turn it on to the highest speed setting.
9. Record the voltage, current and power.
10. Repeat this measurement and recording every 30 seconds for 3 minutes.

Preparing the Data

Have the students enter the voltage, current and power into the tables below:

Without Fan – Heating Up

Time	mV	mA	mW
0 sec			
30 sec			
60 sec			
90 sec			
120 sec			
150 sec			
180 sec			

With Fan – Cooling Down

Time	mV	mA	mW
0 sec			
30 sec			
60 sec			
90 sec			
120 sec			
150 sec			
180 sec			

Analyzing the Results

Using the data in the two tables have the students make a graph that starts with the data in the first table and continues with the data in the second table. If you used the **Renewable Energy Monitor** connected to a computer to do the experiment the graphed data should resemble the final plot, which looks like Figure 1 below. Notice the dip in voltage as the solar panel heats up followed by a rise as it cools down. Heat negatively affects the solar panel's power output while cold improves it.

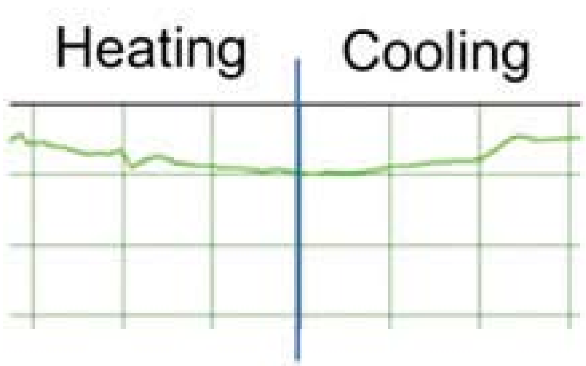


Figure 1 – The Effects of Heat and Cooling on the Solar Panel's Voltage

What If ???

Have the students speculate on the following hypothetical questions.

1. What if it rained on a solar panel and then the sun came out. Would the solar panel produce more power output after it rained than if it stayed in the sun all day?

2. What if you lived high in the rocky mountains of Colorado? Would your solar panels produce more power on a sunny day in the winter than if you lived in South Florida?

Links to the Renewable Energy Science Educational Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 22 – The Helios solar plane
Page 26 –The Electromagnetic Spectrum
Page 32 – Solar Cell Materials

Web Links

To learn more about solar cells start with this link from the "How Stuff Works" website. http://science.howstuffworks.com/solarcell.htm

Do More Research

To learn more about solar cells start with this link from the "How Stuff Works" website. http://science.howstuffworks.com/solar-cell.htm

1. If an airplane like the Heilos made by Aerovironment were powered completely by solar energy, how long could it stay aloft? See page 22 of the RE Science Educational Manual for a clue then do some research on the web.

2. What newer types of solar cell materials are better at producing more power as compared with silicone? Do the newer types absorb more sunlight to produce power?

3. Do you think your house or apartment could be powered completely by solar power or be supplemented by solar power, or do you think solar power would not work at all based on where you live?

The Effect of Shade on Solar Panels

LESSON OVERVIEW

This lesson demonstrates how a solar panel looses much of its power when even a small part of it is shaded.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will observe the photovoltaic effect of sunlight and artificial light producing electricity.
- Students will learn how both overcast and shade affect solar panels.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that shade from trees, clouds and man made objects can cause a disproportionate decrease in power output and can even cause physical damage to a solar panel.

Students come to understand that:

1. Shade is like turning off an internal power switch that shuts off most of the power to the rest of the solar panel.
2. Solar panels can be damaged by shade if they do not have the appropriate internal protection.
3. Solar panels on space satellites must always be repositioned as they travel in orbit around the Earth.

STUDENT ACTIVITIES

Students study the effect of shade on a solar panel by first placing it in direct light without any shade. Then the entire solar panel is shaded by placing a sheet of facial tissue between the light source and the panel to simulate overcast. The tissue is removed and then only a small portion of the solar panel is shaded with an opaque object like a regular piece of paper while the rest of the panel is fully illuminated. For each trial students measure the solar panel's voltage, current and power levels in order to perform later analysis.

SAFETY

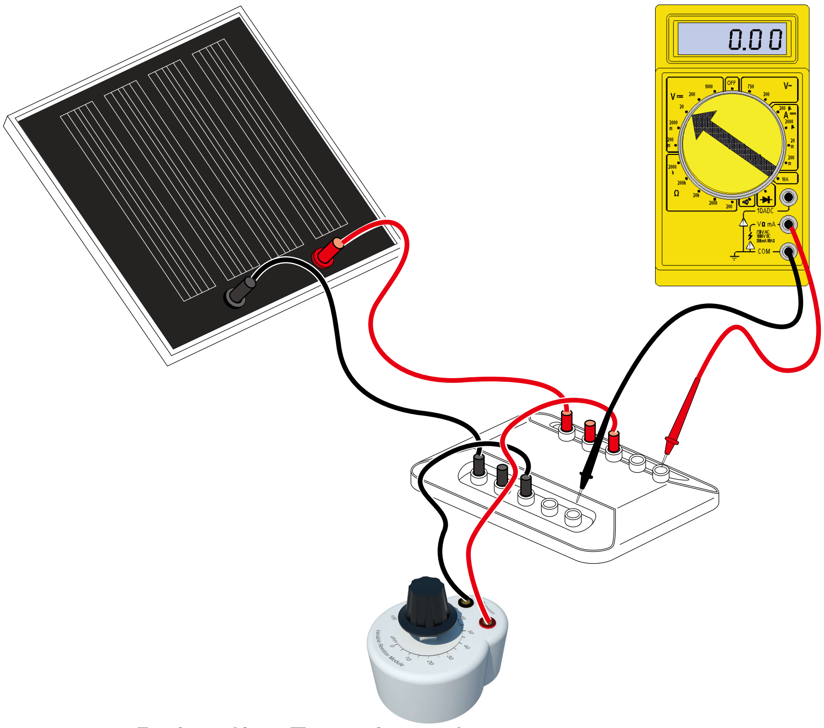
Normal caution must be exercised when using an artificial light source like a table lamp to illuminate a solar panel. Be sure NOT to overheat the solar panel as it will become HOT TO THE TOUCH and may MELT THE PLASTIC.

The Experiment with a Multimeter

Materials

1 - Solar panel
1 - Goose neck table lamp
1 - 100 ohm potentiometer
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Equipment Setup



Doing the Experiment

Caution: Do not overheat the solar panel or touch it if it becomes hot!

1. Set the potentiometer to 10 ohms.
2. Set the multimeter dial to DC Volts with a range of at least 5 VDC.
3. Set the table lamp above the solar panel and turn on the light – or place the panel in direct sunlight which is best.
4. Record the voltage.
5. Place a single sheet of facial tissue between the light source and the solar panel in order to shade the entire panel but have enough low light shining on the panel as if it were an overcast day.
6. Record the voltage.
7. Remove the facial tissue.
8. Apply a regular piece of paper directly over one fourth (¼) of the solar panel to cover that portion completely. Refer to Figure 1.
9. Record the voltage.

Figure 1 – Paper Shading ¼ Solar Panel

Preparing the Data

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the 10 ohm resistor load. Refer to the **Experiment Guide** section for details on how to do this.

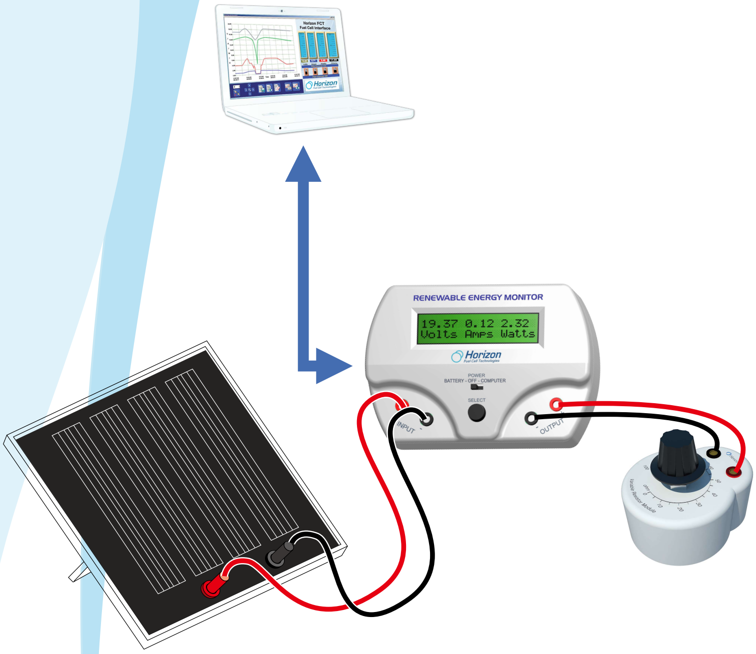
Step	Volts	Amps	Watts
Full light			
Overcast			
Shading			

The Experiment with the Renewable Energy Monitor

Materials

1 - Solar panel
1 - Goose neck table lamp
1 - 100 ohm potentiometer
2 – Red hookup leads
2 – Black hookup leads

Equipment Setup



Doing the Experiment

Caution: Do not overheat the solar panel or touch it if it becomes hot!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Ohms display appears.

3. Adjust the potentiometer for 10 ohms. Light must be shining on the solar panels for this to occur.
4. Push the Select Button until the Volts Amps Watts display appears.
5. Set the table lamp above the solar panel and turn on the light – or place the panel in direct sunlight which is best.
6. Record the voltage, current and power.
7. Place a single sheet of facial tissue between the light source and the solar panel in order to shade the entire panel but have enough low light shining on the panel as if it were an overcast day.
8. Record the voltage, current and power.
9. Remove the facial tissue.
10. Apply a regular piece of paper directly over one fourth (¼) of the solar panel to cover that portion completely. Refer to Figure 2.
11. Record the voltage, current and power.

Figure 2 – Paper Shading ¼ Solar Panel

Preparing the Data

Have the students enter the voltage, current and power data into the table below:

Step	Volts	Amps	Watts
Full light			
Overcast			
Shading			

Analyzing the Results

Have the students use the power data in the table to compute the percentage of power loss due to normal overcast and then to partial shading. Here is an example of how to do this:

% Power Loss = (Overcast / Full Light) * 100%

% Power Loss = (Shading / Full Light) * 100%

If you used the **Renewable Energy Monitor** connected to a computer you can clearly see the amount of voltage, current and power lost in both tests (Figure 3). It shows that partial shading is almost as bad as total shading on power output. The plot starts with the voltage, current and power at a high level (1). Then it drops to the lowest level when the entire panel is shaded by the facial tissue paper (2). It returns to normal again (3) and then it is partially shaded by the sheet of paper (4).

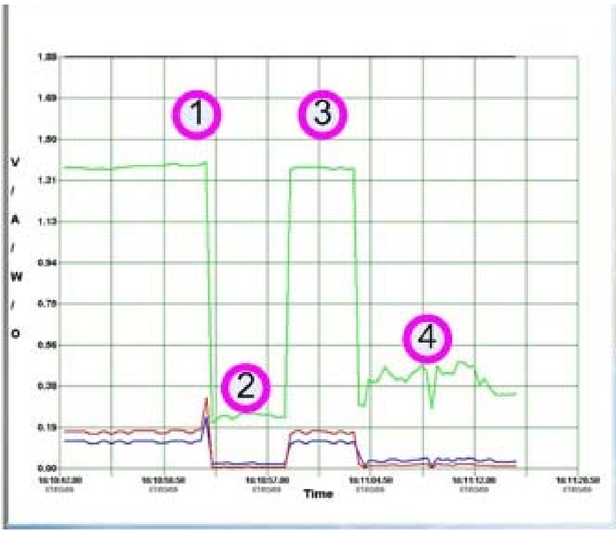


Figure 3 – Plot of Shade on Solar Panel

Tell students to think of the solar panel as made up of several solar cells wired in series (which it is). When one solar cell is shaded it cuts off power to the other cells. This is like the lights on a Holiday Tree; when one light goes out, the entire string of lights go out. Figure 4 is an illustration of what the inside of a solar panel looks like. Each yellow star represents a solar cell with light shining on it. When all the cells are illuminated it's like having an uninterrupted circuit with all the switches ON.

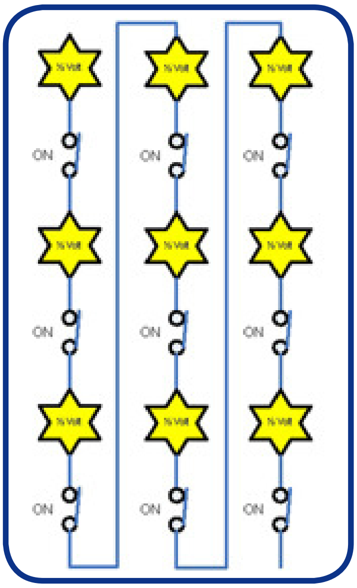


Figure 4 – All Solar Cells Illuminated

Figure 5 is an illustration of what happens when just one solar cell is shaded. The entire circuit is broken and no electricity can flow. What's worse is the solar cells that are illuminated get hot trying to find a path for their built-up energy. This damages the solar cells that are illuminated and eventually damages the entire solar panel.

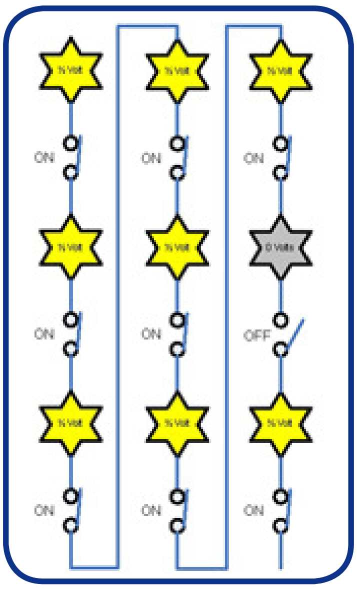


Figure 5 – One Solar Cell is Shaded

Links to the Renewable Energy Science Education Manual

To learn more about how solar panels are constructed from solar cells refer to the Experiment Guide and to the **Renewable Energy Science Education Manual** (page 25 – Principles and Characteristics).

What If ???

Have students speculate on the following hypothetical questions.

1. What if you were a spacecraft engineer and you had to make sure that the solar panels on the satellite you were designing would always face the sun as the satellite orbited around the Earth. This would provide the satellite electronics with full power at all times and not damage the solar panel. You can assume that the solar panels can be moved with motors. Look at the satellite in Figure 6 and notice that half of the solar panels are illuminated and half are shaded. Can you figure out a way to make them all face the sun?

Figure 6 – Satellite in Obit

2. What if you had a solar panel on your house or apartment and it snowed on it. What do you think will happen to the power output when the sun comes outagain? How about when the sun melts some of the snow but not all of it as in Figure 7?

Figure 7 – Snow on Solar Panel

Web Links

To learn more about the effects of shade on solar panels refer to the following web links:

http://www.greenlivingtips.com/articles/237/1/Solar-panel-basics.html

http://www.freesunpower.com/solarpanels.php

Do More Research

Have students research and answer the following questions:

1. If your house or apartment were equipped with solar panels to help power the home, where would you place the panels so that they were never subjected to shade as in Figure 8 below? If they are of the proper grade level have them use Trigonometry to figure out how far a solar panel needs to be placed from trees, chimneys, taller buildings next door, etc.

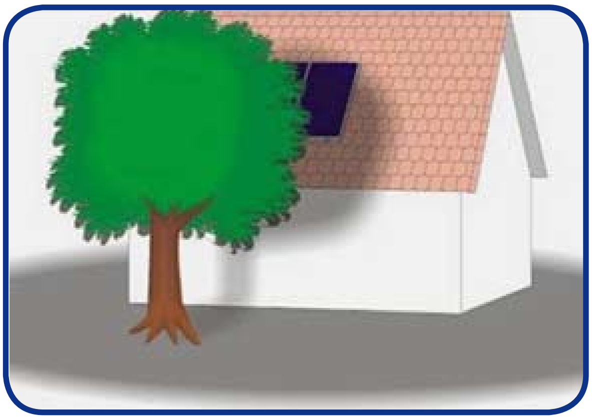


Figure 8 – Tree Shading Solar Panel on Roof

2. Advanced Research Question -Much of the shade that falls on solar panels are from clouds. Shade lessen the flow of electricity from solar panels when clouds pass over; however, if the solar panels are connected to a batterybackup system the batteries could store the energy when the sun shines and give back some of the energy when clouds pass overhead. If a solar panel had a capacity for 100 watts in full sun and only 20 watts when shaded by clouds, what percentage of full sun versus cloud cover would be required to ensure that the backup batteries could supply steady, uninterrupted power level of 50 watts? Assume that the battery has a 200 Amp-hour capacity and is fully charged at sunrise.

Figure 9 – Solar Panels and Clouds

3. Advanced Research Question - An electrical device called a diode can protect a solar panel from draining a battery when the sun is not shining. It only allows current to flow from the solar panel into the battery; it blocks the flow of current from the battery back into the solar panel when the sun is not shining or the solar panel is shaded.

Have students refer to the diagram in Figure 10 to see how such a "blocking diode" is typically used to do this for commercial solar panel installations. Have them explain the operation – especially the function of the diode, which is the subject of the research.

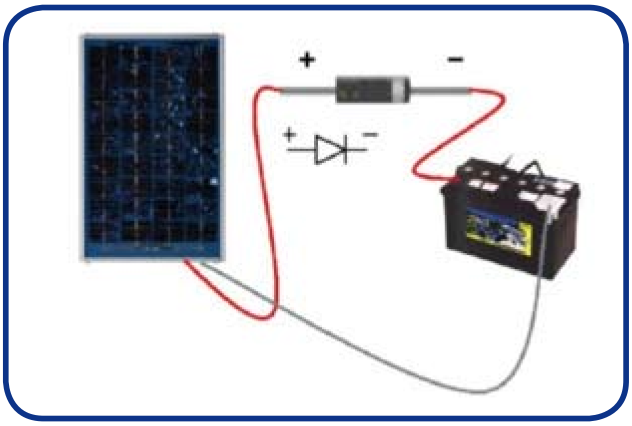


Figure 10 – Blocking Diode in Solar Panel – Battery Circuit

The Effect of Tilt Angle on Solar Panels

LESSON OVERVIEW

This lesson demonstrates how solar panels react to the direct and indirect rays from the sun or an artificial light source in order to produce electricity.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will observe the photovoltaic effect of sunlight and artificial light producing electricity.
- Students will learn how tilt angle affects solar panel power output.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the angle at which a solar panel is oriented towards its light source is directly proportional to its ability to produce usable power.

Students come to understand that:

1. Solar panels must be oriented at the proper angle to the light source for maximum electrical output.
2. Orienting large commercial solar panels outdoors are based on both geographical location and the season of the year.
3. A device called a Sun Tracker can keep solar panels correctly oriented at the sun all day long in order to generate the maximum power from the solar panel.

STUDENT ACTIVITIES

Students adjust the angle of the solar panel relative to the sun or artificial light source and measure voltage, current and power flowing into a resistor load. They correlate the tilt angle to the electrical measurements to determine the differences in electrical generation caused by the angle of tilt. They then determine the best tilt angle for a commercial solar panel at their geographical location and time of year. They analyze and explain the results. They are also introduced to a Sun Tracker.

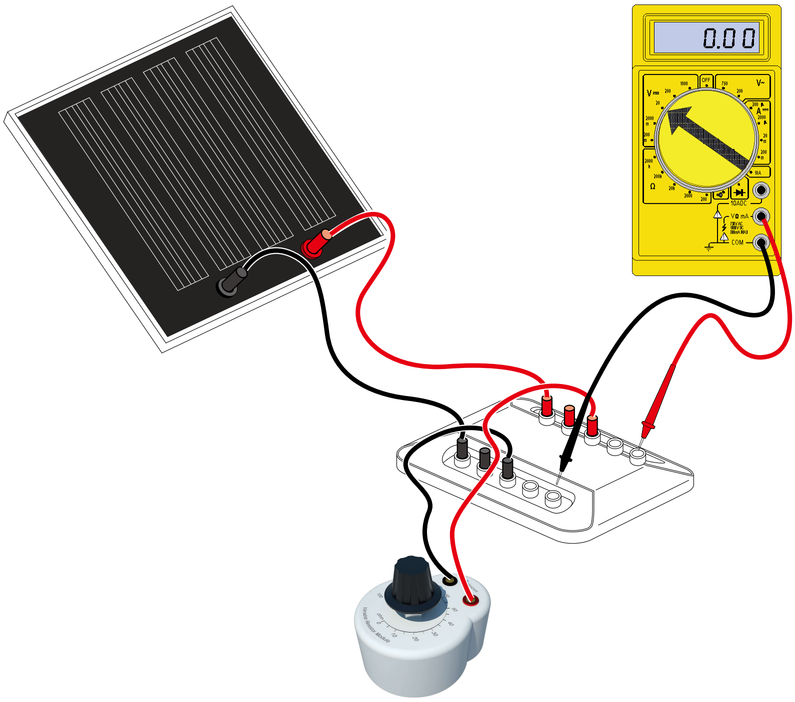
SAFETY

Normal caution must be exercised when using an artificial light source like a table lamp to illuminate a solar panel. Be sure NOT to overheat the solar panel as it will become HOT TO THE TOUCH and may MELT THE PLASTIC.

The Experiment with a Multimeter

Materials

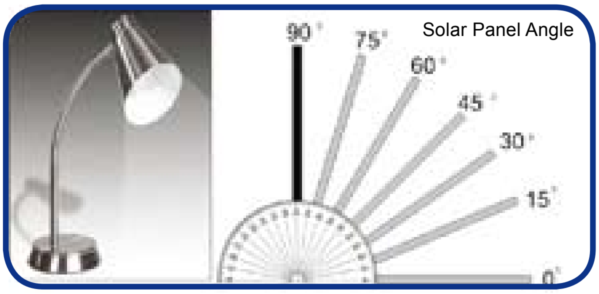
1 - Solar panel
1 – Goose neck table lamp
1 - 100 ohm potentiometer
1 – Protractor (for measuring tilt angle)
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the potentiometer to 10 ohms.
2. Set the multimeter dial to DC Volts with a range of at least 5 VDC
3. Students adjust the solar panel tilt angle in seven positions from 90 angular degrees to 0 degrees in 15 degree steps. At each setting the voltage is recorded.
4. Set the table lamp at about a 45 degree tilt as it shines on the solar panel when the solar panel is vertical. Do not move the table lamp for the other solar panel settings.
5. Use the protractor to set the solar panel at a 90 degree angle (vertical to the table) and record the voltage.
6. Change the angle of the solar panel to each of the next settings of 75, 60, 45, 30, 15 and 0 degrees and record the voltage at each setting.



7. Use the protractor to set the solar panel at a 90 degree angle (vertical to the table) and record the voltage.
8. Change the angle of the solar panel to each of the next settings of 75, 60, 45, 30, 15 and 0 degrees and record the voltage at each setting.

Preparing the Data

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the 10 ohm resistor load. Refer to the **Experiment Guide** section for details on how to do this.

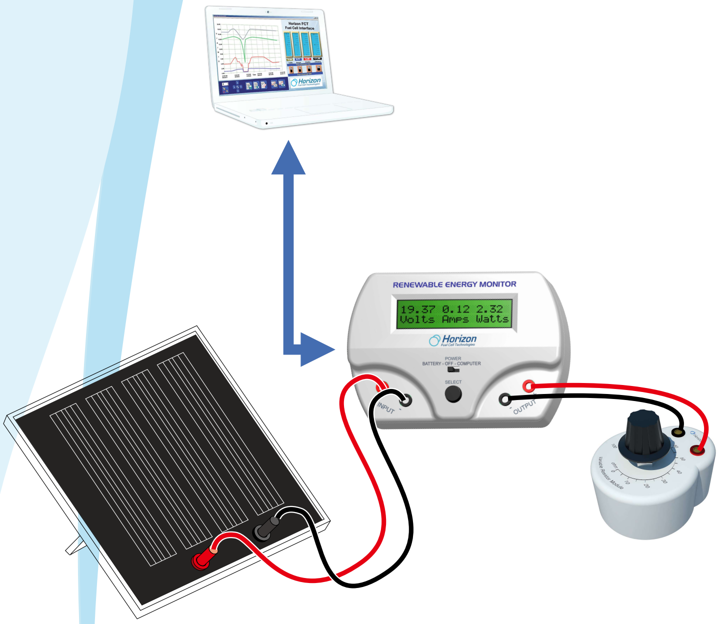
Angle	Volts	Amps	Watts
90			
75			
60			
45			
30			
15			
0			

The Experiment with the Renewable Energy Monitor

Materials

1 - Solar panel
1 – Goose neck table lamp
1 - 100 ohm potentiometer
1 – Protractor (for measuring tilt angle)
2 – Red hookup leads
2 – Black hookup leads

Equipment Setup

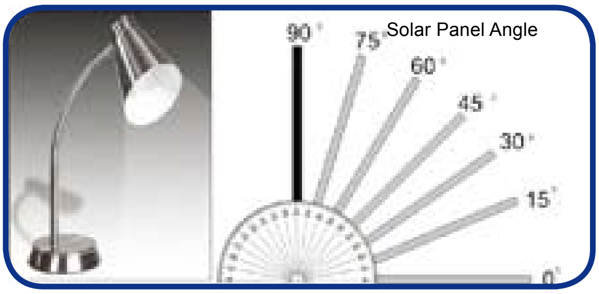


Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Ohms display appears.

3. Adjust the potentiometer for 10 ohms. Light must be shining on the solar panels for this to occur.
4. Push the Select Button until the Volts Amps Watts display appears. Make sure the solar panel is at room temperature to start the experiment.
5. Students adjust the solar panel tilt angle in seven positions from 90 angular degrees to 0 degrees in 15 degree steps. At each setting the voltage, current and power are recorded.
6. Set the table lamp at about a 45 degree tilt as it shines on the solar panel when the solar panel is vertical. Do not move the table lamp for the other solar panel settings.



7. Use the protractor to set the solar panel at a 90 degree angle (vertical to the table).
8. Record the voltage, current and power at 90^0.
9. Change the angle of the solar panel to each of the next settings of 75, 60, 45, 30, 15 and 0 degrees and record the voltage, current and power at each setting.

Preparing the Data

Click on the **Screen View** icon and cycle through the images just captured. Refer to the **Experiment Guide** section for details. Have the students copy the voltage, current and power data just below the meters into the tables below:

Without Fan – Heating Up

Angle	Volts	Amps	Watts
90			
75			
60			
45			
30			
15			
0			

Analyzing the Results

Using the data in the table have the students make a graph that plots the voltage, current and power (vertical axis) against the tilt angle (horizontal axis). If you used the **Renewable Energy Monitor** connected to a computer to do the experiment, the graphed data should resemble the plot in Figure 1 below.

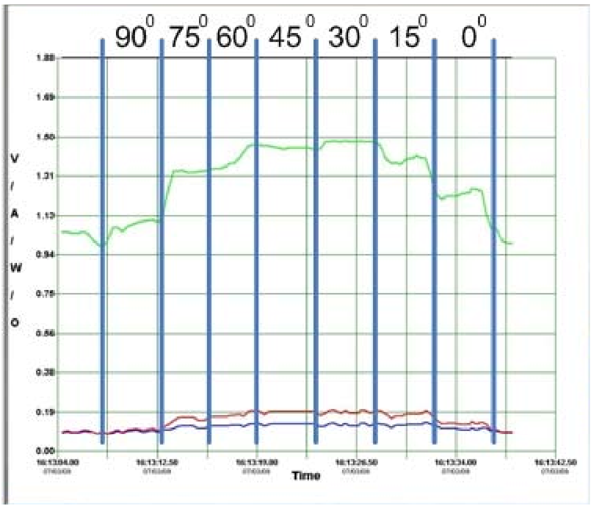


Figure 1 – Plot of Voltage, Current and Power at Various Tilt Angles

As expected the maximum voltage, current and power are generated when the angle of the solar panel matches the angle of the light source.

What If ???

Have students speculate on the following hypothetical questions.

1. What if your class decided to mount a large solar panel on your school property? What "fixed" tilt angle would be best for getting the most power from the sun? The answer depends on two things – (1) the geographical location of your school and (2) the time of year.

First your school's geographical location – or more specifically, its latitude – needs to be determined. Your school's latitude is the angular distance from the Equator to either the North or South Pole depending on what part of the world your school is located. We will assume that your school is in the Northern Hemisphere for this example. If your school is in the Southern Hemisphere then simply reverse some of the references.

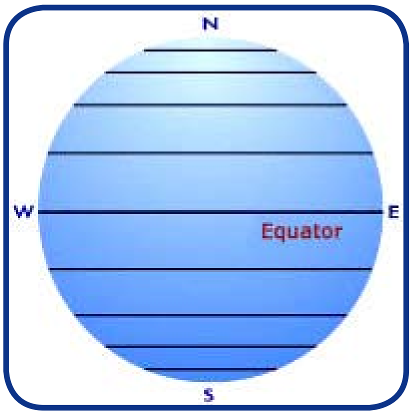


Figure 2 – Lines of Latitude

Latitude is the measure of distance from the equator to either the North or South Pole expressed in degrees from 0^0 at the equator to 90^0 at either pole. Latitude in the northern hemisphere is expressed as a positive number while latitude in the southern hemisphere is expressed as a negative number. Lines of latitude circle the Earth as concentric circles that are parallel to the equator and to one another. Each degree of latitude is subdivided into 60 minutes and each minute is sub-divided into 60 seconds.

To find your school's latitude (and longitude)

go to the following web link

http://itouchmap.com/latlong.html and type in your school's address. The latitude and longitude will show up as a bubble on a satellite map image. We'll see how latitude figures into how to tilt the solar panel shortly.

Now that you have your school's latitude you need to consider the time of year for best results from the solar panel. We know that the sun is higher in the sky in summer and lower in winter as shown in Figure 3.

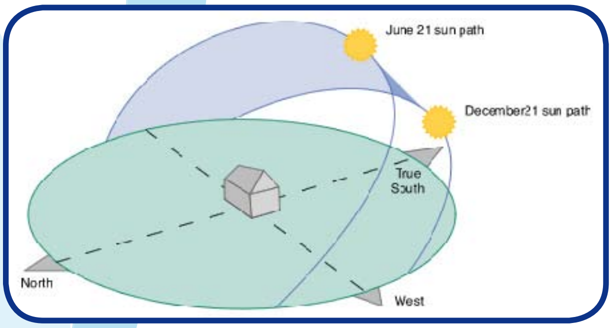


Figure 3 – Sun's Position in Summer and Winter

So it seems like the best angle to position the solar panel would be between the highest and lowest points of the sun's apparent angle in the sky. You can use Figure 4 as a way to determine the best latitude for the season of the year. Just add or subtract about 15 degrees to to adjust for the season.

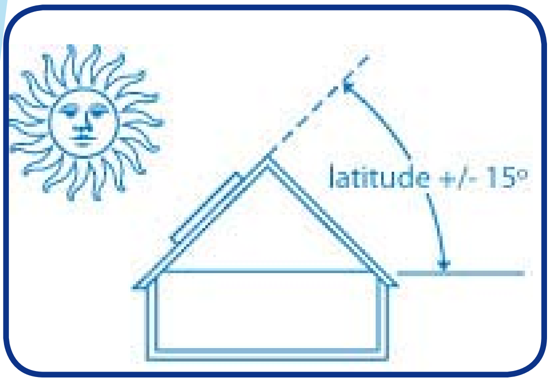


Figure 4 – Computing the Best Tilt Angle for Seasonal Solar Panel Operation

2. Now, what if you could have the solar panel move with the sun as it appears to travel across the sky during the day? You could certainly capture more of the sun's energy and produce more power. There are devices that allow you to do this – they are called Sun Trackers.

A Sun Tracker is really a mechanical device that keeps the solar panel pointed directly at the sun during the day and, with some models, during the seasons. The basic type is called a single-axis Sun Tracker because it only moves the solar panel back and forth as the sun moves across the sky during the day. A more powerful model called a dual-axis sun tracker moves the solar panel up and down depending on the elevation of the sun during the year. Figure 5 shows such a model.

Figure 5 – Dual-Axis Sun Tracker

So what if you could add a Sun Tracker to your solar panel? How much more energy could you capture from the sun as compared with no tracking device? You can find the answers on the web. Just go to a search engine like Yahoo or Google or Bing to find out.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 24 – Types of PV Systems
Page 28 –The Electromagnetic Spectrum

Web Links

To learn more about solar cells start with this link from the "How Stuff Works" website.
http://science.howstuffworks.com/solar-cell.htm

To find out more about solar radiation in your geographical area try this link.
http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/

To determine the best tilt angle for your particular location at anytime of the year go here..
http://ocw.mit.edu/ans7870/SP/SP.769/f04/java/pvapplet/PVPanel.html

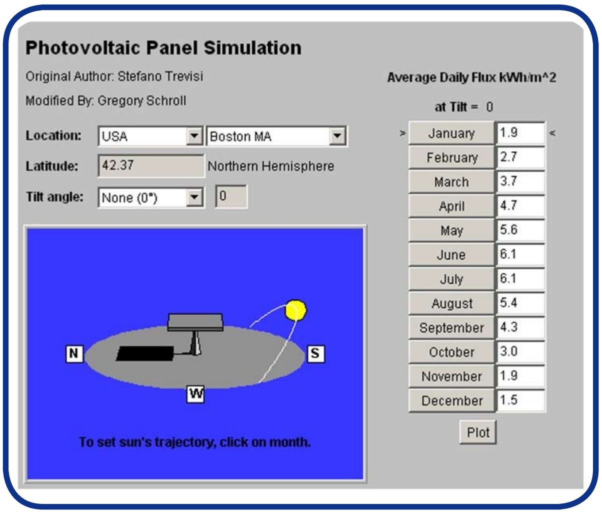


Figure 6 – Photovoltaic Panel Simulation Software

Do More Research

Have students do research on the following topic - Concentrating photovoltaic systems.

Two major types of PV systems are available in the marketplace today: flat plate and concentrators. Both are required to be mounted at specific angles to the sun, while concentrator systems absolutely require a Sun Tracker for proper operation.

Flat plate systems are the most common, and they consist of PV modules on a rigid and flat surface to capture sunlight. These are the common solar panels we see mounted on buildings or towers.

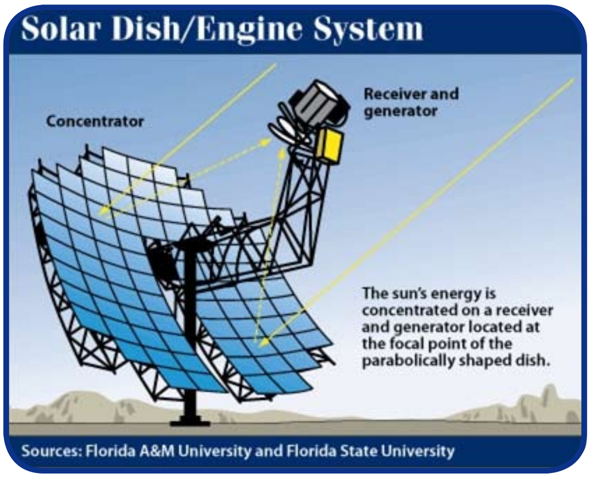
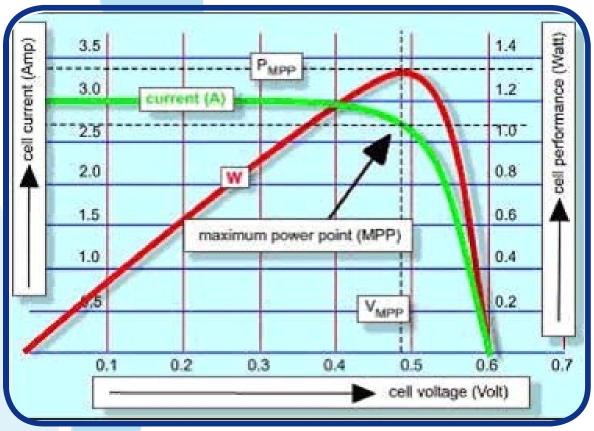


Figure 7 – Solar Concentrator System

Concentrating photovoltaic systems, as in the above image, use a specifically designed area of mirrors or lenses to focus the sunlight into a small area of cells mounted above the mirrors. These systems reduce the amount of semiconducting material, and improve the performance of the system. If these systems have single or dual axis tracking, they are called Heliostat Concentrator Photo Voltaics (HCPV). Although there are many advantages to this type of system it has been limited mainly due to the cost.

Finding a Solar Panel's Maximum Power Point



LESSON OVERVIEW

This lesson demonstrates the concept of the Maximum Power Point (MPP) where the solar panel is capable of delivering its full power into a load. Because the MPP varies with the solar panel's position and loading conditions, it is important to know how to find and maintain the MPP to get the full power output from a solar panel.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will observe the photovoltaic effect of sunlight and artificial light producing electricity.
- Students will learn how to find the maximum power point of a solar panel.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the Maximum Power Point (MPP) is achieved when the resistance of the solar panels matches the load. Students vary the load resistance and tilt angle to produce maximum power.

Students come to understand that:

1. Maximum power is not maximum voltage or maximum current by itself but when voltage and current combine to produce maximum power.
2. Besides changing the value of the load resistance the MPP can vary with changing solar panel's tilt angle.
3. Solar powered race cars use an electronic device that constantly keeps the solar panel's power at a maximum level for the car's electric motor. This device helps win races.

STUDENT ACTIVITIES

Students hookup a solar panel to a potentiometer (variable resistor) load. They adjust the resistance to find the solar panel's MPP. Once the MPP is found they tilt the solar panel to another position and repeat the exercise to see if the MPP has shifted. Data are recorded for each of these two exercises and later analyzed.

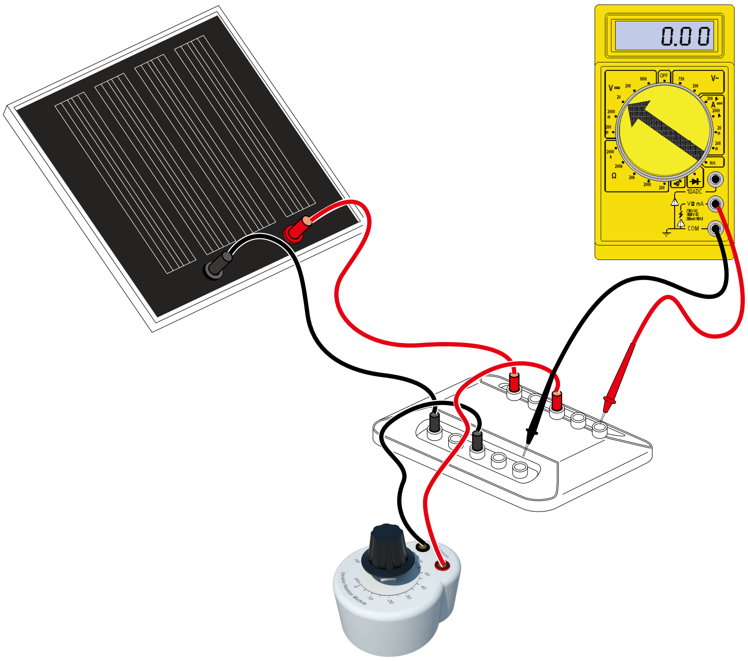
SAFETY

Normal caution must be exercised when using an artificial light source like a table lamp to illuminate a solar panel. Be sure NOT to overheat the solar panel as it will become HOT TO THE TOUCH and may MELT THE PLASTIC.

The Experiment with a Multimeter

Materials

1 – Solar panel
1 – Table lamp with 60 watt blub or sunlight
1 – Protractor
1 – 100 ohm potentiometer
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base



Equipment Setup

Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the potentiometer to 100 ohms
2. Set the multimeter dial to DC Volts with a range of at least 10 VDC.
3. Place the solar panel flat on the table facing straight up.
4. Shine the table lamp directly on the solar panel.
5. Record the voltage.
6. Adjust the potentiometer for 50 ohms and record the voltage.
7. Repeat step 6 for values of 30, 25, 20, 15 and 10 ohms.
8. Tilt the solar panel at a 45 degree angle to the table.
9. Repeat steps 1 through 7.

Preparing the Data

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the indicated resistor load for each step. Refer to the **Experiment Guide** section for details on how to do this.

Solar Panel Flat

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			
25 ohms			
20 ohms			
15 ohms			
10 ohms			

Solar Panel at 45^0

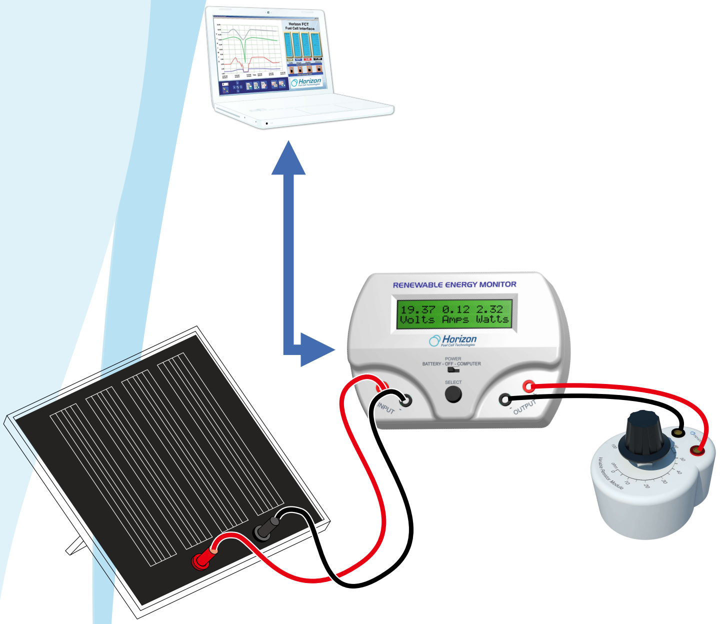
Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			
25 ohms			
20 ohms			
15 ohms			
10 ohms			

The Experiment with the Renewable Energy Monitor

Materials

1 - Solar panel
1- Goose neck table lamp
1 - Protractor
1 - 100 ohm potentiometer
2 – Red hookup leads
2 – Black hookup leads

Equipment Setup



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Ohms display appears

3. Adjust the potentiometer for 100 ohms. Light must be shining on the solar panels for this to occur.
4. Push the Select Button until the Volts Amps Watts display appears.
5. Place the solar panels flat on the table facing straight up.
6. Shine the table lamp directly on the solar panels.
7. Record the voltage, current and power.
8. Push the Select Button until the Ohms display appears.
9. Adjust the potentiometer for 50 ohms. Light must be shining on the solar panels for this to occur.
10. Push the Select Button until the Volts Amps Watts display appears.
11. Record the voltage, current and power.
12. Repeat steps 8 through 11 for 30, 25, 20, 15 and 10 ohms.
13. Tilt the solar panel at a 45 degree angle to the table
14. Repeat steps 1 through 12.

Preparing the Data

Have the students enter the voltage, current and power into the tables below:

Solar Panel Flat

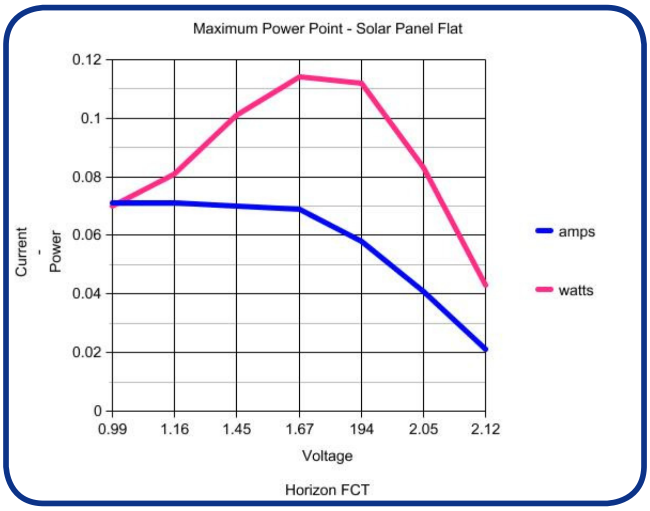
Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			
25 ohms			
20 ohms			
15 ohms			
10 ohms			

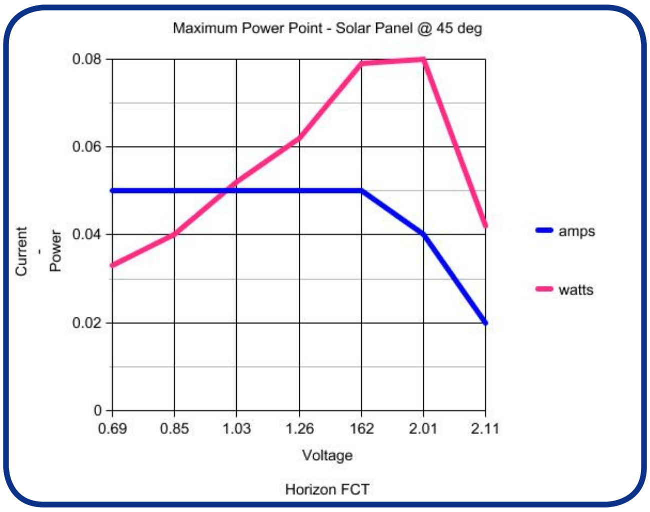
Solar Panel at 45^0

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			
25 ohms			
20 ohms			
15 ohms			
10 ohms			

Analyzing the Results

Using the data in the tables have the students make two graphs. The graph plots the current and power (vertical axis) against the voltage (horizontal axis). One graph plots these values for the solar panel lying flat and the other plots the solar panel at a 45 degree angle. The graphs will look something like the ones below. The data were taken from our measurements. Your plots should resemble these data points. These plots were created using software from the following website: http://nces.ed.gov/nceskids/createAgraph/





What we can see by analyzing these two graphs is that the MPP "shifts" with the solar panel's position. This is important since if the solar panel is mounted on a moving object like a car, boat or airplane, the MPP will always be changing. Think of what the Helios solar powered plane must do to continually track the MPP. It can stay aloft for weeks at a time, so it needs to do this very well – and all the time as it flies.

Figure 1 – Helios Solar Powered Plane

What If ???

Have students speculate on the following hypothetical question.

What if your class decided to build a solar race car? You know that if you just hooked up the car's motor to a solar panel – maybe with a switch in between to start and stop the motor – the solar panel's voltage and power would change as the car moved, much like you saw when you tilted the panel in this experiment. If this happened then the car would speed up and slow down without any control. And since the car is going in unpredictable directions for a Sun Tracker to follow the sun, what kind of circuit can you add between the solar panel and the motor to capture the MPP at all times? Hint…the device is called a MPPT or Maximum Power Point Tracker and you can find information about it on the Web.

Links to the Renewable Energy Science Educational Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 36 – Solar Powered Cars

Page 35 – Solving Solar Powered Issues

Web Links

To learn more about solar powered vehicles – cars, boats and planes - go here.

http://en.wikipedia.org/wiki/Solar_vehicle

To help with our "What If" question here is a link to solar powered race cars.

http://en.wikipedia.org/wiki/Solar_car_racing

Solar powered electric boats are becoming popular. Look at the wide variety of the ones here. All use MPPT technology.

http://en.wikipedia.org/wiki/Electric_boat

Figure 2- RA66 Helio solar-powered 20 meter catamaran

Do More Research

Have students do research on the following topic – inverters:

Excerpted from the RE Science Educational Manual – page 35 "One other important aspect of a PV system is that the energy generated by the system is in the form of direct current (DC). The electricity supplied by the utility and the type used by the appliances in your house is alternating current (AC). Therefore, a device is needed to convert DC to AC. This device is called an inverter. "

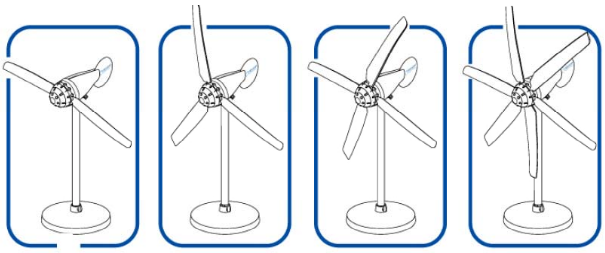
Figure 3 – Simple Appliance Inverter

To convert DC to AC an inverter "chops up" the steady DC voltage which makes it into a very raw form of AC voltage. The raw AC is then "stepped up" to a higher AC voltage by inductors and capacitors which also serve to filter it, as well. The end product is 60 Hz AC power that can run conventional appliances or [in larger systems] actually feed the power grid from solar panels on roofs.

With this background have students investigate inverter technology as it applies to powering small appliances all the way up to feeding the power grid. Here is a good place to start.

http://en.wikipedia.org/wiki/Solar_inverter

Wind Power
How Many Blades Are Best - 1, 2, 3... More ?



Using the right number of blades for a given wind condition is important in extracting the maximum electrical power from a wind turbine. In this experiment students gain an understanding of the choices between the numbers of blades that are necessary to produce the most power.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn about how different numbers of blades produce different power outputs from the wind turbine.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students witness how two, three, four and six blades produce varying amounts of power for the same wind speed.

Students come to understand that:

1. Adding more blades may, or may not, generate more power.
2. Adding more blades creates more "drag" caused by increased wind resistance.
3. Reducing the number of blades may result in higher output power.
4. The wind turbine will run smoother with more blades.

STUDENT ACTIVITIES

Students select from the three types of curved blades supplied for the model wind turbine. They start with two blades attached to the hub and measure and record the wind turbine's power output at the highest fan speed setting. They add additional blades and repeat the experiment until the final number of blades equals six. They then analyze the results of the power generated to determine the optimum number of blades that produce the maximum power output. Students are free to mix and match from the three different blade types supplied with the wind turbine.

SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

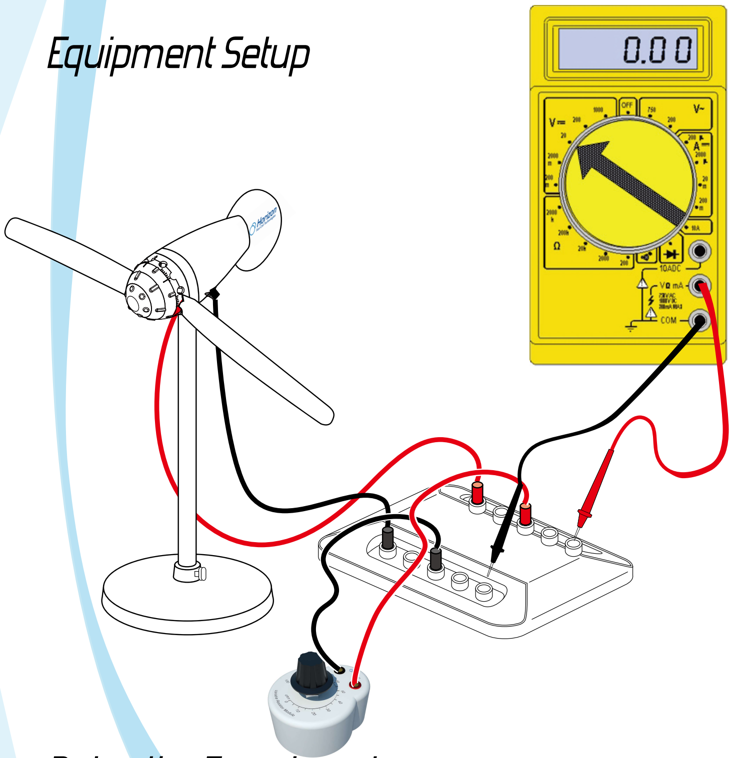
Materials

1 – WindPitch Wind Turbine
1- Table fan (20” diameter recommended)
1 - 100 ohm potentiometer
6 – Curved blades
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Wind Turbine Blades

To begin, install two (2) blades of any type on the wind turbine hub and attach the hub to the alternator shaft. Refer to the **WindPitch Assembly Guide** for instructions on how to do this. You will add more blades later.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

Note: You may mix and match any of the blades that come with the wind turbine. Make sure to arrange the blades on the hub so that they are symmetrical and balanced. Also make sure that you keep the pitch angle the same for each test; the wind turbine is very sensitive to it.

1. Adjust the potentiometer dial to 75 ohms.
2. Set the multimeter dial to Volts with a range of at least 10 volts.
3. Place the table fan in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Measure the voltage.
5. Repeat step 4 with 3 blades
6. Repeat step 4 with 4 blades
7. Repeat step 4 with 6 blades

Preparing the Data

Have the students enter the voltage readings in the table below. Then have them compute the current and power based on the 75 ohm resistor load for each step. Refer to the **Experiment Guide** section for details on how to do this. Listed below is an example of our experiment.

Our Data **Resistance=75 ohms**

Blades	Volts	Amps	Watts
2	6.160	0.083	0.511
3	6.528	0.088	0.574
4	6.375	0.086	0.548
6	6.639	0.089	0.591

Your Data **Resistance=75 ohms**

Blades	Volts	Amps	Watts
2			
3			
4			
6			

The Experiment with the Renewable Energy Monitor

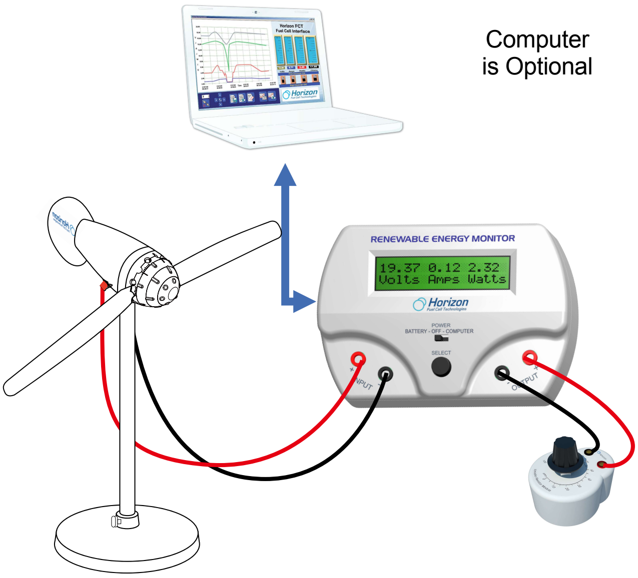
Materials

1 – WindPitch Wind Turbine
1 – Table fan (20” diameter recommended)
1 – 100 ohm potentiometer
6 – Curved blades
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Wind Turbine Blades

To begin, install two (2) blades of any type on the wind turbine hub and attach the hub to the alternator shaft. Refer to the **WindPitch Assembly Guide** for instructions on how to do this. You will add more blades later.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!
Note: You may mix and match any of the blades that come with the wind turbine. Make sure to arrange the blades on the hub so that they are symmetrical and balanced. Also make sure that you keep the pitch angle the same for each test; the wind turbine is very sensitive to it.

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the mV-mA-mW display appears.

3. Place the table fan directly in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Adjust the 100 ohm potentiometer until the maximum power in mW is displayed.
5. Record the voltage, current and power.
6. Repeat step 5 with 3 blades.
7. Repeat step 5 with 4 blades.
8. Repeat step 5 with 6 blades.

Preparing the Data

Listed below is an example of our experiment.

Our Data

Blades	mV	mA	mW
2	6160	83	511
3	6528	88	574
4	6375	86	548
6	6639	89	591

Your Data

Blades	mV	mA	mW
2			
3			
4			
6			

Analyzing the Results

If you used the Renewable Energy Monitor connected to a computer for the experiment, your data plot should look something like Figure 1 for each of the blade settings.

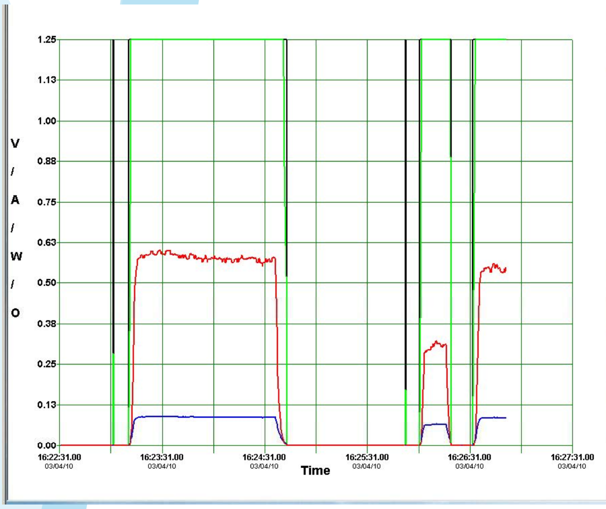


Figure 1 – Plot of Voltage (green) and Power (red) with Different Number of Blades

Our data suggests that the power generally increases with more blades; that is, at a constant wind speed. Your data may, of course, vary from ours as your fan size and speed may be different.

Our Data

Blades	mV	mA	mW
2	6160	83	511
3	6528	88	574
4	6375	86	548
6	6639	89	591

The important thing to consider is what blade shapes you used for the experiment (BP-28, NACA 44 or NACA 63) and how you mixed and matched them. Other blade types may give different results. If you have time you should repeat the experiment with different blade shapes and mixes.

What If ???

Have students speculate on the following hypothetical question.

What if you were a wind turbine engineer and your company asked you to design a wind turbine for both high winds and low winds. Could you design just one wind turbine to fit both requirements? Or would you have to design two different wind turbines; one for high wind and one for low wind?

As an engineer the questions you need to ask yourself are:

1. Does a wind turbine with three blades perform better in high winds or low winds?
2. Does a wind turbine with six blades perform better in high winds or low winds?
3. Where can I find data to support my choices and how can I use the data to design my wind turbine(s).

Fortunately we have some of the data for you to begin your design task; part of this data is the results of this experiment with six blades and the previous experiment with three blades. There are also well established equations to help such as the one below:

$$P = 0.5*\rho*A*V^3$$

Where…

P = Power in Watts

ρ= Air Density in Kg/m³ (about 1.225Kg/m at sea level)

A = Rotor Swept Area in m² = πr² (r= radius of the rotor)

V = Wind Speed in m/s

While air density has some effect on output power, the important parts of the equation have to do with wind speed and blade area. You should notice that the power is proportional to the cube of the wind speed and the square of the radius of the rotor blades. If the radius of the rotor blades is doubled, the swept area is quadrupled. Also, If wind speed decreases by half (1/2), the power generated decreases by 1/8th of the original force. As a light wind contains little force, it may be better to use more blades to capture all the wind power. On the other hand, if the wind speed is heavy, fewer blades may be necessary.

Another factor to consider is how much power can be extracted from the wind regardless of wind speed. Albert Betz was a German Physicist and a pioneer of wind turbine technology. Betz found out that we can only harvest, at maximum, 16/27 or 0.593 of the power from the wind. This number is called the Betz coefficient and is the theoretical maximum efficiency that a wind turbine can harvest from the wind.

In the real world we have to take into account many other factors that affect the wind power being converted into electrical power by the wind turbines. The efficiency of wind turbines is affected by the blade parameters, generator efficiency and the mechanical losses in the gear box, etc.

But remember, you don't want this to happen to your wind turbine, so make sure you design it correctly.

Figure 2 – Wind Turbine on Fire

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 43 – Aerodynamics of Wind Turbines
Page 49 - Energy and Power in the Wind
Page 49 - Potential of Wind Power
Page 49 - Distribution of Wind Speed

Figure 3 – Small Wind Turbine

Web Links

To learn more about small wind turbines for homes and farms…look here.

http://www.awea.org/smallwind/smsyslst.html

http://www.windustry.org/your-wind-project/home-and-farm-scale-wind/home-and-farm-scale-wind

Do More Research

Have students do research on the following topic – small wind turbines:

Small wind turbines; that is, wind turbines that generate between 100 and 500 watts are becoming popular for applications for street lighting, on farms and on boats. These are generally used to charge batteries when the wind is blowing.

Small wind turbines, sometimes along with solar panels are used to charge batteries during the day to power street lights at night with no drain on the power gird. Figure 4 shows such an application.

Figure 4 – Wind Turbine – Solar Panel combination Power Street Light

On farms where auxiliary power is needed to run electric pumps to irrigate fields or to pump water for livestock small wind turbines fill the bill nicely where abundant wind is present. Figure 5 shows an installation.

Figure 5 – Wind Turbine Pumps Water for Livestock

Sailboats are excellent candidates for small wind turbines to charge the onboard batteries, since a the boat's motor is rarely used during cruising and the boat's crew and skipper depend on all sorts of modern electronics to navigate – all of which take a lot of power from the batteries.

Figure 6 – Wind Turbines Charge Sailboat Batteries

What other applications can you think of that could use small wind turbines?

Wind Power
Using Three Different Curved Blade Shapes

Photo Credit – Southwest Windpower

LESSON OVERVIEW

This experiment demonstrates how blades with different curvatures produce different degrees of power output at different wind velocities.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn about three blade shapes that produce different power outputs from the wind turbine.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students will attach three differently shaped blades to the wind turbine and measure which blade shape produces the highest power for each of three wind conditions.

Students come to understand that:

1. Different blade shapes produce varying power levels for specific wind speeds.
2. Certain blade shapes are better in producing power at higher wind speeds while others are better at lower wind speeds.
3. The blades are designed to aircraft standards and are the same as those used in real airplane and helicopter wings – only smaller.

STUDENT ACTIVITIES

Students assemble a model wind turbine with three blades then measure the electrical power output at three wind speeds – low, medium and high. They change the blade type then re-test the electrical power output at the same three wind speed settings. Students then analyze and explain the results of using each blade type.

SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

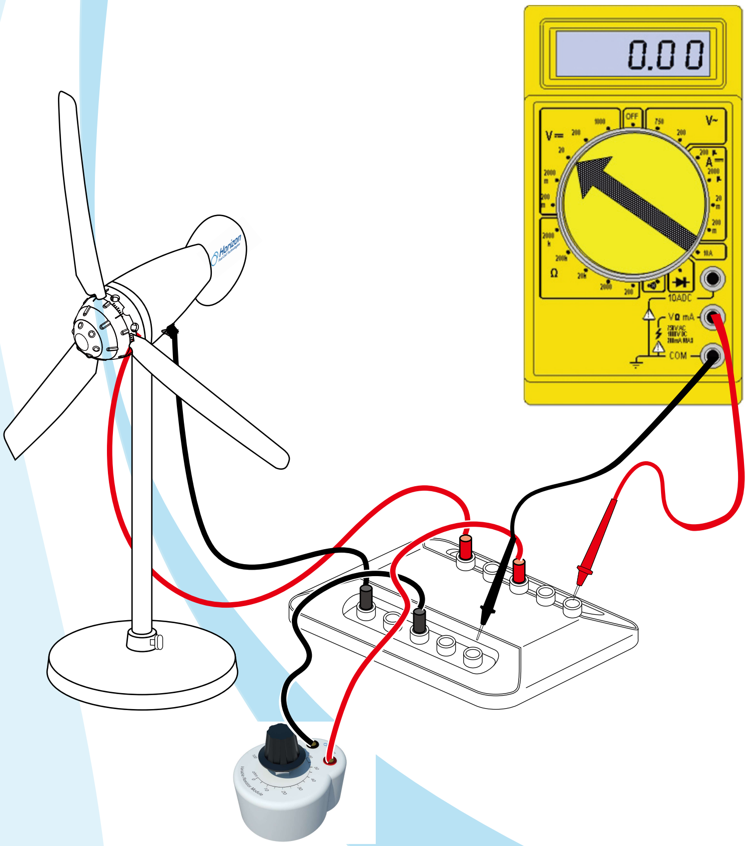
Materials

1 – WindPitch Wind Turbine
1 – Table fan (20" diameter recommended)
1 – 100 ohm potentiometer
3 – BP-28 blades
3 – NACA-44 blades
3 – NACA-63 blades
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Wind Turbine Blades

Install three (3) BP-28 blades on the wind turbine hub and attach the hub to the alternator shaft. Set the pitch to 15 degrees. Refer to the **WindPitch Assembly** Guide for instructions on how to do this.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Adjust the potentiometer dial to 75 ohms.
2. Set the multimeter dial to Volts with a range of at least 10 volts.
3. Place the table fan in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Record the voltage.
5. Set the table fan to a medium speed setting.
6. Record the voltage.
7. Set the table fan to the lowest speed setting.
8. Record the voltage.
9. Replace the blades with type NACA-44 and repeat steps 3 through 8.
10. Replace the blades with type NACA-63 and repeat steps 3 through 8.

Preparing the Data

Have the students enter the voltage readings in the table below. Then have them compute the current and power based on the 75 ohm resistor load for each step. Refer to the **Experiment Guide** section for details on how to do this. Listed below is an example we did using data we collected. Add two other similar tables for the other two blade types.

Our Data

Wind Speed	Volts	Amps	Watts
High	4.2	0.080	0.336
Medium	2.4	0.088	0.210
Low	1.3	0.038	0.049

Your Data

Wind Speed	Volts	Amps	Watts
High			
Medium			
Low			

The Experiment with the Renewable Energy Monitor

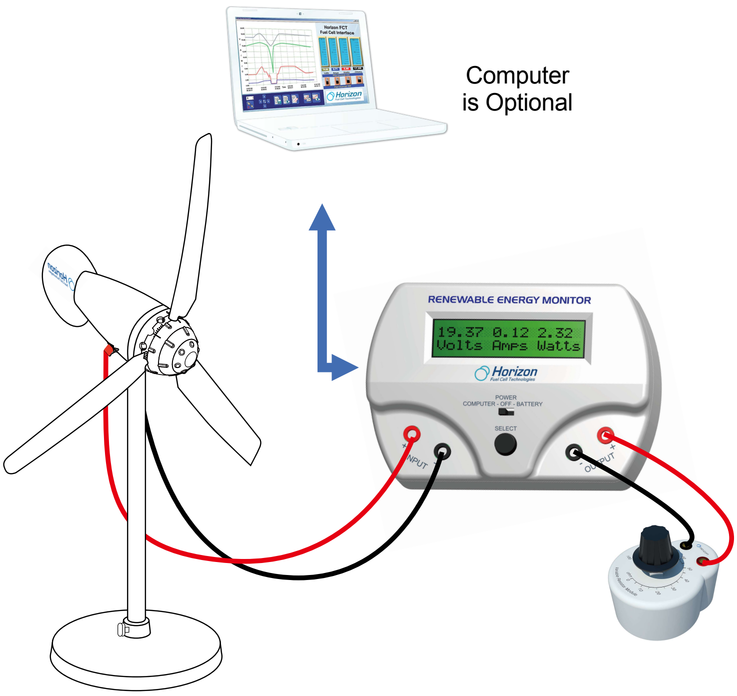
Materials

1 – WindPitch Wind Turbine
1- Table fan (20” diameter recommended)
1 - 100 ohm potentiometer
3 – BP-28 blades
3 – NACA-44 blades
3 – NACA-63 blades
2 – Red hookup lead
2 – Black hookup lead

Wind Turbine Blades

Install three (3) BP-28 blades on the wind turbine hub and attach the hub to the alternator shaft. Set the pitch to 15 degrees. Refer to the **WindPitch Assembly Guide** for instructions on how to do this.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the mV-mA-mW display appears.

3. Place the table fan directly in front of the wind turbine and about 2 feet away from it and set it to its highest speed setting.
4. Adjust the 100 ohm potentiometer until the maximum power in mW is displayed.
5. Record the voltage, current and power.
6. Set the table fan to a medium speed setting.
7. Record the voltage, current and power.
8. Set the table fan to the lowest speed setting.
9. Record the voltage, current and power.
10. Replace the blades with type NACA-44 and repeat steps 1 through 9.
11. Replace the blades with type NACA-63 and repeat steps 1 through 9.

Preparing the Data

Have the students enter the voltage, current and power readings in the table below. Add two other similar tables for the other two blade types.

Our Data 3 BP-28 Blades at 15^0 Pitch

Wind Speed	mV	mA	mW
High	4200	80	336
Medium	2400	88	210
Low	1300	38	49

Your Data 3 BP-28 Blades at 15^0 Pitch

Wind Speed	mV	mA	mW
High			
Medium			
Low			

Analyzing the Results

If you used the **Renewable Energy Monitor** connected to a computer for the experiment, your data plot should look something like Figure 1 for each of the wind speed settings.

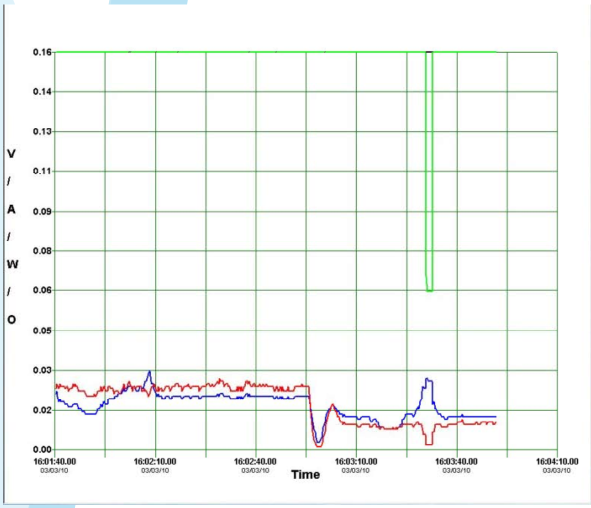


Figure 1 – Plot of Power Levels for BP-28 Blades

Our Data BP-28 Blades at 15^0 Pitch

Wind Speed	mV	mA	mW
High	4200	80	336
Medium	2400	88	210
Low	1300	38	49

Our Data 3 NACA-44 Blades at 15^0 Pitch

Wind Speed	mV	mA	mW
High	4200	80	336
Medium	2400	88	210
Low	1300	38	49

Our Data 3 NACA-63 Blades at 15^0 Pitch

Wind Speed	mV	mA	mW
High	4200	80	336
Medium	2400	88	210
Low	1300	38	49

The results from our tests suggest that the BP-28 generates the most power at all fan speed settings. Your results may vary due to your fan speed settings and distance from the wind turbine.

Wind Speed	Most Power Blade Type
High	BP-28
Medium	BP-28
Low	BP-28

What If ???

Have students speculate on the following hypothetical question.

If you were an engineer and were directed by your company to build a real wind turbine using any of the three blade types here, what blade type would you choose? Your answer will depend, in part, on how fast the wind blows in the area where the wind turbine will be installed.

For example, if you were to install a wind turbine in the middle of a large city where the wind usually low due to buildings that interfere with the normal wind flow, you would choose one blade type.

Then if your wind turbine's site was in the country with a lot more space but with a lot of trees around to breakup the wind, you might choose another.

Finally, if the wind turbine were installed on a flat, arid plain where the wind blows unobstructed night and day you may choose even another. Therefore, based on your data decide on the type of blade for each of the three examples above and tell why you chose it.

Links to the Renewable Energy Science Educational Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 45 – Types of Wind Turbines

Page 47 – Parts of a Wind Turbine

Web Links

Advanced Airfoils for Wind Turbines is a great link that describes how wind turbine blades are similar but different from aircraft blades due to the different stress levels experienced by them.

Figure 2 – Checking Turbine Blades for Stress

http://www.osti.gov/accomplishments/document s/fullText/ACC0195.pdf

The following link is from NREL, the National Renewable Energy Laboratory in Colorado. It explains airfoil designs using the same blade types used in the experiment.

http://wind.nrel.gov/designcodes/papers/NREL%20Airfoil%20Families%20for%20HAWTs.pdf

Do More Research

Have students do research on the following topic – The Basic Aerodynamic Operating Principles of Wind Turbines

This experiment demonstrated the effects of three wind turbine blade types that are really shaped like aircraft wings. Aircraft wings generate lift and the principles involved in this process is the subject of the research.

There are two basic principles involved with creating lift – the Bernoulli Principle and the Coanda Effect. Though the Bernoulli Principle explains the source of lift in an aircraft wing, on or about 1930 a Romanian engineer by the name of Henri Coanda (1866- 1972) discovered another effect that plays an even larger role in producing lift.

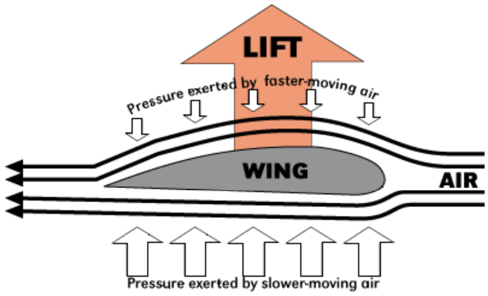
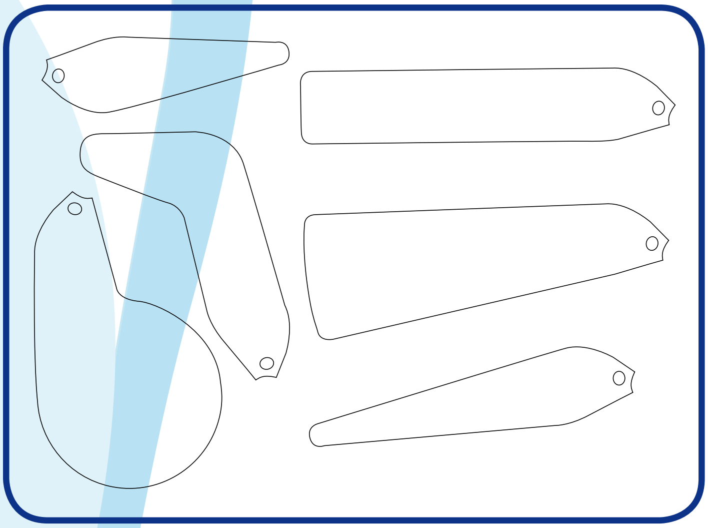


Figure 3 – Bernoulli Principle

The Coanda Effect states that a fluid or gas stream will hug a convex contour when directed at a tangent to that surface. It can be demonstrated by placing the back of a spoon against a running stream of water. The pattern of the water will conform to the spoon's curve. If you hold the spoon so that it is free to swing, you should be able to notice that the spoon is actually being pulled towards the stream of water. The same effect occurs with an airplane wing. If the wing is curved, the airflow will follow the curvature of the wing. Thus, wind turbine blades designed to aircraft standards also conform to the Coanda Effect.

Figure 4 – Example of the Coanda Effect
Image credit for Henri Coanda - Wikipedia

Wind Power Using Blades You Make Yourself



LESSON OVERVIEW

This experiment demonstrates how blades your students make themselves can power the wind turbine. Students can make the blades into any shape and use combinations of three or six of them.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn about blade shapes they make themselves to produce different power outputs from the wind turbine.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students design new and uniquely shaped blades that attach to the wind turbine to see which blade shapes work best in slow and fast wind conditions. They also test three and six blades that they attach to the hub to see what combination of wind speed and number of blades creates the most power. Students gain an understanding of how to make blades that are balanced and work well when spinning.

Students come to understand that:

1. Different blade shapes produce varying power levels for specific wind speeds.
2. Certain blade shapes are better in producing power at higher wind speeds while others are better at lower wind speeds.
3. More blades may or may not produce more power under all wind conditions.
4. Shorter blades are better for high wind conditions and longer blades are better for low wind conditions.

STUDENT ACTIVITIES

Students design blades using common materials like cardboard paper found in most classrooms. They can customize the blades into any shape and paint them in any color. Then they attach them to the model wind turbine and measure the electrical power output at three wind speeds – low, medium and high. Students then analyze and explain the results of using each blade shape.

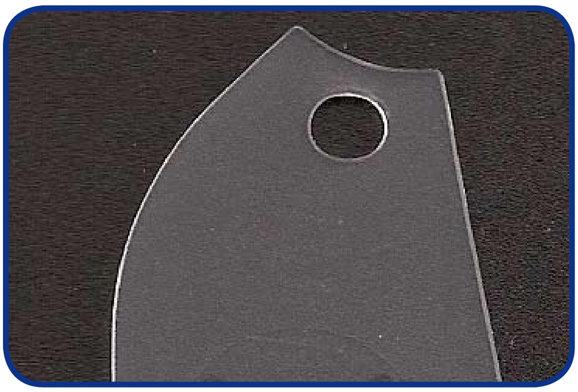
SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

Guide for Making Custom Blades

Designing and cutting out custom blades including the wind vane from sheet plastic is a fun thing for students to do. However, they must be made aware of the following practical issues to be successful – and safe!

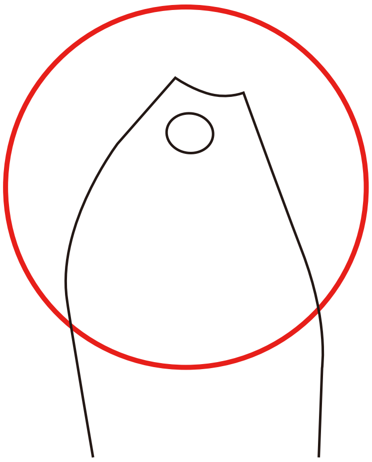
1. The blades can be made from any paper materials such as construction paper or cardboard paper that is rigid enough to withstand the wind and not bend too easily. First draw out the basic shape on a sheet of paper. Then cut it out and use it as a template over the actual cardboard paper or other material to make the actual blades.
2. Use scissors and a hole punch to cut the blades to the shape you want.
3. The blades must be cut so that they are balanced or else the wind turbine will not spin properly.
4. Important - The blades must also be made so that they don't fly apart or break when spinning. This creates a dangerous safety hazard. ***Always have students wear safety goggles when any of the blades are spinning.***
5. Each blade must be able to fit into the hub provided. This means that the bottom end of each blade must conform to the template below. The rest of the blade can be any shape as long as it meets the requirements of steps 1 through 4 above. Your wind turbine came with three flat blades so use this end as a guide for making your own.

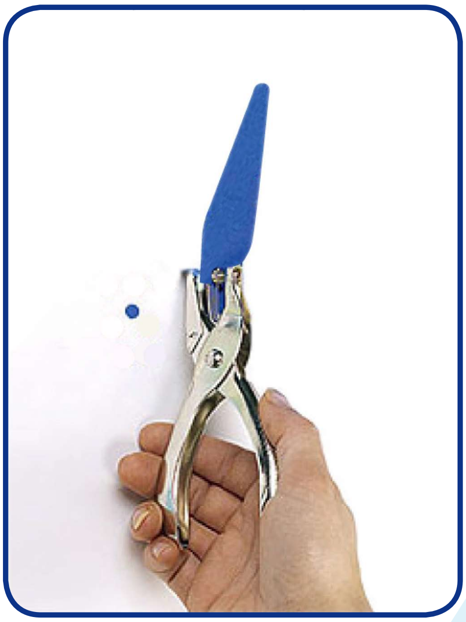


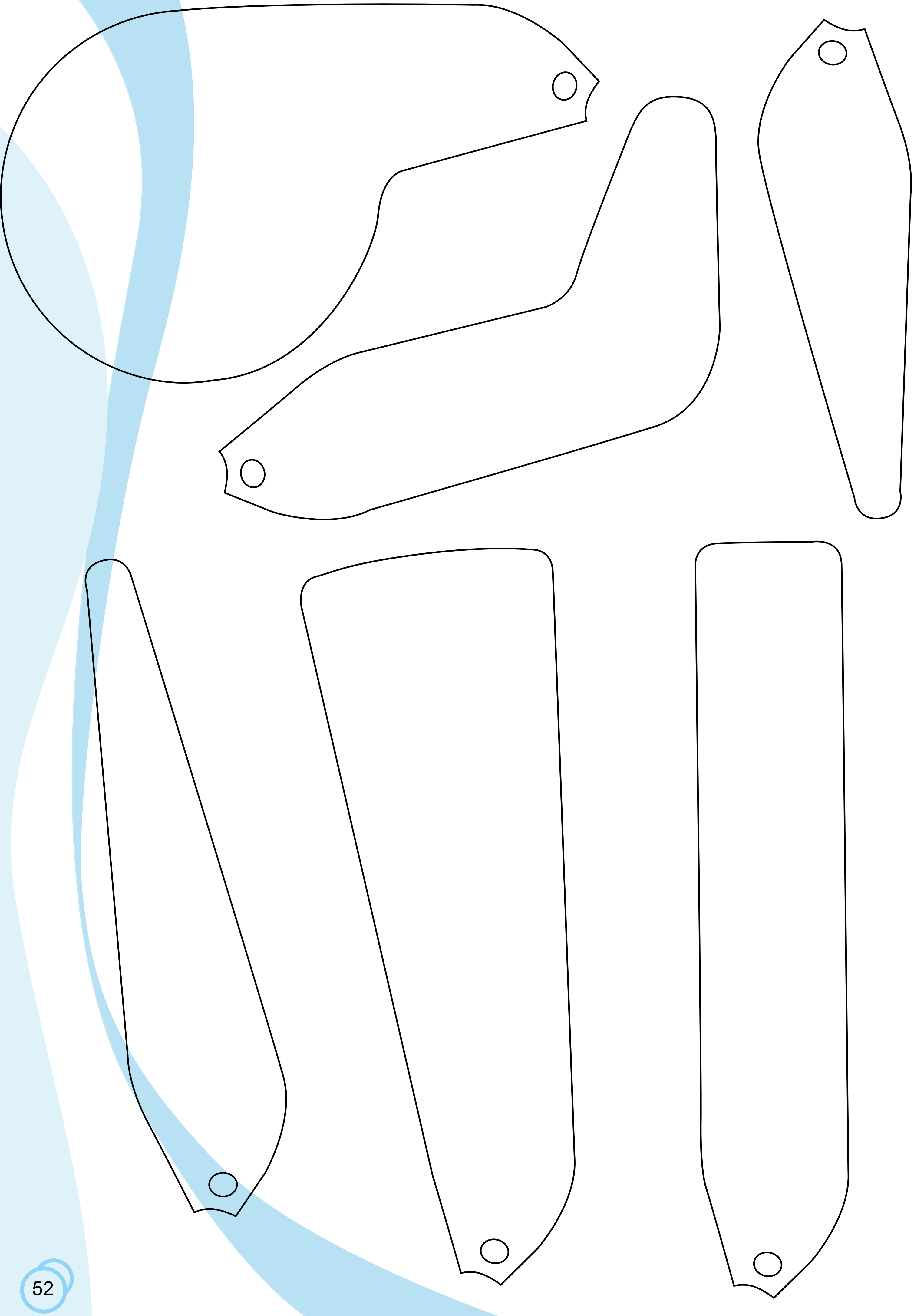
6. For more fun allow the students to color or paint the blades so that they are more customized and attractive. The following are some examples of custom blades, but use your imagination – the sky's the limit – just make sure to follow the rules outlined above.
7. Give your blades a name so that you can tell which ones you used for each experiment.

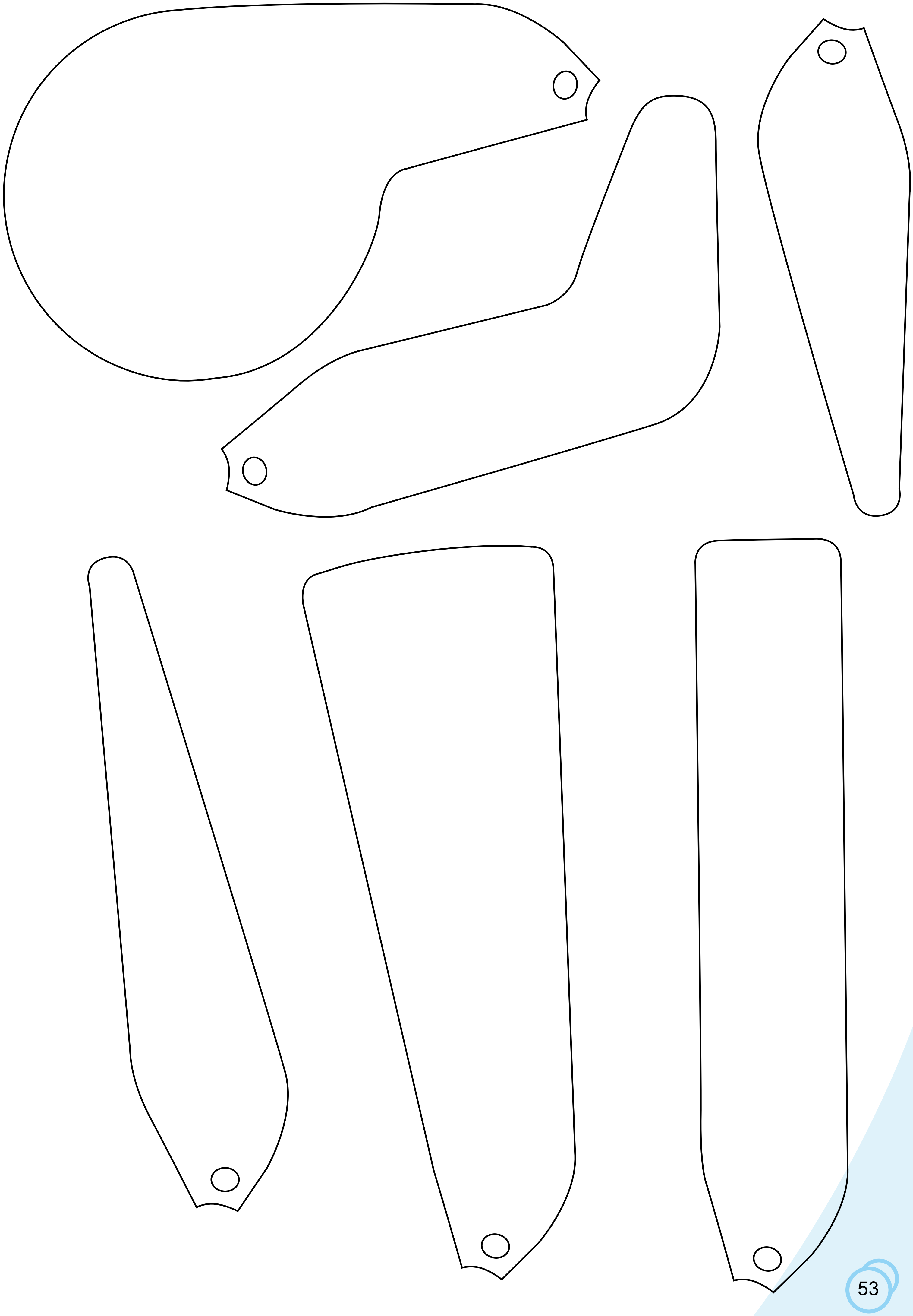
Examples of Custom Blades

Here are some examples of the kinds of blades that you can make yourself. Make sure to create both long and short blades with some narrow and some wide.









The Experiment with a Multimeter

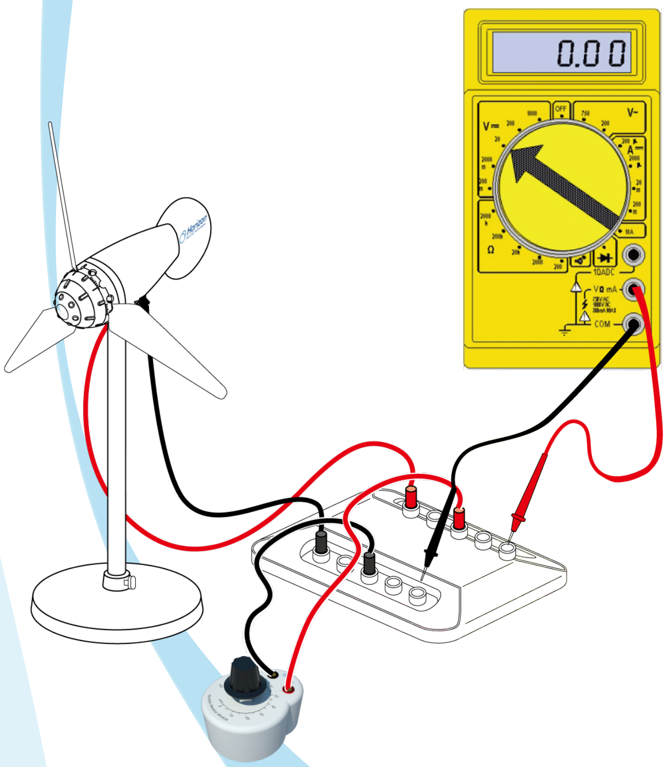
Materials

1 – WindPitch Wind Turbine
1 – Table fan (20" diameter recommended)
1 – 100 ohm potentiometer
3 or 6 Custom blades
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Wind Turbine Blades

To begin, install three (3) blades on the wind turbine hub and attach the hub to the alternator shaft. Refer to the WindPitch Assembly Guide for instructions on how to do this. You will add more blades later.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Adjust the potentiometer dial to 75 ohms.
2. Set the multimeter dial to Volts with a range of at least 10 volts.
3. Place the table fan in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Record the voltage.
5. Set the table fan to a medium speed setting.
6. Record the voltage.
7. Set the table fan to the lowest speed setting.
8. Record the voltage.
9. Repeat steps 3 through 8 with 6 blades

Preparing the Data

Have the students enter the voltage readings in the table below. Then have them compute the current and power based on the 75 ohm resistor load for each step. Refer to the Experiment Guide section for details on how to do this. Add a similar table for six blades.

Your Data **3 Custom Flat Blades**

Wind Speed	Volts	Amps	Watts
High			
Medium			
Low			

The Experiment with the Renewable Energy Monitor

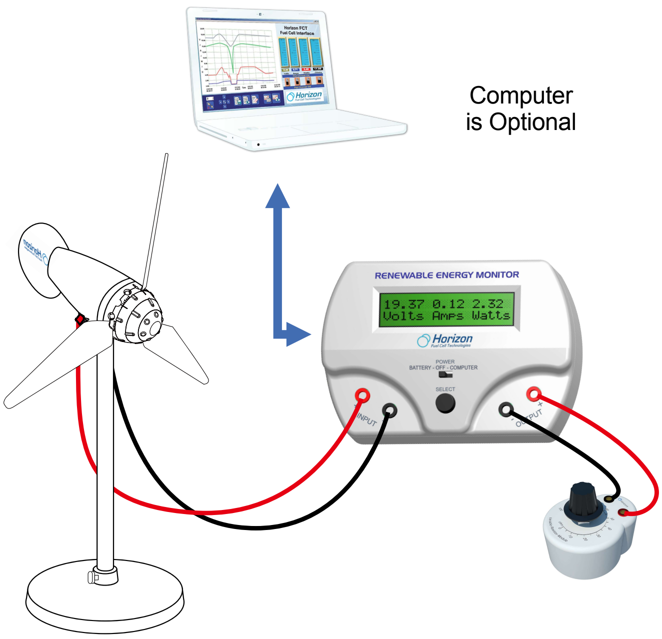
Materials

1 – WindPitch Wind Turbine
1 – Table fan (20” diameter recommended)
1 – 100 ohm potentiometer
3 or 6 Custom Blades
2 – Red hookup lead
2 – Black hookup lead

Wind Turbine Blades

To begin, install three (3) blades on the wind turbine hub and attach the hub to the alternator shaft. Refer to the **WindPitch Assembly Guide** for instructions on how to do this. You will add more blades later.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the mV-mA-mW display appears.

3. Place the table fan directly in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Adjust the 100 ohm potentiometer until the maximum power in mW is displayed.
5. Record the voltage, current and power.
6. Set the table fan to a medium speed setting.
7. Record the voltage, current and power.
8. Set the table fan to the lowest speed setting.
9. Record the voltage, current and power.
10. Repeat steps 4 through 9 with 6 blades

Preparing the Data

Have the students enter the voltage, current and power readings in the table below. Add a similar table for six blades.

Your Data **3 Custom Made Blades**

Wind Speed	mV	mA	mW
High			
Medium			
Low			

Analyzing the Results

If you used the Renewable Energy Monitor connected to a computer for the experiment, your data plot should look something like Figure 1 for each of the three wind speed settings.

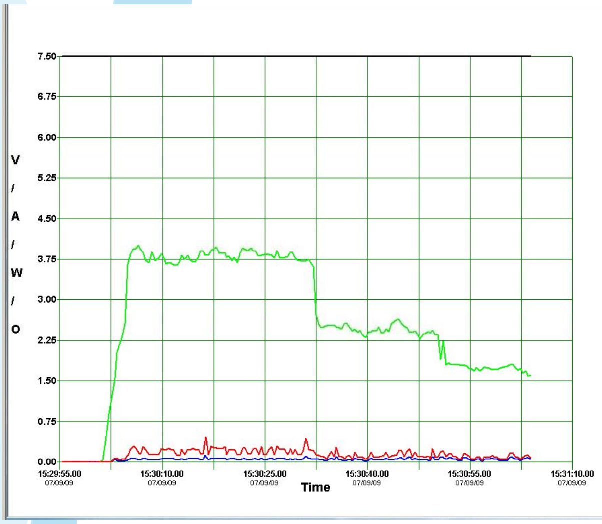


Figure 1 – Plot of Voltage at Three Wind Speeds

Your Data 3 Custom Made Blades

Wind Speed	mV	mA	mW
High			
Medium			
Low			

Your Data 6 Custom Made Blades

Wind Speed	mV	mA	mW
High			
Medium			
Low			

What If ???

Have students speculate on the following hypothetical question.

What if you wanted to build your own wind turbine based on where you live; would you use a flat blade design or a curved blade design? And how many blades would you use – two, thee, six or more? And should the blades be long or short?

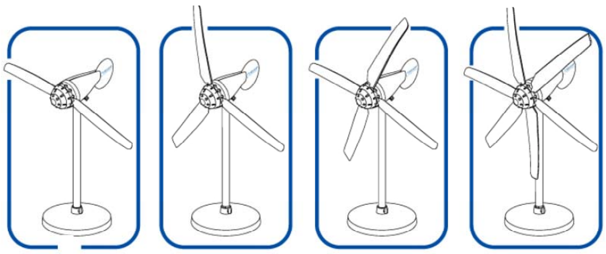


Figure 2 – Two, Three, Four, and Six Blade Turbines

Figure 3 – Traditional Windmill

These may seem like questions not worthy of real consideration; however, where one lives – in the city, the suburbs, low lying country meadows or high in the mountains – has a direct bearing on what type of wind turbine blades, how many and what length are the best to produce the maximum amount of electrical power.

Thus far, the experiments have used both short and long blades in groups of three and six. In all cases the blades are of the "drag" type, since they are flat and do not provide any lift of their own. They are much like the older windmills we are used to seeing.

Traditional windmills (drag type) have used flat blades or sails that would catch the wind and turn a drive shaft. Mechanical energy from the drive shaft would be transmitted through 90 degree gear arrangements and transferred to a point where the mechanical energy was desired, such as a grinding mill. Low wind forces are the choice for this flat-blade design, since grinding wheels and other mechanical parts would be (and have been) destroyed in higher winds.

But for higher wind speeds drag is something to be avoided.

Drag is defined as the force on an object that resists its motion through a fluid. When this fluid is a gas such as air, the force is called aerodynamic drag, or air resistance.

Aerodynamics are an important consideration when studying wind turbines, as aerodynamic drag will decrease the efficiency of wind turbines. As turbine blades rotate with the wind and spin the motor drive shaft, the mechanical force that slows down the system can reduce the amount of power generated. Therefore, increasing the efficiency and reducing the drag on the moving blades is key to generating the maximum amount of power from wind turbines.

These are the main ways to reduce drag in wind turbine systems:

- changing the pitch or angle of the blades
- using fewer blades
- employing light weight materials to reduce the mass of the blades
- using smooth surfaces on the blades as rough surfaces create more friction with the air
- optimizing the shape of the blades to be more aerodynamic.

This last point is important since designing a blade that has lift rather than drag as its main component for turning a rotor will produce much more power in higher winds.

Figure 4 – Large Wind Turbine Blade

A lift-type blade is like airplane propeller, which is really a curved wing that pulls in the air rather than just having the air push it around like a drag-type blade. To work, a lift-type blade needs sufficient wind to make it spin and drive the wind turbine's rotor to make electricity.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 43 – Aerodynamics of Wind Turbines
Page 45 – Types of Wind Turbines

Web Links

To learn more about wind turbine design start here:
http://en.wikipedia.org/wiki/Wind_turbine_design

Do More Research

Have students do research on the following topic – vertical axis wind turbines (VAWT):

Thus far our experiments have used a horizontal axis wind turbine (HAWT). However, there is another category of wind turbines that are suited for lower wind speeds and use in crowded areas like cities, towns and suburban neighborhoods. These are called vertical axis wind turbines and they come in all shapes and sizes.

Excerpted from the RE Science Educational Manual – page 46 "French engineer G. M. Darrieus first developed a vertical axis generator which had some commercial success in the 1920s. The shape of the blades make the vertical axis machine look like a vertical eggbeater.

Figure 5 – Darrieus Wind Turbine

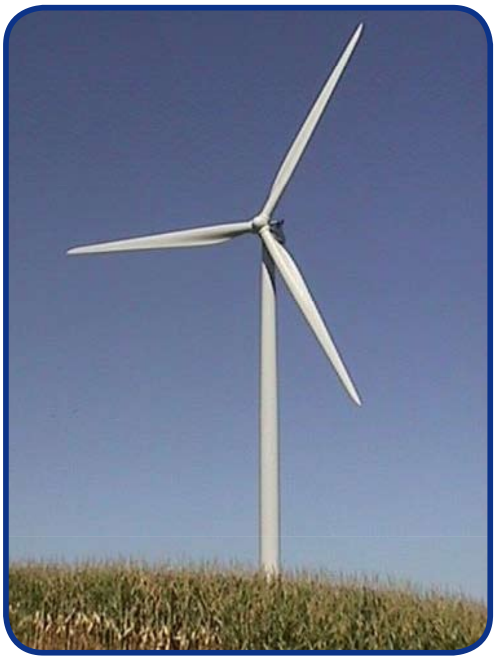
Vertical axis wind turbines can harness winds from every direction without the need to reposition the rotor when the direction changes. The biggest advantage of the vertical axis turbine is that it did not need yaw control to keep it facing into the wind. Another advantage is that the many of the mechanical components are located near the ground where they can be serviced easily. In the vertical configuration, the tower does not need to be as strong as the HAWT because there is not heavy equipment perched on top of the tower.

There are also several disadvantages of vertical axis turbines. One is that the blades are closer to the ground, where the wind speed is lower. Winds closer to the ground are not only slower, but more turbulent – which increases stresses on VAWTs. Also, in low-speed winds, Darrieus rotors have very little starting torque, and the output power must be controlled to protect the generator."
Some of these disadvantages are overcome by incorporating a hybrid design using lift-type blades mounted higher above the ground like this modern VAWT.

Figure 6 – Modern VAWT

With such a wide variety of vertical axis wind turbine designs, students will not be at a loss for finding and researching all sorts of models for any location and wind conditions.

Wind Power Turbine Efficiencies



LESSON OVERVIEW

While power from the wind is free as long as it blows, it is still limited to certain physical laws. This experiment will show you how to measure the extracted wind power with three different resistor loads to determine how efficient the wind turbine converts wind energy to electrical energy.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn to compute efficiency
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that a wind turbine is a combination electrical and mechanical device that uses wind-driven rotating blades connected to a rotor shaft which, in turn, is connected to a generator that produces DC electricity.

Students come to understand that:

1. A wind turbine is a mechanical device that generates electricity using magnets and wire coils that is called an alternator.
2. The amount of electrical power and overall efficiency of the alternator depends on the attached load.
3. The parts of a wind turbine are complex and work together to produce clean, non-polluting electrical power.

STUDENT ACTIVITIES

Students attach a model wind turbine to a variable resistor called a potentiometer. Using a large electric fan, wind is generated in order to spin the wind turbine blades that cause the alternator to create electricity. Students adjust the potentiometer to three resistance values that cause the wind turbine to produce different levels of voltage, current and power. These electrical parameters are measured and used to determine the wind turbine's relative efficiencies with these three load values. Students then analyze and explain the results.

SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

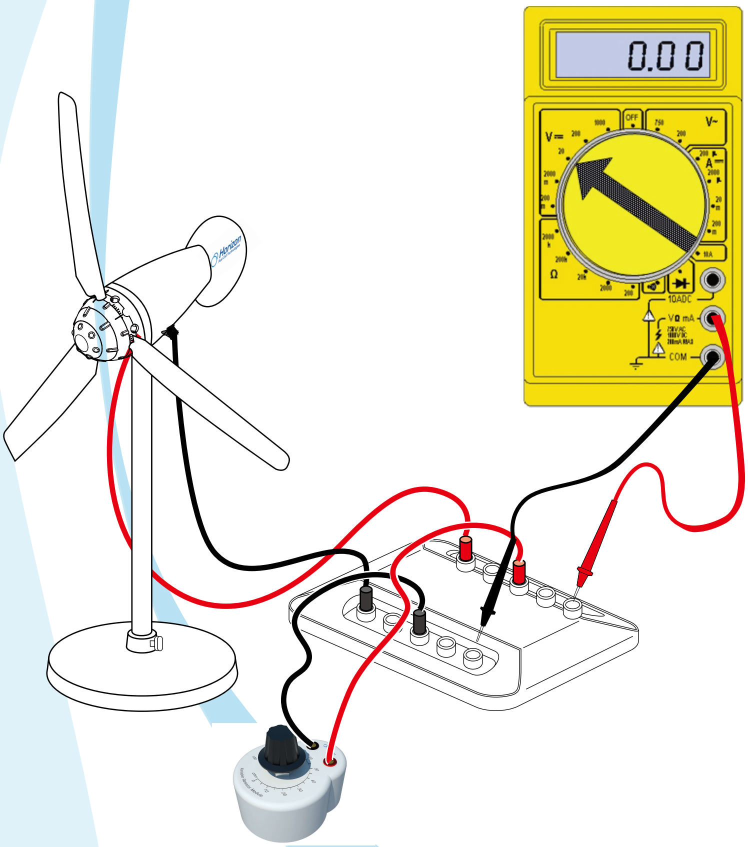
Materials

1 – Wind Turbine with 3 NCAA 44 blades
1 – Table fan (20" diameter recommended)
1 – 100 ohm potentiometer
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Wind Turbine Blades

Install three NCAA 44 blades on the wind turbine hub, set the pitch angle to 15^{0} and attach the hub to the alternator shaft. Refer to the **WindPitch Assembly Guide** for instructions on how to do this.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Adjust the potentiometer dial to 75 ohms.
2. Set the multimeter dial to Volts with a range of at least 10 volts.
3. Place the table fan in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Record the voltage.
5. Adjust the potentiometer for 50 ohms.
6. Record the voltage.
7. Adjust the potentiometer for 25 ohms.
8. Record the voltage

Preparing the Data

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the indicated resistor load for each step. Refer to the **Experiment Guide** section for details on how to do this. As an example we did it for the data we took. Your results will vary.

Our Data

Resistance	Volts	Amps	Watts
75 ohms	5.548	0.074	0.411
50 ohms	4.570	0.092	0.420
25 ohms	3.139	0.124	0.398

Your Data

Resistance	Volts	Amps	Watts
75 ohms			
50 ohms			
25 ohms			

The Experiment with the Renewable Energy Monitor

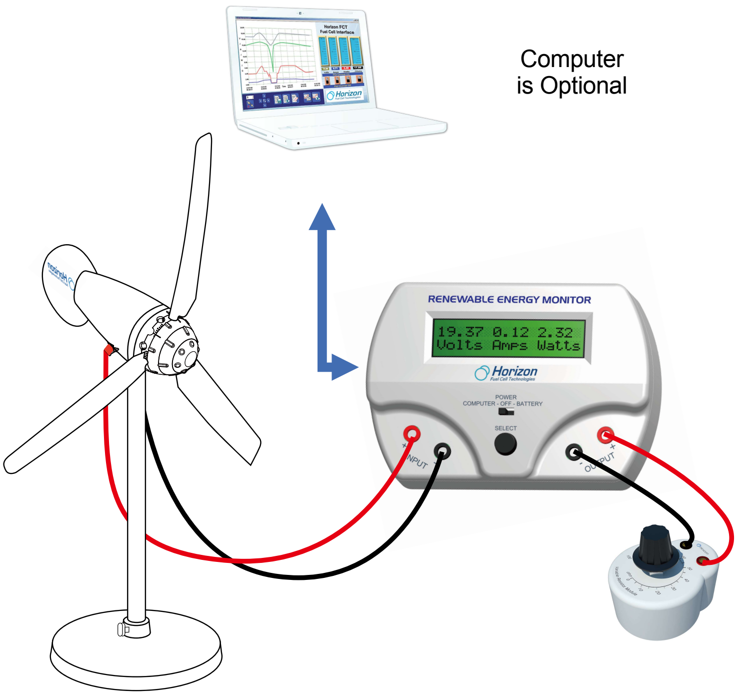
Materials

1 – Wind Turbine with 3 NCAA 44 blades
1- Table fan (20” diameter recommended)
1 - 100 ohm potentiometer
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Wind Turbine Blades

Install three NCAA 44 blades on the wind turbine hub, set the pitch angle to 15^{0} and attach the hub to the alternator shaft. Refer to the **WindPitch Assembly Guide** for instructions on how to do this.

Equipment Setup



Doing the Experiment

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Ohms display appears.

3. Place the table fan directly in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Adjust the potentiometer for 75 ohms.
5. Push the Select Button until the mV-mA-mW display appears and record the voltage, current and power.
6. Push the Select Button for Ohms and adjust the potentiometer for 50 ohms.
7. Push the Select Button for mV-mA-mW and record the voltage, current and power.
8. Push the Select Button for Ohms and adjust the potentiometer for 25 ohms.
9. Push the Select Button for mV-mA-mW and record the voltage, current and power.

Preparing the Data

Enter the data in the table below. As an example we did it for the data we took. Your results will vary.

Our Data

Resistance	mV	mA	mW
75 ohms	5548	74	411
50 ohms	4570	92	420
23 ohms	3139	124	398

Your Data

Resistance	mV	mA	mW
75 ohms			
50 ohms			
23 ohms			

Analyzing the Results

Using the gathered data compute the relative efficiency of the wind turbine. If you used the **Renewable Energy Monitor** for the experiment and had it connected to your computer, your data plots should look like Figure 1 below.

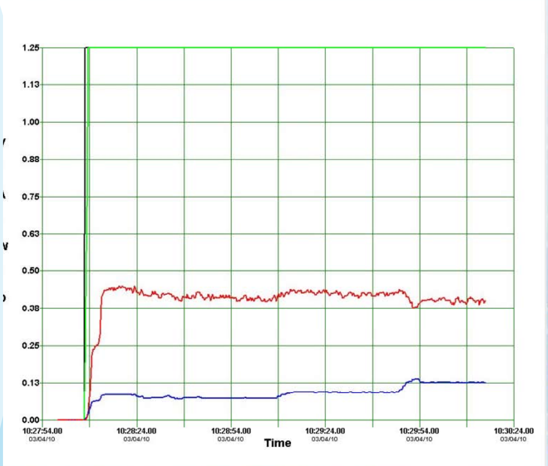


Figure 1 – Plot of Power and Current Levels For Three Resistance Values

Efficiency = (Power@50ohm load / Power@75ohm load) x 100%

E1 = (420 / 411) x 100% = 102.19% (50 ohms)

Efficiency = (Power@25ohm load / Power@75ohm load) x 100%

E2 = (398/ 411) x 100% = 96.84% (25 ohms)

First of all, the 75 ohm load is ideal for this wind turbine as it generally matches the resistance of the internal alternator. We can clearly see that our small wind turbine is more efficient with a lighter (50 ohm) load as compared with a heaver (25 ohm) load. Remember, the higher the load resistance the smaller the load – and the lower the load resistance the heaver the load. This is a difficult (and counter-intuitive) concept to grasp at first – higher resistance means a lighter load; lower resistance means a heavier load. This experiment is designed to illustrate the concept of various loads on the wind turbine.

What If ???

Have students speculate on the following hypothetical question.

What if you wanted to stop or slow down the wind turbine's spinning blades without using a mechanical break or stopping the blades with your hand? Can it be done and, if so, what would you do?

Well it can be done – and is done the following way - even on large commercial wind turbines with some restrictions.

Set the table fan to the lowest speed setting and start the turbine blades spinning. Then apply a jumper wire directly across the wind turbine's red and black terminals – essentially shorting out any electricity. Notice how the blades slow down or even stop depending on the strength of the wind. Why?

The wind turbine is trying to supply power into a short circuit with limited or no success. This is like riding a bicycle on a flat road and then trying to climb a steep hill with the same peddling power; eventually the bicycle slows down or stops because its power source (you) cannot generate enough force to keep it going. Gravity is the force that causes the bicycle to use more power on a hill - and low resistance is the reason why the wind turbine stops or slows down. Most of its energy is now going into [wasted] heat.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 45 – Types of Wind Turbines
Page 47 – Parts of a Wind Turbine

Web Links

A very good start on wind turbine theory and practice can be found here:
http://science.howstuffworks.com/wind-power.htm

A terrific animation of wind turbine action plus other good information:
http://www1.eere.energy.gov/windandhydro/wind_animation.html

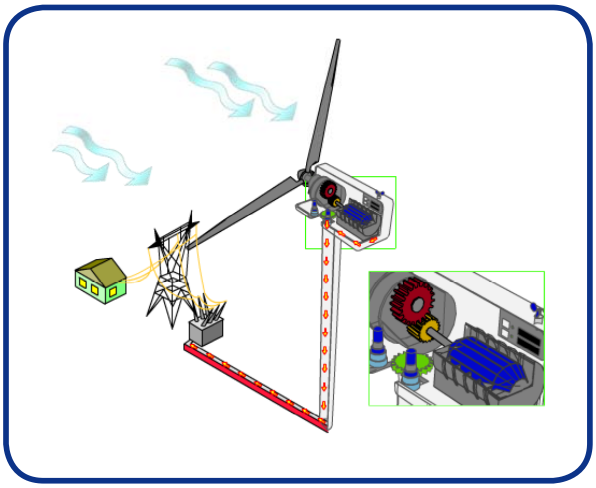


Figure 2- Wind Turbine Animation Website Image

Do More Research

Have students do research on the following topic – Parts of a wind turbine:
Excerpted from the RE Science Educational Manual – page 47: "The principle behind wind turbines is very simple: the energy in the wind turns two or three blades around a rotor. The rotor is connected to the shaft, which spins a generator to create electricity.
Wind turbines are mounted on a tower to capture the energy from the wind. The higher the blades are, the more they can take advantage of faster and less turbulent wind.
A simple wind turbine consists of three main parts, the blades, shaft and generator:
1) Blades: The blade acts as barriers to the wind. When the wind forces the blade to move, some of the wind energy is transferred to the rotor.
2) Shaft: When the rotor spins, the shaft also spins, and transfers the mechanical energy into rotational energy.
3) Generator: A generator uses the difference in electrical charge (electromagnetic induction) to produce a change in voltage. Voltage is actually electrical pressure, the force that moves an electrical current. The voltage drives the electrical current (AC power) through power lines for distribution."

Figure 3 – Parts of a Wind Turbine

With this background have students investigate more about the parts of a wind turbine – especially, the gearing system that contributes more to power generation and losses than all the other parts combined.
Here's a great place to start:
http://www1.eere.energy.gov/windandhydro/wind_how.html

Wind Power
Measuring RPM

Photo Credit – DIY WindTurbine.info

LESSON OVERVIEW

This experiment demonstrates the relationship between a wind turbine's RPM (Revolutions per Minute) speed and the electrical power produced. Students gain an understanding about wind speed, turbine speed and the resultant power output.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn the relationship between wind speed and turbine RPM.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

This experiment shows the relationship between wind speed and a model wind turbine's RPM – Revolutions per Minute – speed. The surprising element in the learning outcome is that an electrical load can slow the RPMs with the same wind speed.

Students come to understand that:

1. A wind turbine's RPM is directly related to the wind speed – without an electrical load.
2. The introduction of an electrical load (a variable resistor) will cause the wind turbine blade rotations (RPM) to slow down in proportion to the resistance.
3. The wind turbine can be stopped from rotating by introducing a heavy electrical load – even while the wind is still blowing.

STUDENT ACTIVITIES

Students assemble the wind turbine using three BP-28 curved blades and set the blade pitch to 15 degrees. With the table fan on the highest speed setting students measure the wind turbine's RPM without an electrical load. An electrical load is introduced and the students measure the effects of RPM.

SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

Note: This Experiment cannot be done with a multimeter – only with the Renewable Energy Monitor

The Experiment with the Renewable Energy Monitor

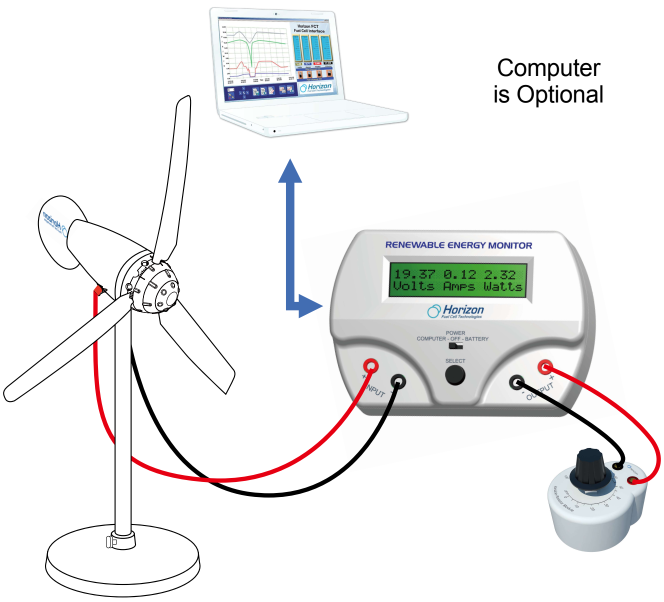
Materials

1 – WindPitch Wind Turbine
1- Table fan (20” diameter recommended)
1 - 100 ohm potentiometer
3 –BP-28 Blades
2 – Red hookup lead
2 – Black hookup lead

Wind Turbine Blades

Install three BP-28 blades on the wind turbine hub and attach the hub to the alternator shaft. Adjust the blade pitch to 15 degrees. Refer to the **WindPitch Assembly Guide** for instructions on how to do this.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.

2. Push the Select Button until the Ohms display appears.

3. Place the table fan directly in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Adjust the potentiometer until the resistance reads 100 ohms.
5. Push the Select Button until the RPM display appears. Record the RPM reading.
6. Push the Select Button until the Ohms display appears.
7. Adjust the potentiometer until the resistance reads 50 ohms.
8. Push the Select Button until the RPM display appears. Record the RPM reading.
9. Push the Select Button until the Ohms display appears.
10. Adjust the potentiometer until the resistance reads 25 ohms.
11. Push the Select Button until the RPM display appears. Record the RPM reading.
12. Push the Select Button until the Ohms display appears.
13. Adjust the potentiometer until the resistance reads 10 ohms.
14. Push the Select Button until the RPM display appears. Record the RPM reading.

Preparing the Data

Have the students enter the RPM values in the table below.

Your Data **3 BP-28 Blades @ 15°**

Resistance	RPM
100 ohms	
50 ohms	
25 ohms	
10 ohms	

Analyzing the Results

If you used the Renewable Energy Monitor connected to a computer for the experiment, your data plot should look something like Figure 1 for each of the four resistance settings

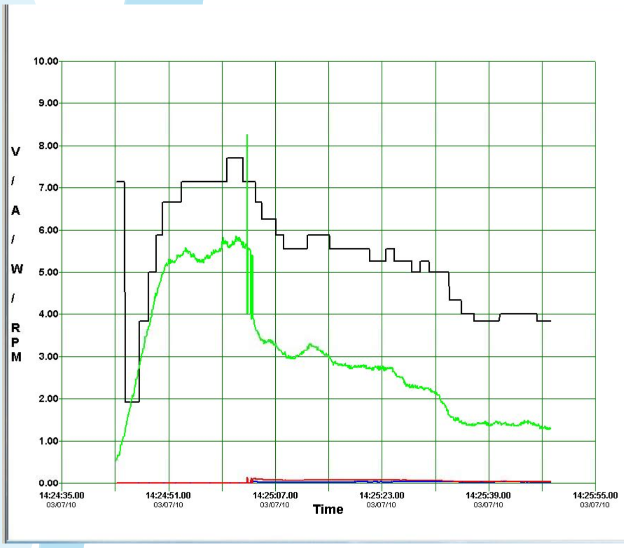


Figure 1 –Voltage/RPM at Four Resistance Values

Our Data 3 BP-28 Blades @ 15°

Resistance	RPM
100 ohms	500
50 ohms	370
25 ohms	250
10 ohms	94

From the above data you can see how a change in resistance can affect the voltage, current, power and RPM - the lower the resistance, the lower the RPM. If you reduce the resistance to zero (a short circuit) you may be able to completely stop the wind turbine from spinning. This depends on the fan speed being a bit slower than full speed.

What this experiment shows is that the wind turbine is attempting to supply more and more power to a heavier load (less resistance) while the fan wind speed, its only power source, remains the same. This is like you trying to peddle your bicycle up a steeper and steeper hill. You will slow down because you, the power source for the bike, only have so much to give – just like the fan has only so much power in its wind speed to give to the wind turbine.

What If

Have students speculate on the following question:

If you had a large commercial-grade wind turbine and you connected it so that it could supply all the power to your house or apartment, what would happen to the RPM if you turned on the following appliances – one at a time?

- A single light bulb
- A coffee pot
- An air conditioner
- An electric washer and dryer

In this example assume that the wind blows at a constant speed all day and all night. In your answer explain how much power each appliance requires to operate.

Web Links

To learn more about wind turbine RPM and wind tip speed, look here:
http://www.kidwind.org/PDFs/SUPPORT_Math_Tip%20Speed%20Ratio.pdf

Do More Research

Have students use the above web link and other information found on the WWW to research the aerodynamics of wind turbine design. Besides the web link above this is a good link to start their investigations:
http://www.awea.org/faq/vawt.html

Wind Power
Tuning for Maximum Power

Image Credit: Treehugger.com

LESSON OVERVIEW

This experiment demonstrates that there is a Maximum Power Point (MPP) where the wind turbine generates the most electrical power. The goal of this experiment is to find the MPP for one blade shape at three different pitch angles and at high, medium and low speed wind conditions.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn to adjust a variable resistor load to find the maximum power point (MPP).
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

This experiment uses a variable resistor like the round knob on the volume control on your car radio Just like tuning in a particular radio station you can fine tune the wind turbine's performance to generate maximum power by adjusting the variable resistor to the correct value

Students come to understand that:

1. A variable resistor acts as a load or absorber of electrical power coming from the spinning wind turbine. Adjusting its value to the proper setting will produce maximum power.
2. Maximum power varies depending on the wind speed, the blade shape, the number of blades and the blade pitch. It is constantly changing based on these and other conditions like heat and air resistance of the spinning blades.
3. There is a narrow range of resistance values that will produce maximum power for the model wind turbine.

STUDENT ACTIVITIES

Students assemble the wind turbine using three BP-28 curved blades and adjust the blade pitch angle at three settings – 15, 30 and 45 degrees. For each pitch angle they adjust the 100 ohm variable resistor to acquire maximum electrical power from the wind turbine as it spins at the highest fan speed setting.

SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

Note: This Experiment cannot be done with a multimeter – only with the Renewable Energy Monitor

The Experiment with the Renewable Energy Monitor

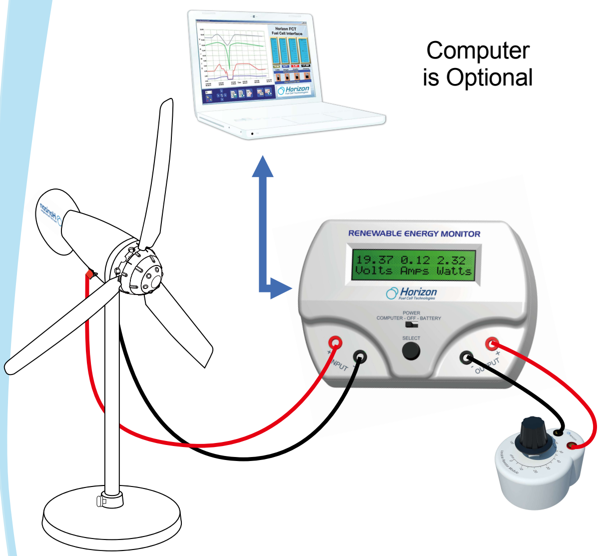
Materials

1 – WindPitch Wind Turbine
1 – Table fan (20” diameter recommended)
1 – 100 ohm potentiometer
3 –BP-28 Blades
2 – Red hookup lead
2 – Black hookup lead

Wind Turbine Blades

Install three BP-28 blades on the wind turbine hub and attach the hub to the alternator shaft. Adjust the initial blade pitch to 15 degrees. Refer to the WindPitch Assembly Guide for instructions on how to do this.

Equipment Setup



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the mV-mA-mW display appears.

3. Place the table fan directly in front of the wind turbine about 2 feet away from it and set it to its highest speed setting.
4. Adjust the 100 ohm potentiometer until the maximum power in mW is displayed.
5. Record the voltage, current and power.
6. Push the Select button and record the ohms.
7. Set the table fan to a medium speed setting.
8. Adjust the 100 ohm potentiometer until the maximum power in mW is displayed.
9. Record the voltage, current, power and ohms.
10. Set the table fan to the lowest speed setting.
11. Adjust the 100 ohm potentiometer until the maximum power in mW is displayed.
12. Record the voltage, current, power and ohms.
13. Repeat steps 4 through 11 at a pitch angle of 30 degrees.
14. Repeat steps 4 through 11 at a pitch angle of 45 degrees.

Preparing the Data

Have the students enter the voltage, current, power and resistance readings in the table below. Add similar tables for 300 and 450 pitch angles.

Our Data 3 BP-28 Blades @ 15°

Wind Speed	mV	mA	mW	ohms
High	3868	96	371	40
Medium	2951	39	115	75
Low	1923	30	58	64

Your Data 3 BP-28 Blades @ 15°

Wind Speed	mV	mA	mW	ohms
High				
Medium				
Low				

Analyzing the Results

If you used the Renewable Energy Monitor connected to a computer for the experiment, your data plot should look something like Figure 1 for each of the three wind speed settings.

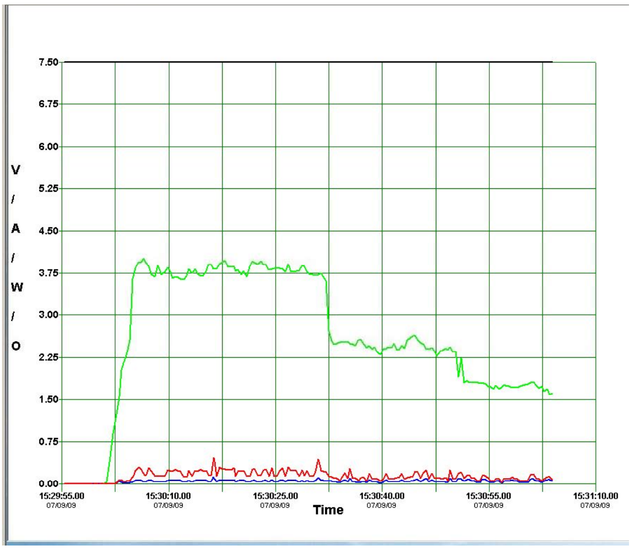


Figure 1 – Plot of Voltage at Three Wind Speeds

Our Data 3 BP-28 Blades @ 15°

Wind Speed	mV	mA	mW	ohms
High	3868	96	371	40
Medium	2951	39	115	75
Low	1923	30	58	64

Our Data 3 BP-28 Blades @ 30°

Wind Speed	mV	mA	mW	ohms
High	3000	58	174	52
Medium	1937	31	60	63
Low	1333	20	27	67

Our Data 3 BP-28 Blades @ 45°

Wind Speed	mV	mA	mW	ohms
High	1889	39	74	48
Medium	1152	20	23	58
Low	811	13	11	62

From the above data you can see how just a small change in resistance can affect the output power of the wind turbine. Also notice that more power is generated at the 150 blade angle than at the 300 or 450 blade angles. This is because the blades present more "drag" to the oncoming wind at these higher angles. It's important to note that more resistance is needed for maximum power at the lower wind settings because the wind turbine cannot supply a heaver load at lower wind speeds.

What If ???

Have students speculate on the following question:

What if you were a wind turbine engineer and your assignment is to build a wind turbine with a "fixed" blade pitch for several customers. The goal of your wind turbine design is to capture maximum wind power from the fixed blade angle depending on the wind condition. Your answers depend mainly on the data you gathered for this experiment.

One customer lives in the high desert away from buildings and trees where the wind blows all the time, day and night, at high speed. What blade pitch angle would you use for this wind turbine?

Another customer lives in the country where the wind is moderate most of the time and there are lots of trees to interfere with the wind but not block it totally. What blade pitch angle would you use for this wind turbine?

A third customer lives in the city in a high-rise apartment. There isn't much room for a wind turbine but the building owner will allow the person to put a wind turbine on the building roof. The wind on the roof is usually low and unstable due to the other larger buildings that block it from reaching the turbine. What blade pitch angle would you use for this wind turbine design?

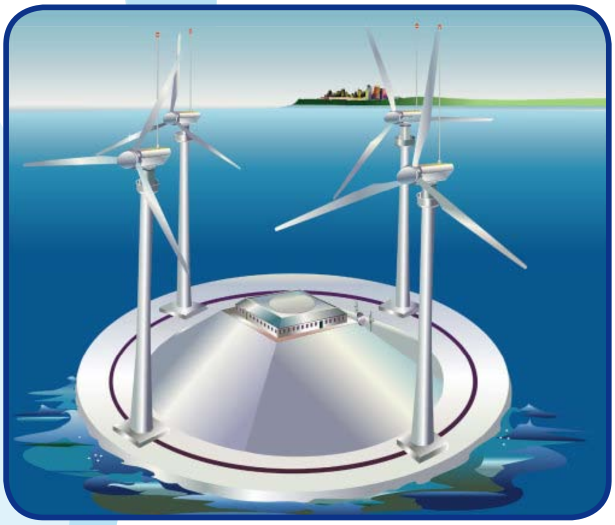
Web Links

To learn more about wind turbine blade pitch design and control start here:
http://www.docstoc.com/docs/5549553/multi-blade-wind-turbine

Do More Research

Have students use the above web link and other information found on the WWW to research Maximum Power tracking called MPPT.

Wind Power To Generate Hydrogen



Floating Wind Powered Hydrogen Storage Station
Credit PSEN.com Concept drawing by Tom L. Lee

LESSON OVERVIEW

This lesson demonstrates how wind power can generate hydrogen and oxygen by electrolyzing water into hydrogen and oxygen gasses. The hydrogen gas is recombined with oxygen from the air to produce electricity using a fuel cell. The fuel cell is used to power a motor. Data from both processes are recorded and analyzed.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a model wind turbine that generates a safe level of DC electricity.
- Students will learn the principles of electrolysis using wind power and fuel cells.
- Students will learn to calculate energy.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the electrical energy produced by a model wind turbine can electrolyze (split) water into hydrogen and oxygen using a device called an electrolyzer. Then students are shown how these two gasses are recombined by a fuel cell to generate electricity to power a small motor.
Students come to understand that:

1. Wind power can be used to generate hydrogen and oxygen in a clean, non-polluting manner.
2. Hydrogen is an "energy carrier" and can be stored for later use in generating electricity.
3. The measured energy in Joules or Watt-seconds is different from power. Energy has a time component and power is an instantaneous reading.

STUDENT ACTIVITIES

Students attach a model wind turbine to an electrolyzer with a water supply and using the electricity produced by the wind turbine, create hydrogen and oxygen. They reverse the process and use the stored hydrogen to power a fuel cell that, in turn, acts as a power source for the electric motor. Data are taken during both the hydrogen generation and motor running process. The data are analyzed to determine the energy used to electrolyze the water as well as the energy used to power the motor.

SAFETY

Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

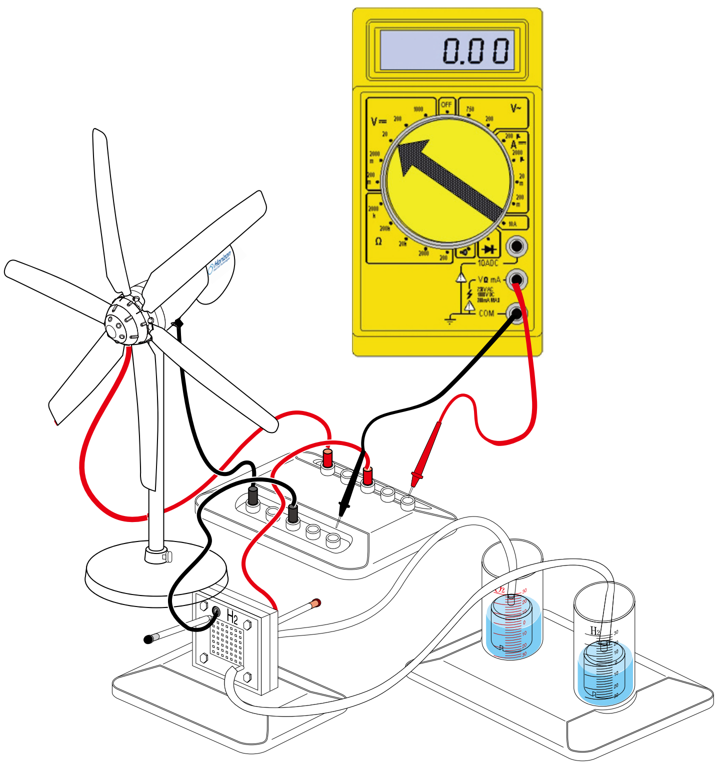
Materials

1 – Wind Turbine with 6 blades
1 – Table fan (20" diameter recommended)
1 – Electrolyzer unit with gas storage containers
1 – Fuel cell
1 – Motor and propeller
1 – Clock, watch or stopwatch
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base

Wind Turbine Blades

Setup the wind turbine hub with six (6) curved blades supplied with the kit. Use combinations of the BP-28, NCAA 44 or NCAA 63 blades. Set the blade pitch to 15 degrees. Refer to the WindPitch Assembly Guide for instructions on how to do this.

Equipment Setup #1



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

Part 1:

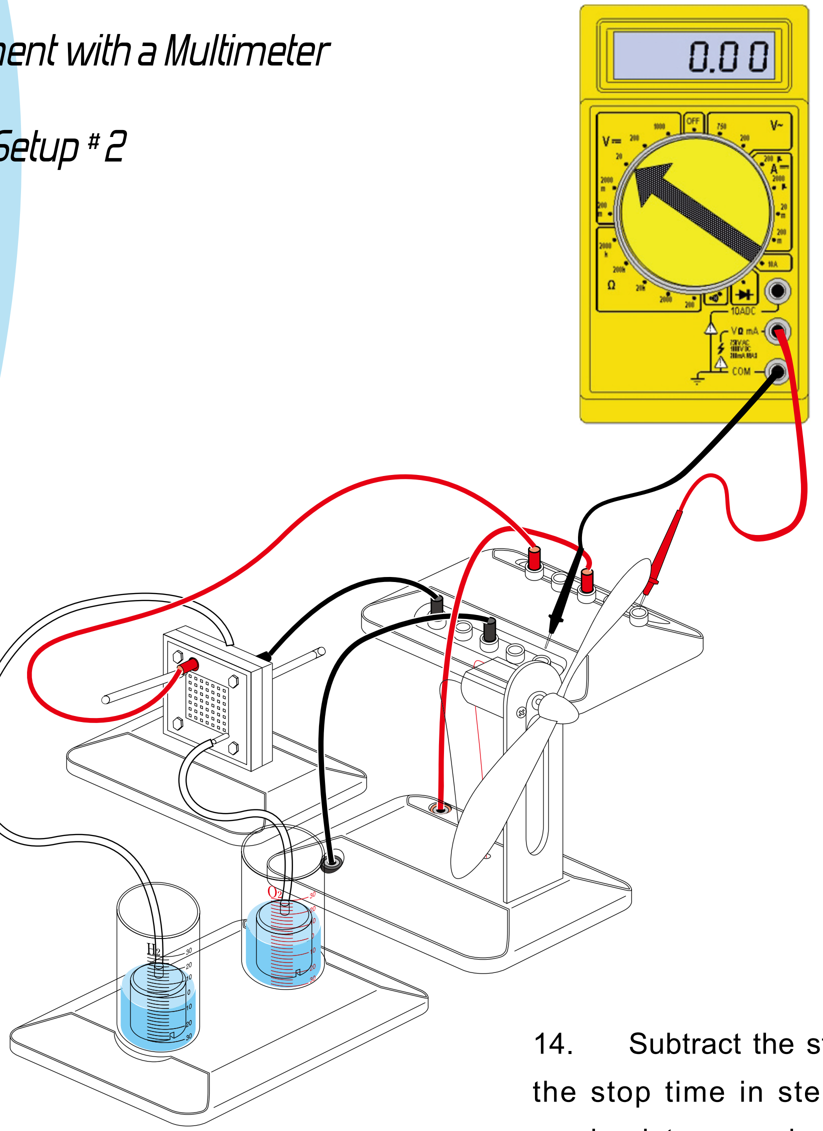
1. Setup the equipment as in Equipment Setup #1.
2. Set the multimeter dial to DC Volts with a range of at least 10 VDC.
3. Fill both the hydrogen and oxygen cylinders to the 20 ml marks with distilled water.
4. Place the table fan directly in front of the wind turbine and set it to its highest speed setting.
5. Make sure that the wind turbine is generating AT LEAST 1.5 volts. If not, move the wind turbine closer to the fan until it does. Also, make sure that the blade pitch is between 10 and 15 degrees. The wind turbine is sensitive to this setting at high wind speeds.
6. Note the time on the clock or watch. Allow the table fan and wind turbine to run for 10 minutes – no longer.
7. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.
8. Turn the table fan OFF after 10 minutes and convert this number into seconds (10 x 60 = 600 seconds).

Proceed to Part 2 of the experiment on the following page.

Setup the equipment as illustrated in Equipment Setup #2

The Experiment with a Multimeter

Equipment Setup # 2



Part 2:

9. Remove the wind turbine from the setup and replace it with Experiment Setup #2.

10. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

11. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.

12. Allow the motor to run until the hydrogen is used up.

13. Note the time when the motor-propeller stops turning.

14. Subtract the start time in step 9 from the stop time in step 12 and convert this number into seconds.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the Experiment Guide section for details on how to do this.

Our Data

	Seconds	Volts	Amps	Watts
Part 1	600	1.523	0.025	0.381
Part 2	20	0.732	0.380	0.278

Your Data

	Seconds	Volts	Amps	Watts
Part 1				
Part 2				

The Experiment with the Renewable Energy Monitor

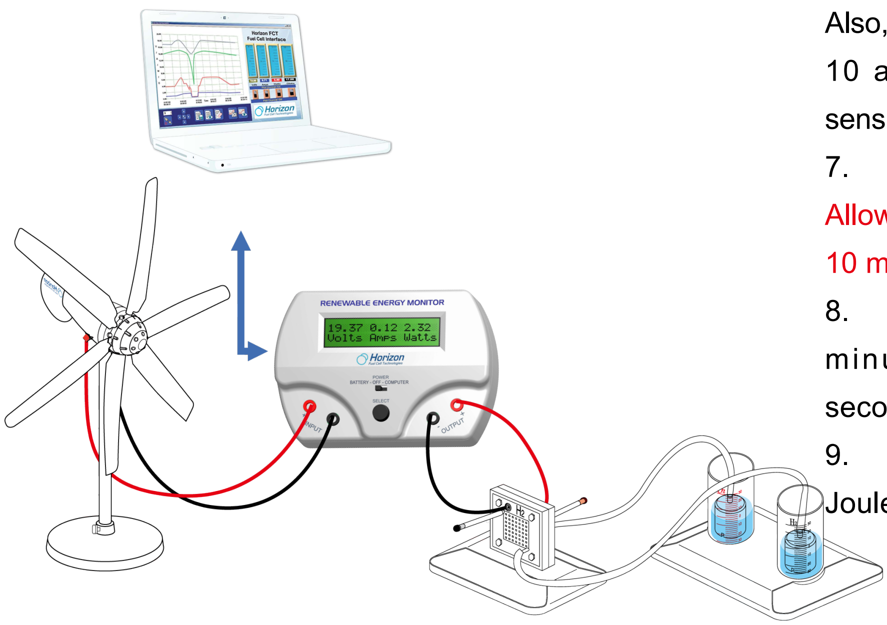
Materials

1 – Wind Turbine with 6 blades
1 – Table fan (20" diameter recommended)
1 – Electrolyzer unit with gas storage containers
1 – Fuel cell
1 – Motor and propeller
1 – Clock, watch or stopwatch
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base

Wind Turbine Blades

Setup the wind turbine hub with six (6) curved blades supplied with the kit. Use combinations of the BP-28, NCAA 44 or NCAA 63 blades. Set the blade pitch to 15 degrees. Refer to the **WindPitch Assembly Guide** for instructions on how to do this.

Equipment Setup # 1



Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

Part 1:

1. Setup the equipment as in Equipment Setup #1.
2. Set the **Renewable Energy Monitor** switch to Battery or Computer depending on your hookup.
3. Push the Select Button until the mV-mA-mW display appears.

4. Fill both the hydrogen and oxygen cylinders to the 20 ml marks with distilled water.
5. Place the table fan directly in front of the wind turbine and set it to its highest speed setting.
6. Make sure that the wind turbine is generating AT LEAST 1.5 volts. If not, move the wind turbine closer to the fan until it does. Also, make sure that the blade pitch is between 10 and 15 degrees. The wind turbine is sensitive to this setting at high wind speeds.
7. Note the time on the clock or watch. Allow the table fan and wind turbine to run for 10 minutes – no longer.
8. Turn the table fan OFF after 10 minutes and convert this number into seconds (10 x 60 = 600 seconds).
9. Push the Select Button until the Joules display appears.

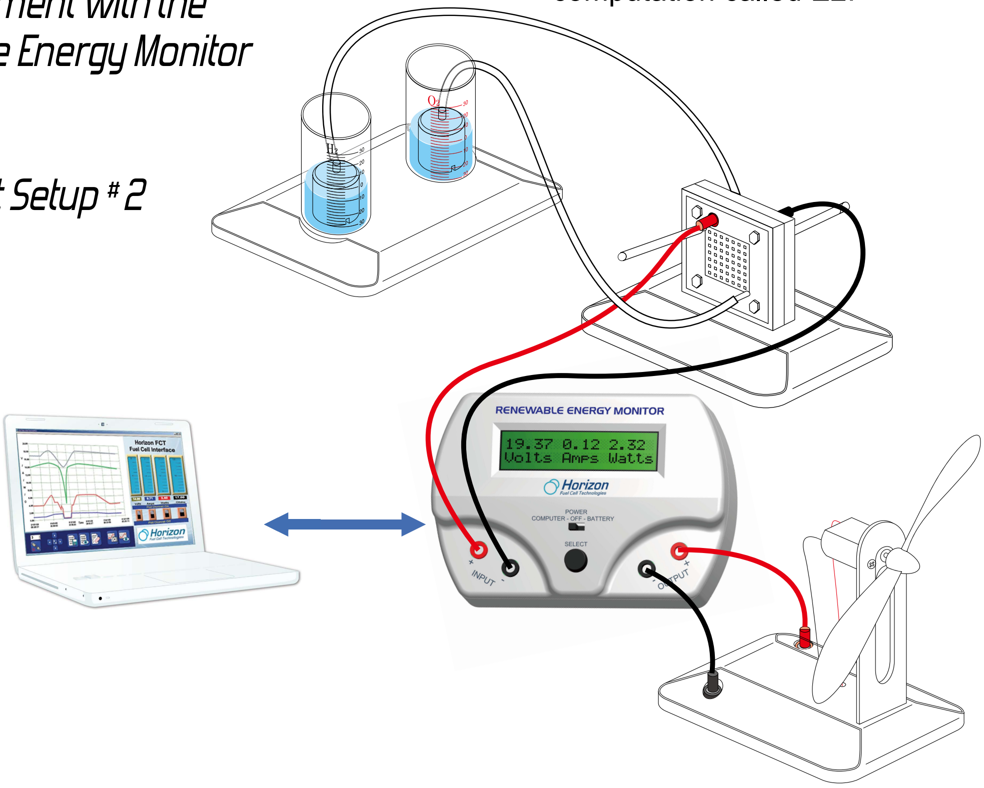
10. Note the value of this reading as reference for the following energy computation called E1.

Proceed to Part 2 of the experiment on the following page.

Setup the equipment as illustrated in Equipment Setup #2

The Experiment with the Renewable Energy Monitor

Equipment Setup # 2



Part 2:

11. Remove the wind turbine from the setup and replace it with Experiment Setup #2.

12. Connect the Red wire to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

13. Note the time when the motor-propeller stops turning.

14. Subtract the start time in step 8 from the stop time in step 10 and convert this number into seconds.

15. Push the Select Button until the Joules display appears.

16. Note the value of this reading as reference for the following energy computation called E2.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. As an example we entered our data.

Our Data

	Seconds	Volts	Amps	Watts
Part 1	600	1.523	0.025	0.381
Part 2	20	0.732	0.380	0.278

Your Data

	Seconds	Volts	Amps	Watts
Part 1				
Part 2				

Analyzing the Results

Using the data in the table recorded for **Part 1** compute the energy used to generate hydrogen. Energy is computed as power times time. As an example, using the values for our data in **Part 1** the energy is computed as follows:

E1 = Power x Time

E1 = 0.381 x 600

E1 = 228.6 watt-seconds or Joules

If you were using the **Renewable Energy Monitor** a plot similar to Figure 1 shows the initial voltage ramp up from 0.75 volts to just over 1.50 volts at the very beginning of the electrolysis cycle. The Decomposition of Water experiment shows that this is the very minimum voltage for splitting water into hydrogen and oxygen; plus, the current and power are very low, as well so hydrogen generation will be minimal.

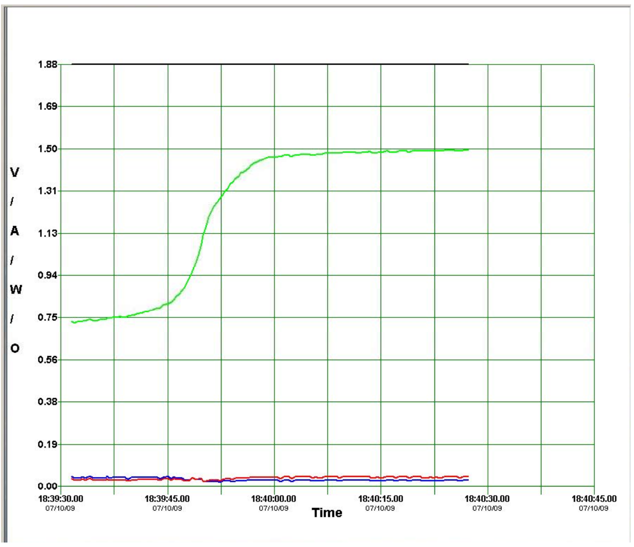


Figure 1 – Electrolyzing Cycle

Next, using the data in the table recorded for **Part 2** compute the energy consumed by the motor and spinning propeller. As an example, using the values for our data in **Part 2** the energy is computed as follows:

E2 = Power x Time

E2 = 0.278 x 20

E2 = 5.56 watt-seconds or Joules

If you were using the Renewable Energy Monitor a plot similar to Figure 2 shows the energy transferred from the fuel cell into the motor-propeller load. Notice how quickly it occurs.

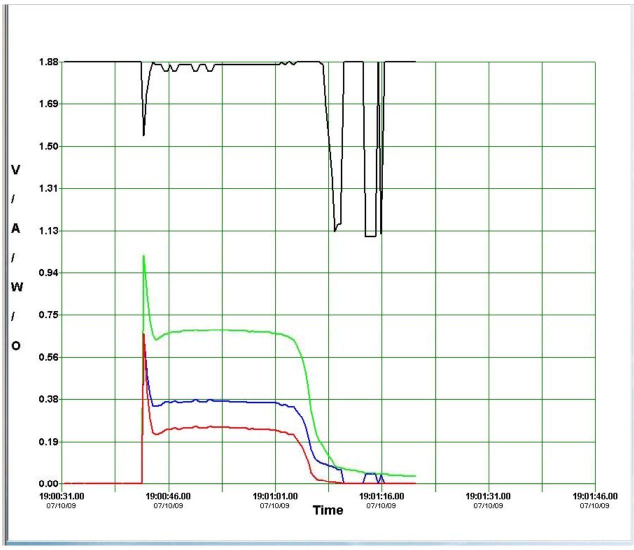


Figure 2 – Discharge Cycle

As you can easily conclude by the short running time of the motor, our wind turbine is not up to the task of creating sufficient hydrogen to keep the motor running for a long period of time. The charging time of 10 minutes or 600 seconds is sixty (30) times longer than the motor running time of 20 seconds (our test result).

However, this is not the case for commercial wind turbines as the next sections of the experiment will point out.

What you did learn is how to compute energy. Energy and power are related but power has no time component while energy is measured as power times time. That's why it's expressed here as watt-seconds. Your electric meter is calibrated and read in watt-hours in order to compute how much you should be charged for using electricity each month. You can convert watt-seconds to watt-hours by dividing watt-seconds by 3600.

Watt-hours = watt-sec x (min/60sec) x (hour/60min) = watt-sec / 3600

What If ???

Have students speculate on the following hypothetical questions:

What if there was no more gasoline in the world to run our cars (and this will happen someday soon), could we use hydrogen to power our cars instead of gasoline?

If so, then how would you develop a system to generate enough hydrogen to supply fuel to all the cars – just like oil companies have done to import oil, refine it into gasoline and then truck it to filling stations?

If wind turbines can generate hydrogen as this experiment shows (but not very well) then think about how wind farms can be built to split water into oxygen and hydrogen. And then figure out how to store the hydrogen and truck it to filling stations just like oil companies do with gasoline.

And besides hydrogen who will purchase the pure oxygen created by this same process? Or will it be better to let it escape into the atmosphere and add to the oxygen in the air as from tree and plant photosynthesis?

Information in the next sections can help in your effort to answer these questions.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to answer the What If questions and to prepare to do more research on the experiment.

Page 50 - Simple Estimate of Wind Turbine Energy

Page 51 – Wind Farms

Web Links

To learn more about hydrogen production using wind farms on land look here: http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html

And an interesting way to do it at sea: http://www.windhunter.org/

Do More Research

Have students do research on the following topic – wind-based hydrogen production, storage and distribution:

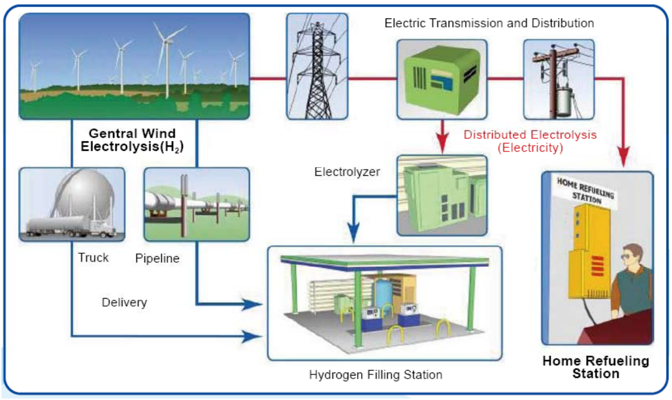


Figure 3 – Hydrogen Distribution Diagram

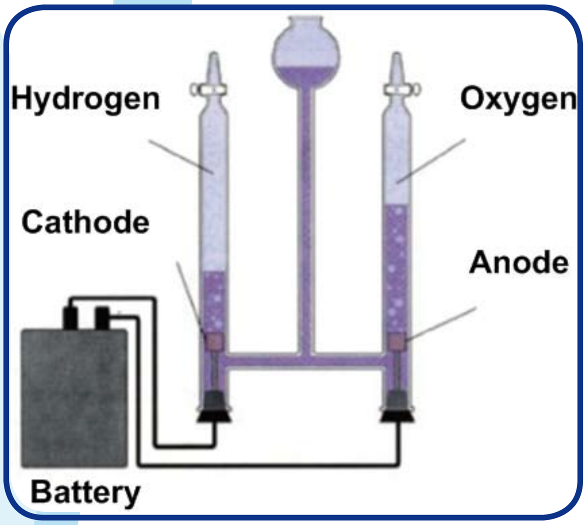
The following web links from NRL – the National Research Laboratory - can form the basis for background information on this topic:

http://www.nrel.gov/docs/fy06osti/39534.pdf

http://www.nrel.gov/docs/fy04osti/35404.pdf

Have students discuss and then write about viable methods to generate hydrogen from plain water using wind farms along with how to store and distribute the hydrogen to the general public. Have them speculate on what a "Hydrogen Economy" will look like and how different it will be compared to our current fossil fuel based economy.

Electrolysis Mode - Generating Hydrogen and Oxygen from Water



LESSON OVERVIEW

This lesson demonstrates how pure water can be decomposed into hydrogen and oxygen gases using a device called an electrolyzer.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn the principles of electrolysis using a battery and fuel cells.
- Students will learn to calculate energy.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the electrical energy produced by a 3-volt battery can electrolyze (split) water into hydrogen and oxygen. Then students are shown how these two gasses are created in a 2:1 proportion consistent with the commonly known chemical symbol for water – H_2O.

Students come to understand that:

1. Because hydrogen is not a free element in nature on Earth electrolysis is necessary to decompose water into hydrogen and oxygen.
2. The process of electrolysis can also be accomplished with algae and other plant species.
3. Modern electrolysis methods can produce large quantities of hydrogen [under pressure] that can be used to power cars and electrical appliances.

STUDENT ACTIVITIES

Students attach a 3-volt battery to electrolyzer apparatus to produce hydrogen and oxygen from water. Students measure the electrical power and time required to perform this process and then analyze the results.

SAFETY

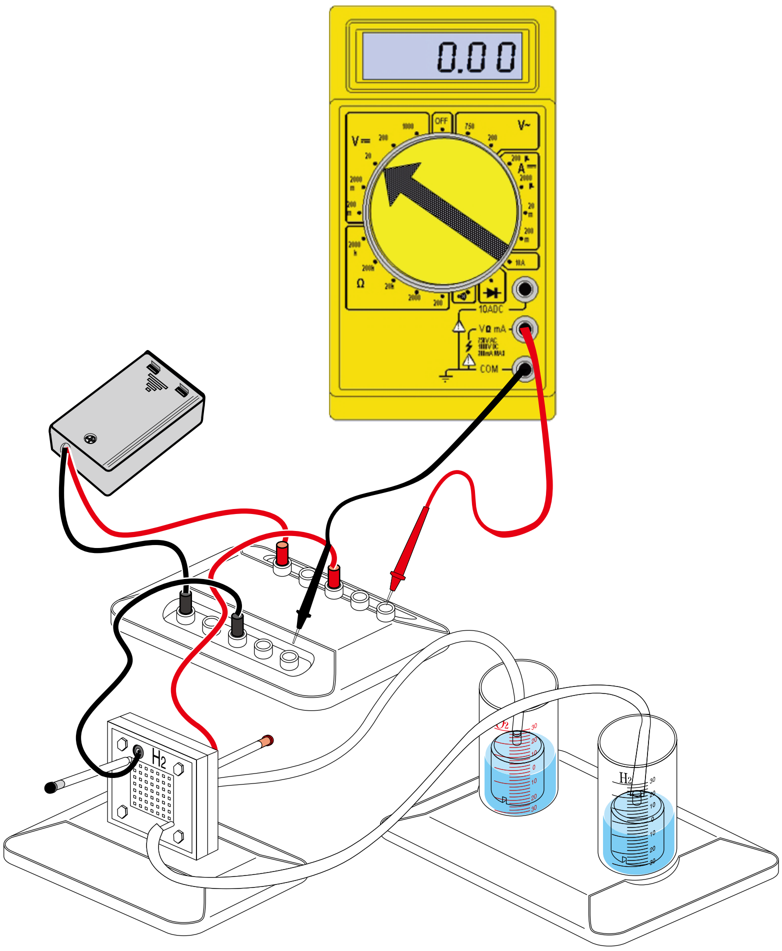
Be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

Materials

1 – Battery Pack (3 volt battery with switch)
1 – Electrolyzer apparatus
1 – Clock, watch or stopwatch
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base

Equipment Setup



Doing the Experiment

1. Set the multimeter dial to DC Volts with a range of at least 5 VDC.
2. Fill both the hydrogen and oxygen cylinders to the 0 ml marks with distilled water. Make sure that the inner containers completely fill with water.
3. Set the ON-OFF switch on the battery pack to ON.
4. Note the time on the clock or watch to begin timing how long it takes for the hydrogen to fill to the 10ml level on the hydrogen cylinder.
5. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.
6. Set the battery switch to OFF when the hydrogen cylinder reaches the 10ml mark.
7. Note the time it took to create this level of hydrogen, convert it to seconds and enter it into the table below.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this. As an example we entered our data.

Our Data

	Seconds	Volts	Amps	Watts
Part 1	180	2.173	0.543	1.18

Your Data

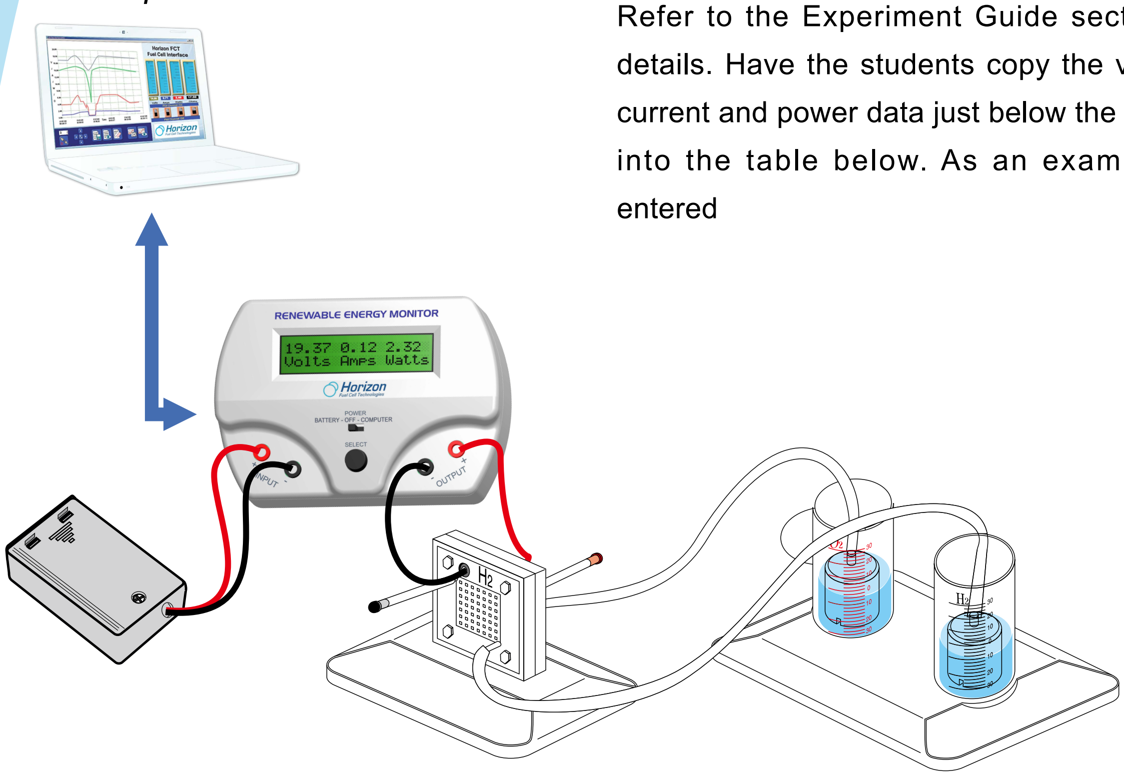
	Seconds	Volts	Amps	Watts
Part 1				

The Experiment with the Renewable Energy Monitor

Materials

1 – Battery Pack (3 volt battery with switch)
1 – Electrolyzer apparatus
1 – Clock, watch or stopwatch
2 – Red hookup lead
2 – Black hookup lead
1 – Circuit Board Module Base

Equipment Setup



Doing the Experiment

1. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water.Make sure to completely fill in the inner containers, as well.

2. Set the ON-OFF switch on the battery pack to ON.

3. Note the time on the clock or watch to begin timing how long it takes for the hydrogen to fill to the 10ml level on the hydrogen cylinder.

4. Click on the Screen Capture icon to record the voltage, current and power. Note the date and time, since the file name for the image is based on it.

5. Set the battery switch to OFF when the hydrogen cylinder reaches the 10ml mark.

6. Note the time it took to create this level of hydrogen and enter it into the table below.

Preparing the Data

Click on the Screen View icon and cycle through the images just captured.
Refer to the Experiment Guide section for details. Have the students copy the voltage, current and power data just below the meters into the table below. As an example we entered

Our Data

Seconds	mV	mA	mW
180	2173	543	118

Your Data

Seconds	mV	mA	mW

Analyzing the Results

First, notice that the oxygen level is at the 5ml mark, which is half the level of hydrogen produced at the 10ml mark. This confirms that water is two parts hydrogen and one part oxygen as the common H2O symbol implies.

If you were using a **Renewable Energy Monitor** with a computer a plot similar to Figure 1 shows the process of the electrolysis cycle from the beginning to about 30 seconds into it. The battery voltage of over 2 volts is more than is required for electrolysis. The **Decomposition of Water** experiment shows that about 1.5 volts this is the very minimum voltage necessary for splitting water into hydrogen and oxygen.

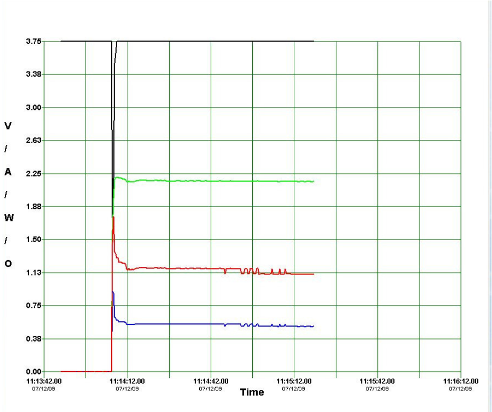


Figure 1 – Electrolyzing Cycle

Using the data in the table compute the energy used to generate hydrogen. Energy is computed as power times time. As an example, using the values for our data the energy is computed as follows:

E1 = Power x Time

E1 = 01.18 x 180

E1 = 212.4 watt-seconds

You can convert watt-seconds to watt-hours by dividing watt-seconds by 3600.

Watt-hours = watt-sec x (min/60sec) x (hour/60min) = watt-sec / 3600

What If ???

Have students speculate on the following hypothetical questions:

1. What if you were a chemist or chemical engineer and were interested in creating a new "hydrogen battery" – one that you could fill with hydrogen and then plug into your cell phone or laptop computer? When the hydrogen was used up you could just refill it again like recharging a regular battery. Knowing about the electrolysis cycle can give you a big hint as to how to start.

2. What if you were a biologist and knew that certain plants like algae give off hydrogen gas naturally, how could you capture this hydrogen and use it to make electricity?

Information in the next sections can help in your effort to answer these questions.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to answer the What If questions and to prepare to do more research on the experiment.

Page 54 - Introduction
Page 57 – Types of Electrolyzer Designs
Page 65 - Opportunities for Electrolysis

Web Links

To learn more about hydrogen production using algae look here:

http://www.wired.com/science/discoveries/news/2002/08/54456

Do More Research

Have students do research on the following topic – designs and types of electrolyzers.

Excerpted from the Renewable Energy Science Education Manual - “Electrolyzers can be divided into two main designs: unipolar and bipolar. The unipolar design typically uses liquid electrolyte, and the bipolar design uses a solid polymer electrolyte.

Unipolar Design

The first electrolyzers used a unipolar design. An example of a simple unipolar design is illustrated in Figure 2 below. The electrodes, anodes and cathodes are suspended in a tank filled with a 20 – 30 % electrolyte solution. Each cell is connected in parallel, and operated at 1.9 – 2.5 volts. This design is easy to make and repair, but is not as efficient as more modern designs.

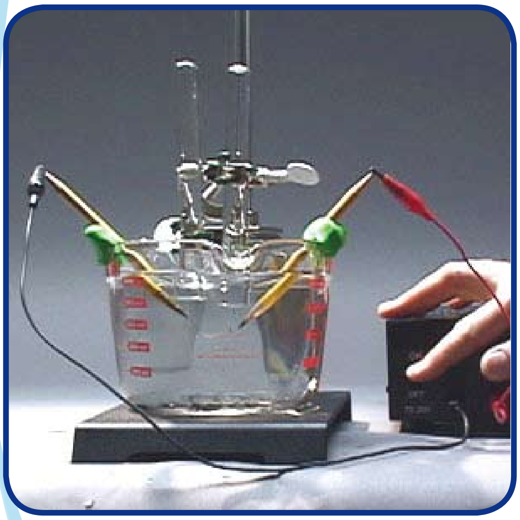
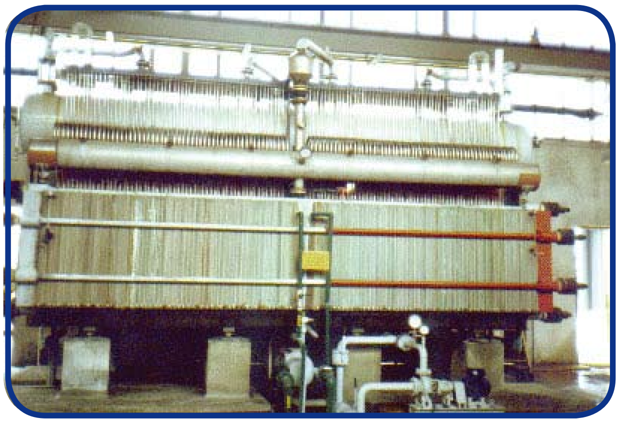


Figure 2 – Unipolar Electrolyzer

Bipolar Design

The bipolar design has many layers that are clamped together as shown in Figure 3. The cells are connected in series, which results in higher stack voltages. This stack can be small since the layers are very thin. Some advantages to the bipolar design are higher current densities, and the production of higher pressure hydrogen gas. Historically, an asbestos layer was used to separate the cells, but new polymer materials such as Ryton® has replaced this.



Electrolyzer Types

Electrolyzers can be divided into two main types: the alkaline and the polymer exchange membrane (PEM)-based electrolyzer. These electrolyzer types are based upon the electrolyte that each electrolyzer has. The alkaline type uses liquid electrolyte, and the PEM-based electrolyzer uses a solid polymer electrolyte. The construction of an electrolyzer is very similar to a battery or fuel cell. It consists of an anode, a cathode and an electrolyte. At the negative electrode, the protons are removed from the electrolyte, and electrons are provided by the external electrical supply.”

Fuel Cell Mode - Generating Electricity from Hydrogen and Oxygen

LESSON OVERVIEW

This lesson demonstrates how a fuel cell generates electricity from combining hydrogen and oxygen. The Fuel Cell Mode as it is called is just the reverse of the Electrolysis Mode where water is split into hydrogen and oxygen. In the Fuel Cell mode the hydrogen and oxygen are recombined to create electricity.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a reversible PEM fuel cell in the fuel cell mode.
- Students will learn the principles of generating DC electricity with a fuel cell.
- Students will learn to calculate energy.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the hydrogen and oxygen produced in the experiment entitled “Electrolysis Mode – Generating Hydrogen and Oxygen from Water” can now be recombined to generate DC electricity to drive a small electric motor.

Students come to understand that:

1. A fuel cell is like a battery that supplies voltage and current into a load as long as a supply of hydrogen and oxygen are available.
2. Fuel cells can operate with other substances besides hydrogen and oxygen including alkaline and methanol.
3. The choice of fuel cell electrolyte material is dependent on the application for which it is intended.

STUDENT ACTIVITIES

Students produce a sufficient quantity of hydrogen and oxygen via an electrolyzer then allow the fuel cell to recombine these gasses to generate electricity. An electric motor is used to consume the electricity. Power from the fuel cell is measured with the motor just free-spinning and with it connected to a propeller as a load. Data are taken and later analyzed to determine the loading effect of the propeller.

SAFETY

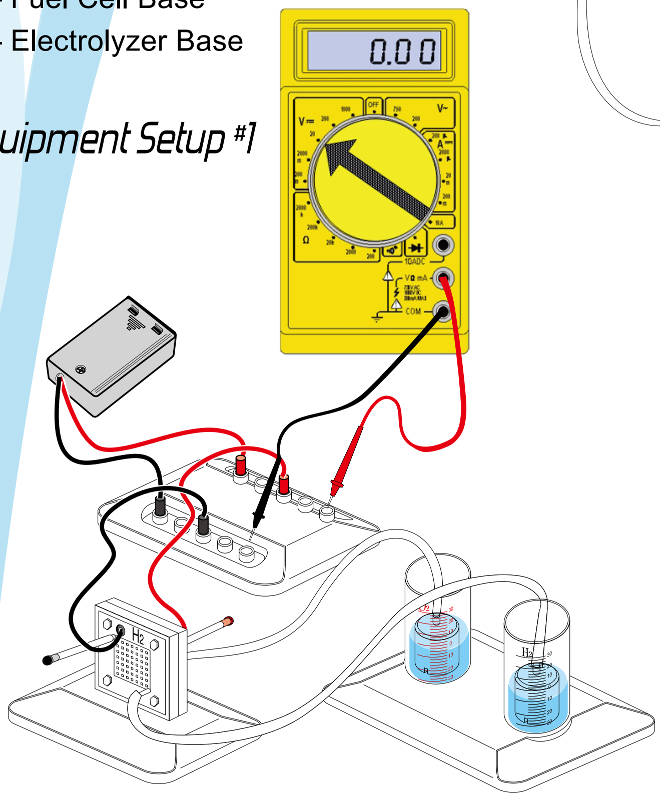
Be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

Materials

1 – Battery Pack (3 volt battery with switch)
1 – Electrolyzer apparatus
1 – Fuel cell
1 – Motor and propeller
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base
1 – Fuel Cell Base
1 – Electrolyzer Base

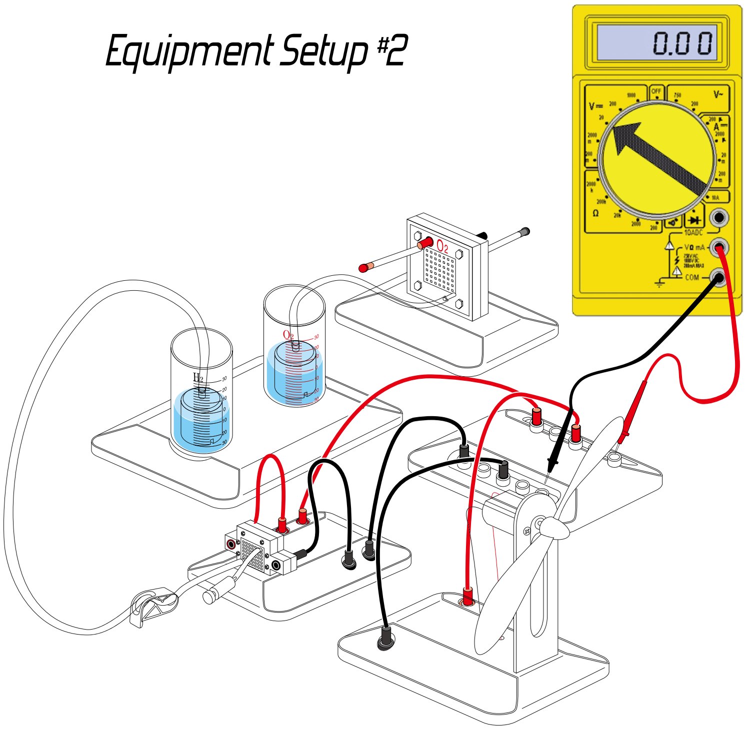
Equipment Setup #1



Doing the Experiment

1. Set the multimeter dial to DC Volts with a range of at least 5 VDC.
2. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers completely fill with water.
3. Set the ON-OFF switch on the battery pack to ON.
4. Set the battery switch to OFF when the water in the hydrogen cylinder reaches the 10ml mark.
5. Switch to Equipment Setup #2. Take care to maintain the hydrogen and oxygen supplies by following the directions in the **Experiment Guide**.

Equipment Setup #2



6. With the motor shaft free spinning record the voltage and current. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.
7. Apply the propeller to the motor shaft and record the voltage and current again.

Preparing the Data

Have the students enter the voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this. As an example we entered our data.

Our Data

	Volts	Amps	Watts
No Prop	0.757	0.165	0.125
With Prop	0.630	0.339	0.214

Your Data

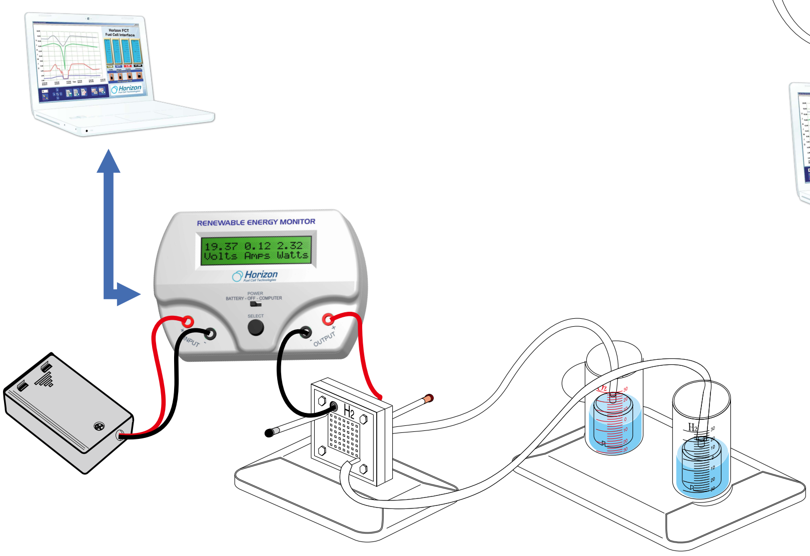
	Volts	Amps	Watts
No Prop			
With Prop			

The Experiment with the Renewable Energy Monitor

Materials

1 – Battery Pack (3 volt battery with switch)
1 – Electrolyzer apparatus
1 – Fuel cell
1 – Motor and propeller
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base
1 – Fuel Cell Base
1 – Electrolyzer Base

Equipment Setup #1

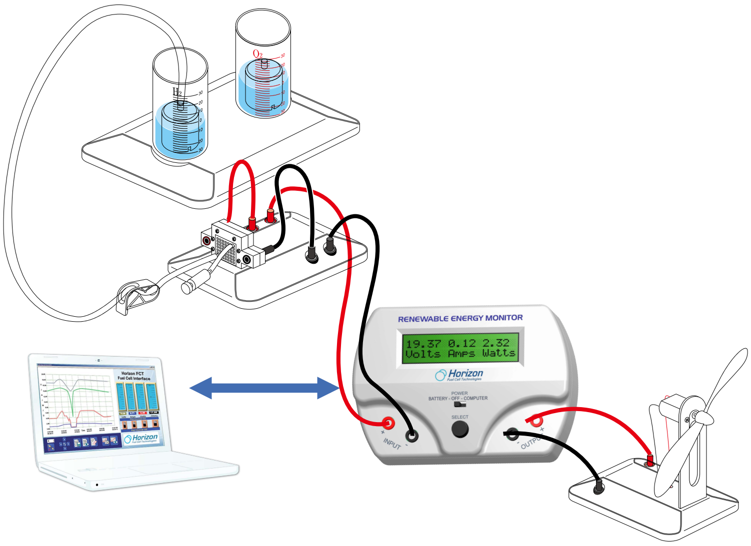


Doing the Experiment

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the mV-mA-mW display appears

3. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers completely fill with water.
4. Set the ON-OFF switch on the battery pack to ON.
5. Set the battery switch to OFF when the water in the hydrogen cylinder reaches the 10ml mark.
6. Switch to Equipment Setup #2. Take care to maintain the hydrogen and oxygen supplies by following the directions in the **Experiment Guide**.

Equipment Setup #2



7. With the motor shaft free spinning record the voltage, current and power.
8. Apply the propeller to the motor shaft and record the voltage, current and power again.

Preparing the Data

Have the students enter the voltage, current and power into the table below.

Our Data

	Volts	Amps	Watts
No Prop	0.757	0.165	0.125
With Prop	0.630	0.339	0.214

Your Data

	Volts	Amps	Watts
No Prop			
With Prop			

Analyzing the Results

A quick look at the data shows that the free spinning motor uses less power than the motor-propeller combination. This makes sense since the propeller is creating a heaver load for the motor by pushing air so the motor must work harder and even turn slower to keep up.

If you were using a **Renewable Energy Monitor** connected to a computer a plot similar to Figure 1 shows the motor free spinning without a propeller.

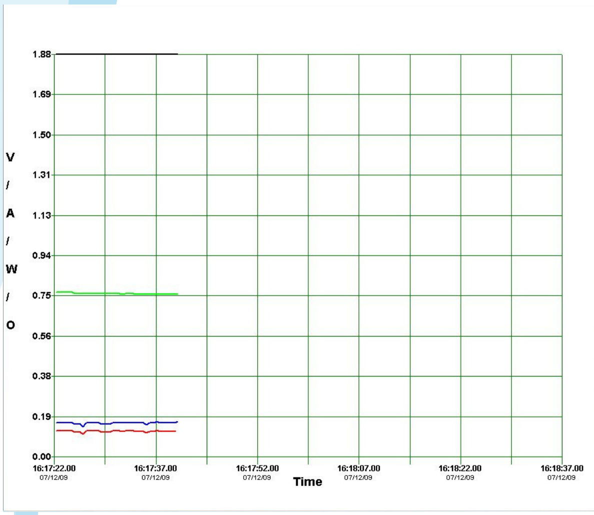


Figure 1 – Motor Free Spinning with No Propeller

Figure 2 shows the motor with the propeller attached. Notice the large dip in voltage and the increase in current and power when the propeller is attached to the shaft.

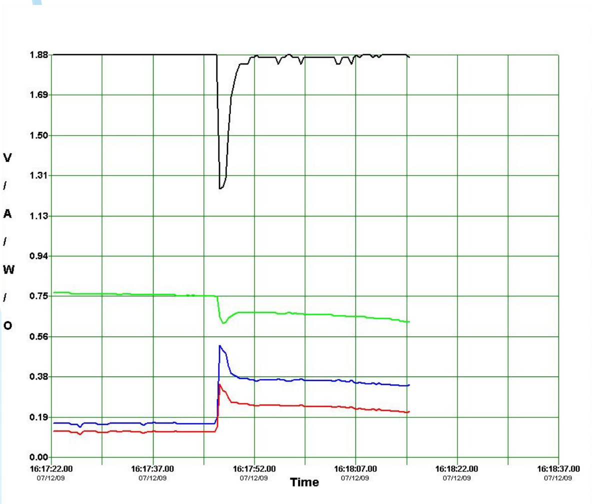


Figure 2 – Motor with Propeller

What If ???

Have students speculate on the following hypothetical question:

1. What if you were an astronaut and were about to go into space for a week or more. How much water would you have to bring along with you for drinking? Remember what you're learning about fuel cells and their ability to create water when supplying electricity to answer this intelligently.
2. What type of fuel cell would you choose to run your car's electric motor?

Information in the next sections can help in your effort to answer these questions.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to answer the What If questions and to prepare to do more research on the experiment.

Page 75 –Types of Fuel Cells

Page 79 – How Do Fuel Cells Work?

Web Links

To learn more about different kinds of fuel cells, look here:

http://library.thinkquest.org/04apr/00215energy/fuel_cells/fuel_cells.htm

http://americanhistory.si.edu/fuelcells/basics.htm

Do More Research

Have students do research on the following topic – different types of fuel cells.

Excerpted from the Renewable Energy Science Education Manual - "Many types of fuel cells are currently being researched. The six primary types of fuel cells are differentiated from one another on the basis of the electrolytes and/or fuel used with that particular type of fuel cell. The operating temperature and size of fuel cells are often the determining factor is which fuel cell will be used for specific applications. Fuel cell types include the following:

- Polymer electrolyte membrane fuel cells (PEMFCs)
- Alkaline fuel cells (AFCs)
- Phosphoric acid fuel cells (PAFCs)
- Solid oxide fuel cells (SOFCs)
- Molten carbonate fuel cells (MCFCs)
- Direct methanol fuel cells (DMFCs)

Polymer Exchange Membrane Fuel Cell (PEMFC)

The polymer electrolyte membrane (also called proton exchange membrane or PEM) fuel cell delivers high-power density while providing low weight, cost, and volume. A PEM fuel cell consists of a negatively charged electrode (anode), a positively charged electrode (cathode), and an electrolyte membrane, as shown in Figure 3.

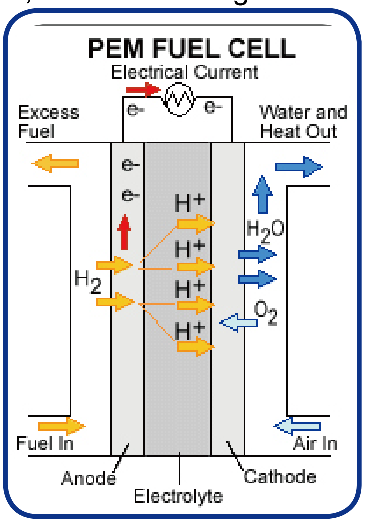


Figure 3 – PEMFC Fuel Cell

Alkaline Fuel Cells (AFCs)

Alkaline fuel cells (AFCs) have been used by NASA on space missions and can achieve powergenerating efficiencies of up to 70 percent. The operating temperatures of these cells range between 150C to 200C. This is advantageous because the cathode reaction is fast in the alkaline electrolyte, which means higher performance. Several companies are examining ways to reduce costs and improve operating flexibility. Alkaline fuel cells typically have a cell output from 300 watts to 5 kW. An illustration of an alkaline fuel cell is shown in Figure 4."

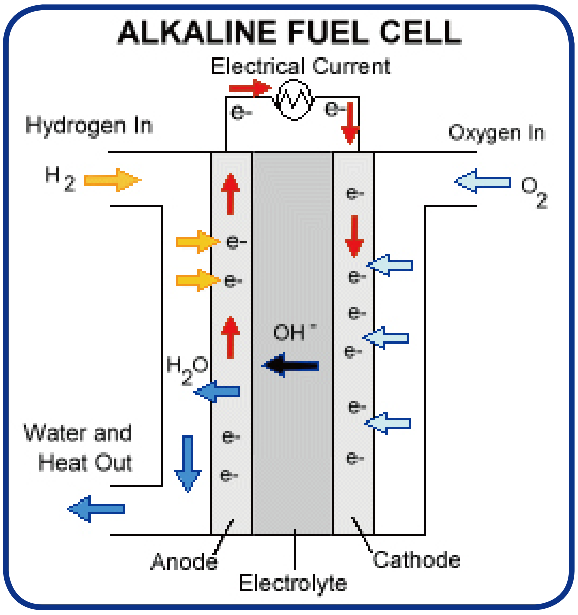
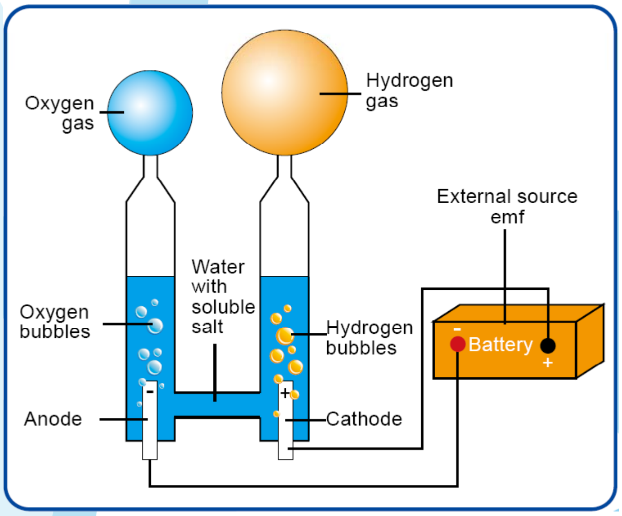


Figure 4 – Alkaline Fuel Cell

These are just two of six fuel cell types that should be the subject of investigation. Once again, refer to the web links on the previous page and to the Renewable Energy Science Education Manual for more details.

Determining the Minimum Voltage for Water Decomposition



LESSON OVERVIEW

This lesson examines the minimum voltage for the decomposition of water into hydrogen and oxygen. This is called the "Decomposition Voltage" and it is higher than the theoretical value of 1.23 volts. The reasons for this difference are explained.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use a reversible PEM fuel cell in the electrolysis mode.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that pure water has a minimum voltage at which it can be electrolyzed into hydrogen and oxygen. The theoretical voltage is 1.23 volts DC; however, the actual voltage is slightly higher due to factors that are explained in the lesson.

Students come to understand that:

1. The process of electrolysis can be done with voltages that are within the reach of everyday solar panels and wind turbines – two non-polluting energy sources for generating hydrogen and oxygen.
2. Electrolyzed hydrogen can be used as a fuel for mobile applications as in fuel cell powered cars, bicycles, motorcycles and boats.
3. Electrolyzed oxygen can either be vented into the air or compressed and stored in cylinders for medical and industrial applications.

STUDENT ACTIVITIES

Students use a solar panel connected to a reversible fuel cell that acts as an electrolyzer in order to determine the Decomposition Voltage of water. They adjust the solar panel's angle towards a light source until the electrolyzer begins to produce measurable amount of hydrogen and oxygen. Data are taken and later analyzed to determine why the actual decomposition voltage is above the theoretical voltage of 1.23 volts DC.

SAFETY

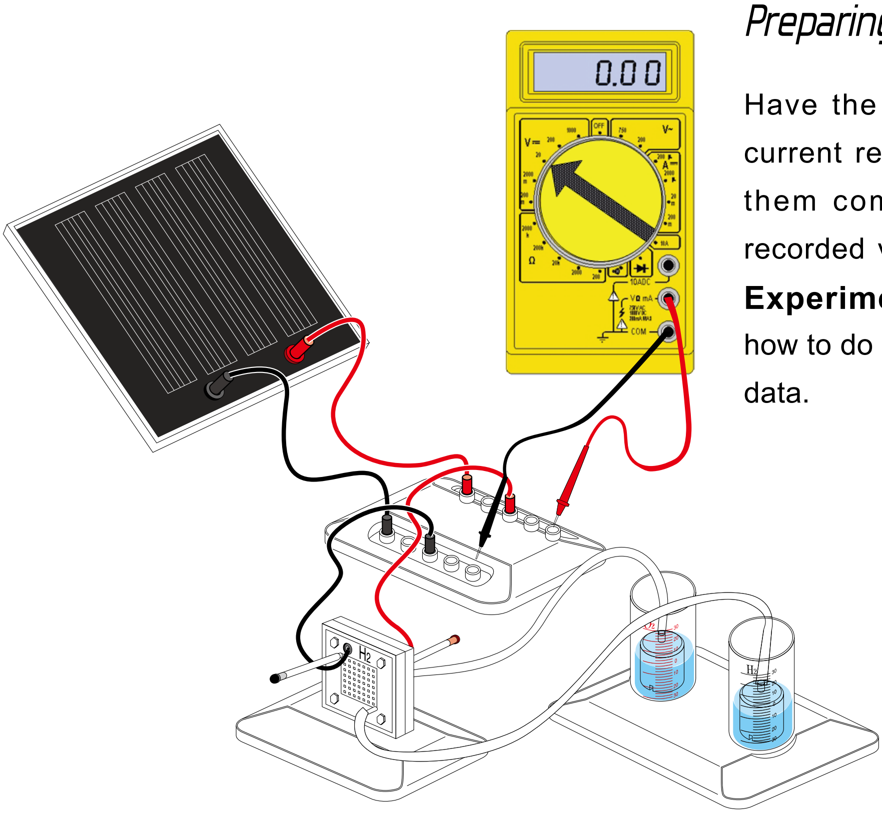
Be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

Materials

1 – Solar Panel
1 – Goose neck table lamp
1 – Electrolyzer apparatus
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base

Equipment Setup #1



Doing the Experiment

1. Set the solar panel face down so as not to generate any meaningful voltage.
2. Set the multimeter dial to Current or A with a range of at least 10 ma. We will first measure current before voltage.
3. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers completely fill with water.
4. Slowly tilt the solar panel towards the light source.
5. When the multimeter begins to indicate a measure of current above a few milliamps, record this current.
6. Maintain the solar panel at the same angle and set the multimeter to read voltage. This will be the Decomposition Voltage value.
7. Record the voltage reading at the instant the current start to flow. The voltage will immediately increase above this point, but it is the value of voltage at which the reaction (jump) occurs that’s important.

Preparing the Data

Have the students enter the voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this. As an example we entered our data.

Our Data

	Volts	Amps	Watts
	1.470	0.024	0.035

Your Data

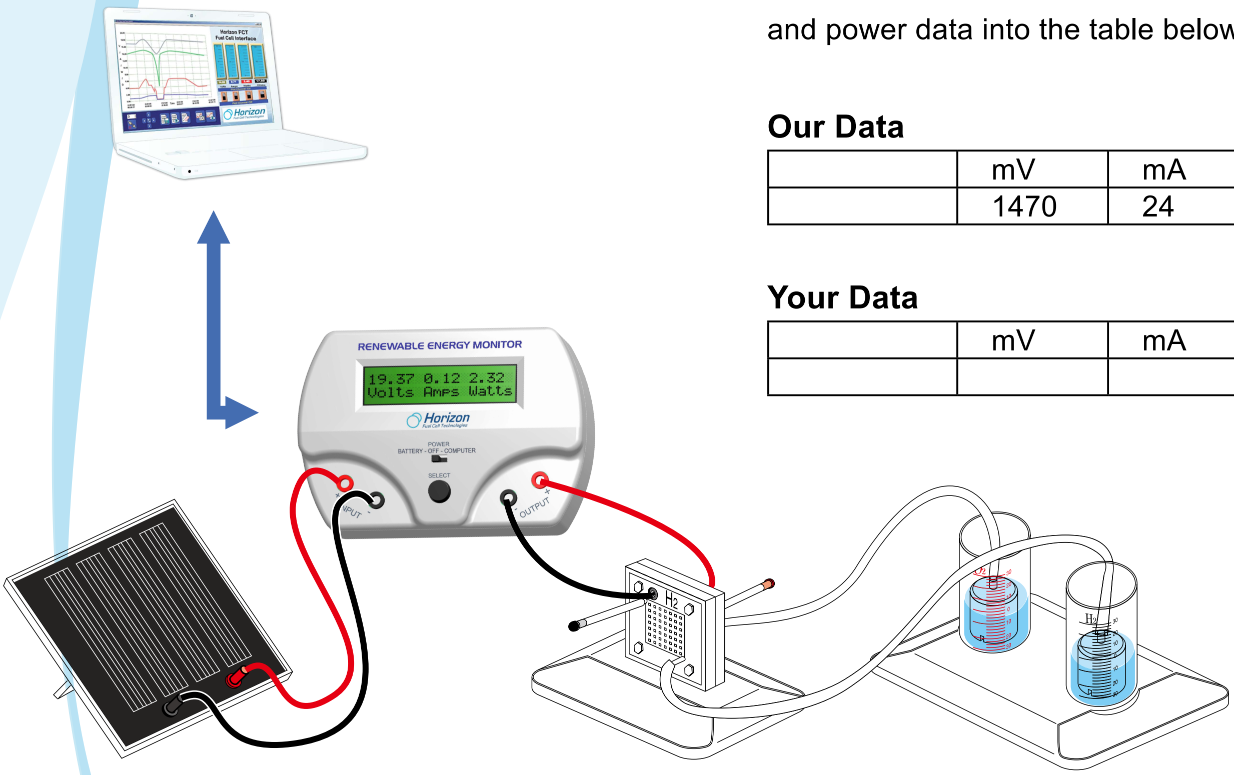
	Volts	Amps	Watts

The Experiment with the Renewable Energy Monitor

Materials

1 – Solar Panel
1 – Goose neck table lamp
1 – Electrolyzer apparatus
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base

Equipment Setup #1



Doing the Experiment

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the mV-mA-mW display appears.

3. Set the solar panel face down so as not to generate any meaningful voltage.
4. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers completely fill with water.
5. Slowly tilt the solar panel towards the light source.
6. When the LCD display begins to indicate a measure of current above a few milliamps record the voltage, current and power.

Preparing the Data

Have the students record the voltage, current and power data into the table below.

Our Data

	mV	mA	mW
	1470	24	35

Your Data

	mV	mA	mW

Analyzing the Results

If you were using a **Renewable Energy Monitor** connected to a computer a plot similar to Figure 1 shows how the voltage slowly rises as the solar panel is tilted toward the light. Then it quickly jumps to a higher level, about 1.5 volts which is called the Decomposition Voltage value when current begins to flow and hydrogen and oxygen begin to be electrolyzed. The voltage will immediately increase above this point, but it is the value of voltage at which the reaction (jump) occurs that's important.

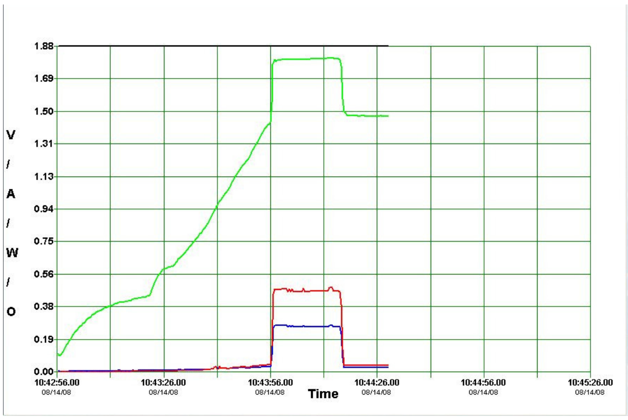


Figure 1 – Decomposition Voltage Value

History

Splitting water by passing an electric current through it was first done by Nicholson and Carlisle in 1800. Water was the first substance to be "electrolyzed" using the battery which had just been invented by Signor Volta to produce the electric current.

Chemistry

The equation for the cathode half-reaction in the electrolysis of water is:

$4\ H_3O+ + 4\ e^- \text{-->} 2\ H_2 + 4\ H_2O$ reductions, at the cathode

The equation for the anode half-reaction in the electrolysis of water is:

$6\ H_2O \text{-->} O_2 + 4\ H_3O+ + 4\ e^-$ oxidation, at the anode

The equation for the net reaction is the sum of the half-reactions:

$2\ H_2O$ (liquid) --> $2\ H_2$ (gas) + O_2 (gas) DG°rxn = + 474.4 kJ

Water electrolysis requires energy to break the oxygen-hydrogen-bond. This reaction is driven by the voltage applied across the electrodes. The electrochemical decomposition of water cannot occur unless the voltage is high enough to overcome the strength of the hydrogen-oxygen bonds.

Electrical

The minimum voltage necessary to decompose a sample of water at 25°C is 1.23 volts DC. The difference between the theoretical decomposition voltage and the measured voltage is called "overpotential". Overpotential is a function of the fuel cell's inability to expel the hydrogen and oxygen gasses that form on the metal electrodes below a certain voltage; in this case, about 1.5 volts as compared with 1.23 volts. Many other factors are involved in this difference of decomposition voltage; however, the reasons for these differences are beyond the scope of this experiment. Please refer to the following link for more detailed information…

http://en.wikipedia.org/wiki/Electrolysis_of_water

What If ???

Have students speculate on the following hypothetical question:

1. What if you wanted to convert your family car from gasoline to hydrogen? It has already been done, but it can be done in lots of ways. One of the things that you will have to do is figure out how to store the hydrogen; should it be in a gaseous form or should it be in a liquid form? There are advantages and disadvantages to both. Information in the next sections can help in your effort to answer these questions.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to answer the What If questions and to prepare to do more research on the experiment.

Page 73 – Fuel Cells for Automobiles
Page 91 –Vehicular Pressurized Hydrogen Tanks
Page 96 – Worldwide Hydrogen Refueling Stations

Web Links

To learn more about fuel cells for cars, aircraft, motorcycles, boats and other vehicles, look here:
Automobiles:
http://www.horizonfuelcell.com/automotive.htm
Aircraft:
http://www.horizonfuelcell.com/aerospace.htm
Motorcycles:
http://www.autobloggreen.com/2009/03/03/james-may-rides-the-env-fuel-cell-motorcycle/
Boats:
http://www.powerandmotoryacht.com/boattests/0104duffy/index.aspx

Do More Research

Have students do research on the following topic – fuel cell powered automobiles.

Excerpted from the Renewable Energy Science Education Manual – "Most automobile manufacturers have been developing fuel cell vehicles for at least a decade, and have demonstrated at least one prototype vehicle. The major reasons for developing automotive fuel cell technology are their efficiency, low or zero emissions, and fuel that could be reproduced from local sources rather than imported. Automotive fuel cells can have one or all of the following characteristics:

1. A fuel cell is sized to provide all of the power to a vehicle.
2. A battery may be present for startup.
3. A fuel cell typically supplies a constant amount of power, so for vehicle acceleration and other power spikes, additional devices are typically switched on such as batteries, ultra or super-capacitors, and so on.
4. Sometimes a fuel cell is used as the secondary power source. A system is set up where batteries power the vehicle, and the fuel cell just recharges the batteries when needed.
5. A fuel cell can run part or all of the vehicle's electrical system.

The operating temperature of the fuel cell stack for an automobile ranges from 60 to 80 ºC. Operating temperatures above 100 ºC would improve the heat transfer and simplify stack cooling, but most automotive fuel cells use PEMFCs (proton exchange membrane fuel cells) or DMFCs (direct methanol fuel cells) which are limited the operation to temperatures below 100 ºC due to water management issues in the device [10]. The main components of a fuel cell system are shown in Figure 2.

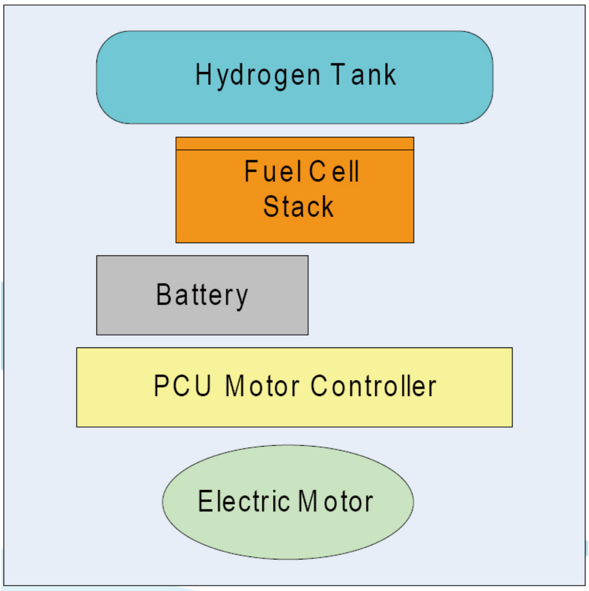


Figure 2 - Hydrogen Fueled Fuel Cell Vehicle

The design of a fuel cell as a power source in transportation applications involves a number of parameters. These include the same power requirement as with any conventional power source, weight and size of the fuel cell, electric motor and power electronics, the type of fueling system, and the distance between fueling and the time it takes to refuel. The fuel cell allows automotive engineers to employ completely non-traditional concepts in vehicle design.

One such design is the General Motors Fuel Cell Car called the “Sequal” with the skateboard design (Figure 3). Fueling options include on-board production of hydrogen from conventional fuels, and on-board hydrogen storage with home or standard refueling stations. The US Department of Energy has opted to only support onboard hydrogen storage. Home refueling stations may employ reformation of hydro-carbon fuels or electrolysis of water.”

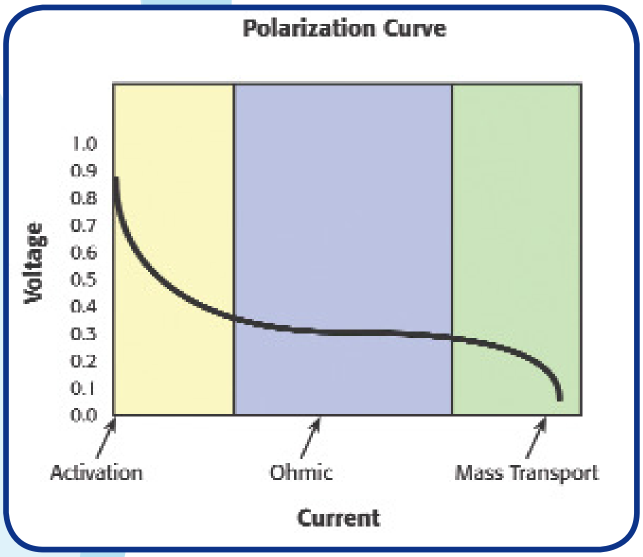
Figure 3 – GM’s Sequal Fuel Cell Car

Another is from an English company; see Figure 4. Developed by Riversimple, the small city car integrates a 6kW fuel cell from Horizon Fuel Cell Technologies. The vehicle maximizes energy efficiency by utilizing lightweight composite materials, eliminating heavy mechanical components, and by networking fuel cells with ultracapacitors and 60% regenerative braking energy into one symbiotic system. The result is ground-breaking: 240 miles (390 km) can be traveled on one small tank of hydrogen weighing only 2.2 lbs (1 kilogram).

Figure 4 – Fuel Cell Car Powered by Horizon FCT Fuel Cell

A new generation of fuel cells developed by Horizon Fuel Cell Technologies has enabled the world’s first low-cost and practical hydrogen car. This UK development unveiled in London is a two-seater zero emissions hydrogen-electric city car with an expected fuel consumption equivalent to 250 miles per gallon (US), four to five times better than today’s best available hybrid electric vehicles. What’s more, this innovative car could be made available to consumers for just 200 ($315) per month.

Polarization States for Hydrogen Fuel Cells



LESSON OVERVIEW

This lesson examines the three fundamental states of a fuel cell when delivering voltage and current into a load – Activation, Ohmic and Mass Transport. These are called the Polarization States and are expressed above as a plot of voltage versus current that illustrates the voltage-current relationship based upon operating conditions such as temperature, humidity, applied load, and fuel/oxidant flow rates.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn to use an electrolyzer and a fuel cell.
- Students will study the manner in which each state of the polarization curve affects the ability of the fuel cell to deliver usable power.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown the three basic operational states of a hydrogen fuel cell as it relates to supplying voltage and current into a load.

Students come to understand that:
1.A fuel cell's behavior is like that of a modern battery. It begins with a short lived, high voltage, low current output and quickly transitions into a long lasting working region depending on the amount of hydrogen that is available. This is followed by a rapid drop in current and power once the hydrogen becomes exhausted.

2.Unlike batteries that must carry their "fuel" with them in the form of a fixed amount of electrolyte solution, fuel cells can operate continuously as long as hydrogen is made available.

3.Portable devices like laptop computers, cell phones and other appliances that depend on fuel cell power must abide by these polarization states for their proper operation.

STUDENT ACTIVITIES

Students produce a sufficient quantity of hydrogen using a reversible fuel cell then selectively apply varying resistor loads to transition through the three states. Data are taken at each state and later analyzed.

SAFETY

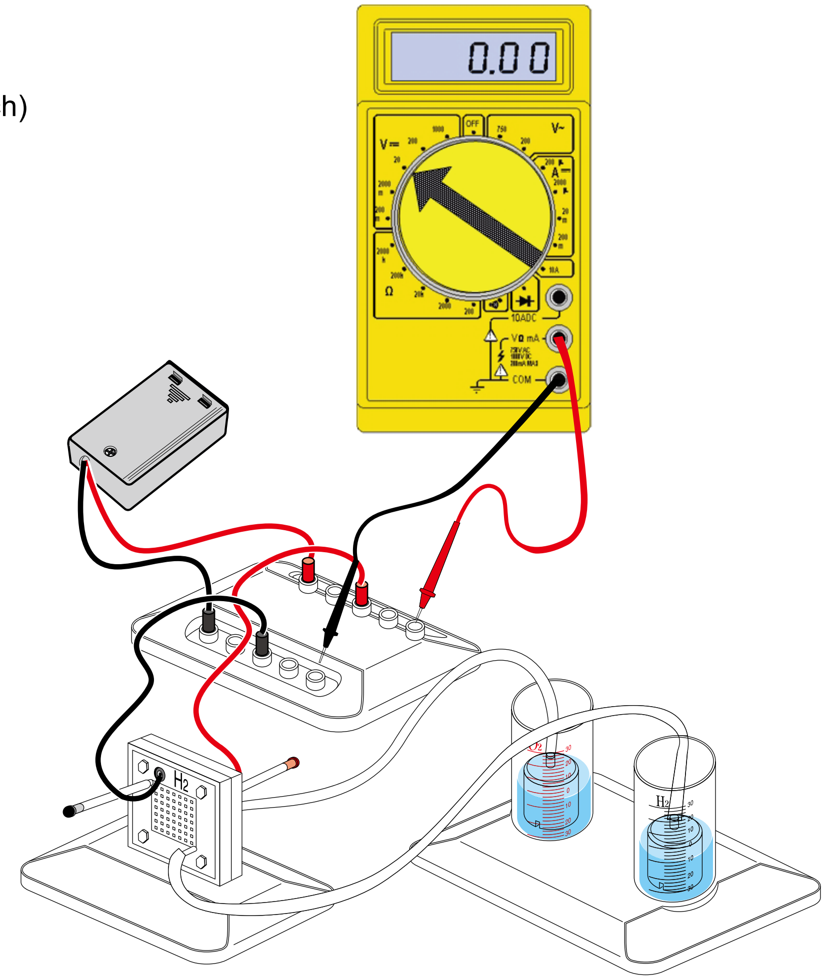
Be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

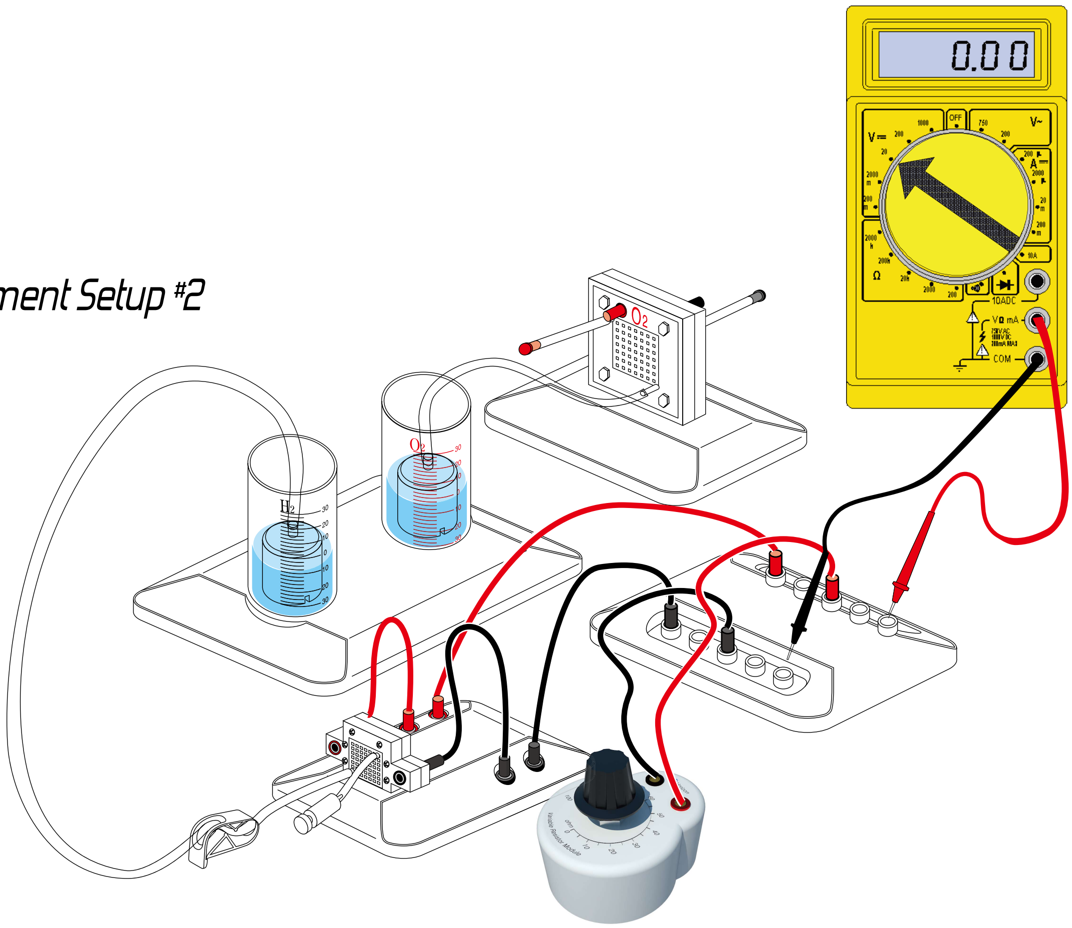
Materials

1 – Battery Pack (3 volt battery with switch)
1 – Electrolyzer apparatus
1 – Fuel cell
1 – 100 ohm potentiometer
1 – Motor and propeller
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base
1 – Fuel Cell Base
1 – Electrolyzer Base

Equipment Setup #1



Equipment Setup #2



Doing the Experiment

1. Set the multimeter dial to DC Volts with a range of at least 5 VDC.
2. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers completely fill with water.
3. Set the ON-OFF switch on the battery pack to ON.
4. Set the battery switch to OFF when the water in the hydrogen cylinder reaches the 10ml mark.
5. Change to Equipment Setup #2. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details. **Do not place the potentiometer in the circuit at this point.**

Equipment Setup #2

6. With only the fuel cell and without any resistor load, record the voltage. Because there is no load the current will be zero. This will define the left-most part of the Polarization Curve.
7. Apply the potentiometer set to 100 ohms across the fuel cell's terminals. Notice that the voltage decreases. The fuel cell is transitioning from the Activation to the Ohmic region. Measure and record the voltage and current.
8. Wait about one (1) minute then adjust the resistance to 50 ohms. Notice another decrease in voltage and an increase in current. Measure and record the voltage and current.
9. Allow about two (2) minutes to elapse and notice that the voltage and current stay at about the same level. This is the advantage of the Ohmic region since the power to the load remains steady.
10. Set the multimeter to measure current for the next step.
11. Adjust the resistance to about 10 ohms in order to hasten the transition from the Ohmic to the Mass Transport region. This may take a few seconds to a few minutes to accomplish depending on your fuel cell's hydrogen supply.
12. When the current begins to decrease record its value then switch to voltage and record it, as well. This will happen reasonably quickly so be prepared to switch the multimeter from current to voltage measurement.

Preparing the Data

Have the students enter the voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this. As an example we entered our data.

Our Data

	Volts	Amps	Watts
Step 6	1.420	0	0
Step 7	0.825	0.014	0.012
Step 8	0.793	0.023	0.018
Step 12	0.702	0.019	0.013

Your Data

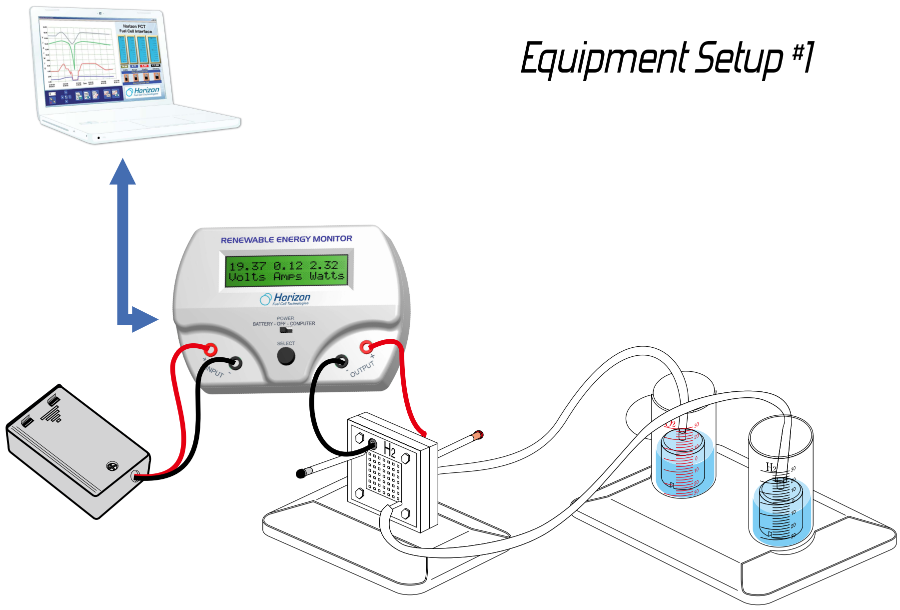
	Volts	Amps	Watts
Step 6			
Step 7			
Step 8			
Step 12			

The Experiment with the Renewable Energy Monitor

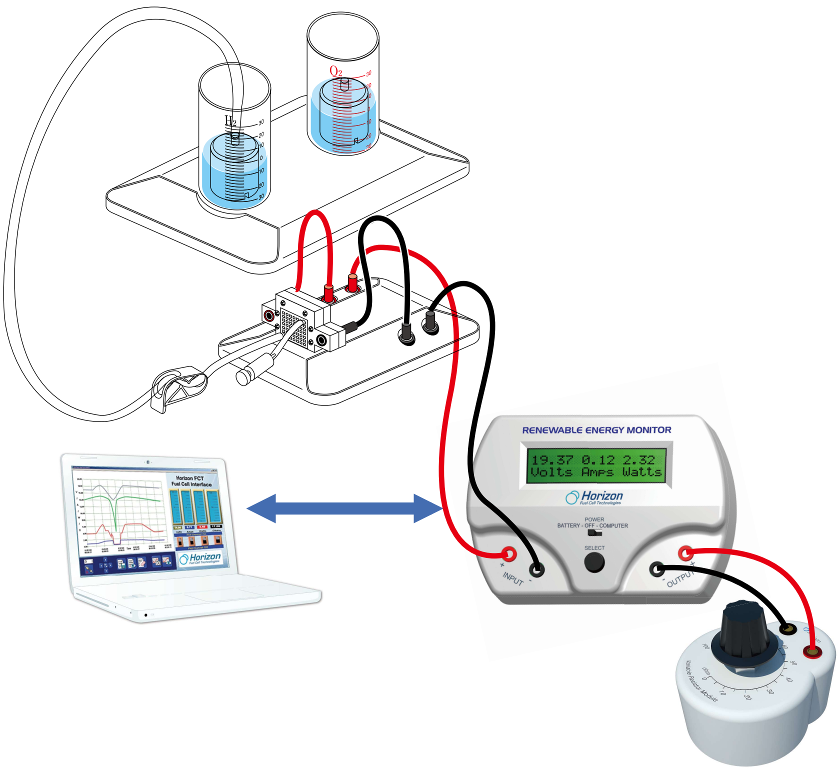
Materials

1 – Battery Pack (3 volt battery with switch)
1 – Electrolyzer apparatus
1 – Fuel cell
1 – 100 ohm potentiometer
1 – Motor and propeller
2 – Red hookup leads
2 – Black hookup leads
1 – Circuit Board Module Base
1 – Fuel Cell Base
1 – Electrolyzer Base

Equipment Setup #1



Equipment Setup #2



Doing the Experiment

11. Set the **Renewable Energy Monitor** switch to Battery or Computer depending on your hookup.

2. Push the Select Button until the mV-mA-mW display appears

3. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers completely fill with water.

4. Set the ON-OFF switch on the battery pack to ON.

5. Set the battery switch to OFF when the water in the hydrogen cylinder reaches the 10ml mark.

6. Change to Equipment Setup #2. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details. **Do not place the potentiometer in the circuit at this point.**

Equipment Setup #2

7. With only the fuel cell and without any resistor load, record the voltage, current and power. Because there is no load the current will be zero. This will define the left-most part of the Polarization Curve

8. Apply the potentiometer set to 100 ohms across the fuel cell's terminals Notice that the voltage decreases. The fuel cell is transitioning from the Activation to the Ohmic region. Record the voltage, current and power at this point.

9. Wait about one (1) minute then adjust the resistance to 50 ohms. Notice another decrease in voltage and an increase in current. Record the voltage, current and power at this point.

10. Allow about two (2) minutes to elapse and notice that the voltage and current stay at about the same level. This is the advantage of the Ohmic region since the power to the load remains steady.

11. Adjust the resistance to 10 ohms in order to hasten the transition from the Ohmic to the Mass Transport region. This may take a few seconds to a few minutes to accomplish depending on your fuel cell's hydrogen supply.

12. When the current begins to decrease record the voltage, current and power.

Preparing the Data

Have the students record the voltage, current and power into the table below.

Our Data

	mV	mA	mW
Step 7	1420	0	0
Step 8	825	14	12
Step 9	793	23	18
Step 12	702	19	13

Your Data

	mV	mA	mW
Step 7			
Step 8			
Step 9			
Step 12			

Analyzing the Results

As previously mentioned the polarization states just recorded mimic a modern battery. Older batteries, usually of the lead acid variety, started with full voltage and current which then gradually decreased with time as the load was maintained. This was evident in flashlights that would start off shining brightly and then slowly got dimmer and dimmer until they went out completely. It was like someone was turning a knob that made the light decrease.

Flashlights with modern batteries like alkaline and now nickel-metal hydride (NiMH) start bright and stay bright throughout their useful life. Only at the very end of their life cycle do they quickly fade in brightness with the flashlight bulb going out almost immediately.

Fuel cells are like modern batteries in this regard. This experiment demonstrated how the voltage and current started at a high value (Activation Region) and then quickly settled to a steady and consistent value (Ohmic Region). Only at the very end when the hydrogen began to run out did it finally fade to zero voltage, current and power (the Mass Transport Region).

If you were using a **Renewable Energy Monitor** a plot similar to Figure 1 shows the Activation Region. Notice the sharp drop in voltage as resistance of 100 ohms is applied in step 8.

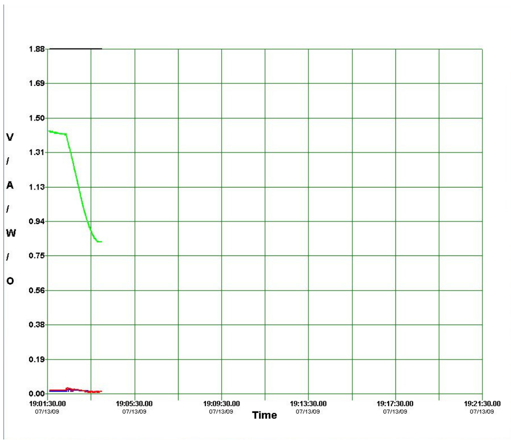


Figure 1 – Plot of Activation Region

Figure 2 shows a plot of the Ohmic Region with resistance of 50 ohms as in Step 9. Notice how steady the voltage, current and power levels remain at this point where sufficient hydrogen is available to power the fuel cell.

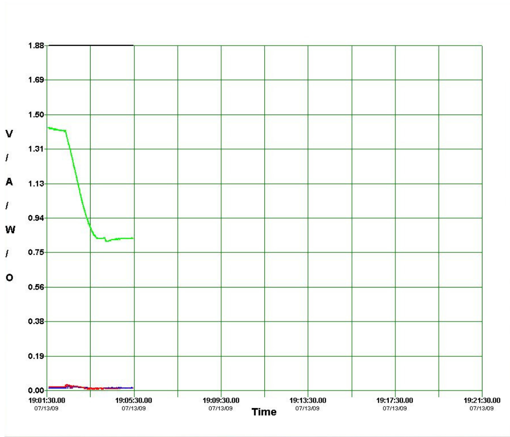


Figure 2 – Beginning of Ohmic Region

Finally, Figure 3 shows the plot of the Mass Transport Region where the hydrogen fuel supply begins to run out. Notice how the voltage, current and power all rapidly decrease.

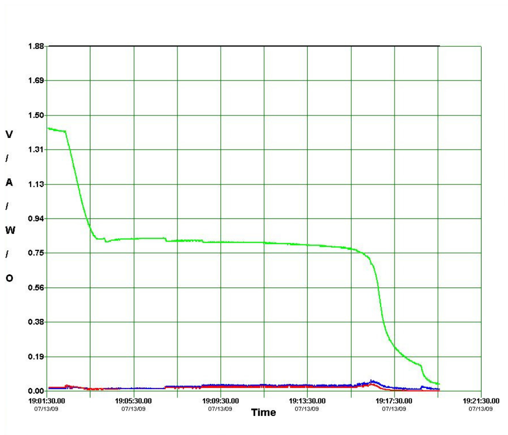


Figure 3 – Plot of Mass Transport Region

The similarity to the stylized plot below on the title page is striking. Use diligence in your experiment to replicate these plots.

What If ???

Have students speculate on the following hypothetical question:

1.What if you wanted to recharge your cell phone's battery but didn't want to use the AC adapter or car charging cable that came with it? Another way would be to use a hydrogen-based recharger. The question, then, is what would such a device look like and where would you go to get hydrogen refills? Remember, you will be protecting the environment if you can find a source of hydrogen that is created from solar or wind energy.

Information in the next sections can help in your effort to answer this question.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to answer the What If questions and to prepare to do more research on the experiment.

Page 71 – Fuel Cell Applications – Portable Sector
Page 82 – Polarisation Curves

Web Links

To learn more about fuel cells for portable applications, look here:

Horizon HydroPaK
http://www.horizonfuelcell.com/portable_power.htm

Cell Phones
http://cleantech.com/news/2446/fuel-cell-powered-cell-phones-show-progress

Do More Research

Have students do research on the following topic – portable fuel cell applications.

Fuel cells now come in all shapes and sizes. Figure 4 shows a fuel cell designed to fit into a laptop computer. These new devices may soon be a substitute, or even replace, batteries.

Figure 4 – Fuel Cells for Laptop Computers

The miniPAK portable electronic device charger from Horizon is designed to meet the needs of users who want more portable energy in one package, at a lower cost than existing rechargeable battery-based options.

Figure 5 – Horizon MiniPak

Build a Solar Farm

LESSON OVERVIEW

This lesson demonstrates methods to arrange multiple solar panels in series and parallel configurations in order to study the voltage, current and power generated. It is designed to be a simulation of a commercial solar farm in model scale where students learn the potential of solar power as a mass energy source. At least two (2) of the same type of solar panels are needed. More than two solar panels can also be accommodated and is encouraged.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will observe the photovoltaic effect of sunlight and artificial light producing electricity.
- Students will learn how to wire solar panels in series and parallel.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that solar panels, like common flashlight batteries, can be arranged in series and parallel configurations with the same general outcomes.

Students come to understand that:

1. Solar panels in series generate more voltage with the same amount of current.
2. Solar panels in parallel generate more current with the same amount of voltage.
3. Solar panels can be arranged in any combination of series and parallel arrangements to generate the desired voltage, current and power required by a particular application.

STUDENT ACTIVITIES

Students first wire two solar panels in series and measure the voltage, current and power going into a fixed resistor load at various tilt angles. This is followed by wiring the same solar panels in parallel and repeating the measurements. Data are taken for later analysis. Additional exercises are performed in the What If section to query student's understanding of how solar panels can be arranged in different series-parallel groups to power popular portable electronic devices.

SAFETY

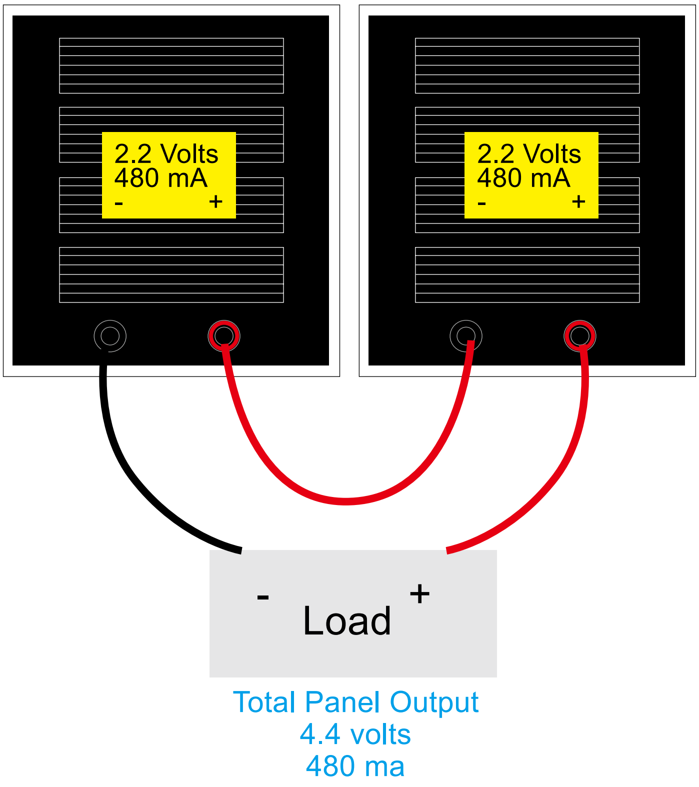
Normal caution must be exercised when using an artificial light source like a table lamp to illuminate a solar panel. Be sure NOT to overheat the solar panel as it will become HOT TO THE TOUCH and may MELT THE PLASTIC.

Background - Arranging Solar Panels in Series and Parallel

Before proceeding with the experiment the following is a guide to arranging solar panels in series and parallel arrangements. It is designed to help with understanding the experiment and the following **What If** questions.

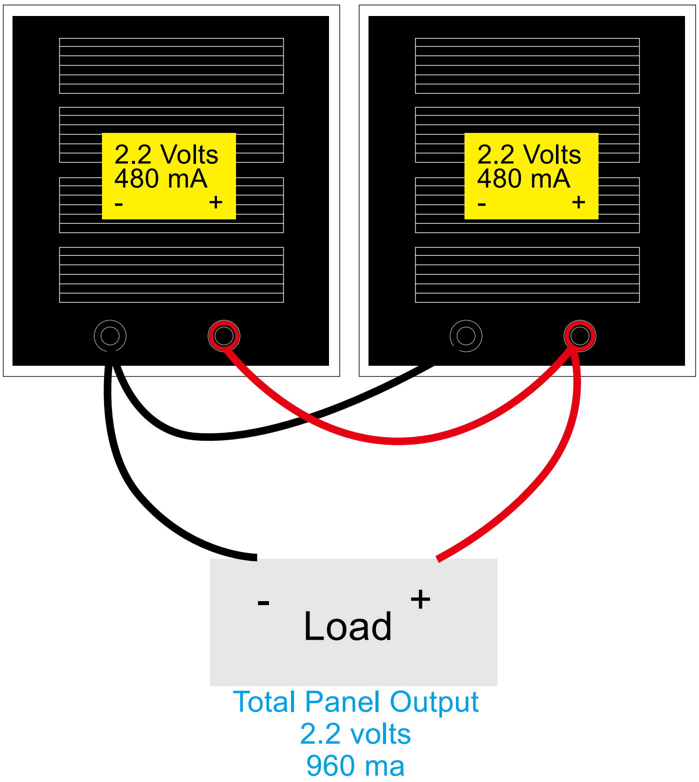
Series Arrangement with Two Solar Panels

This is the fundamental series arrangement for two solar panels. Start with the positive terminal of the left solar panel going to the positive side of the load. Then connect the negative terminal to the positive terminal of the solar panel on the right. The negative terminal of the right panel goes to the negative side of the load. In this arrangement the total solar panel current is equal to the nominal current for one panel. The total voltage is equal to the sum of the voltages for both panels.



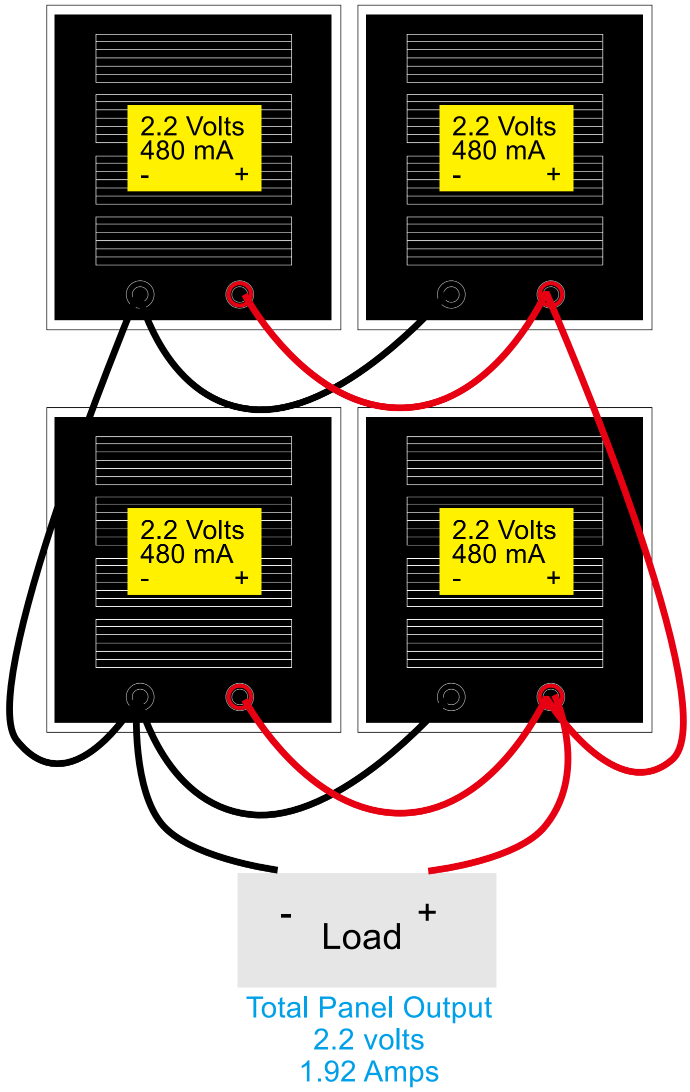
Parallel Arrangement with Two Solar Panels

This is the fundamental parallel arrangement for two solar panels. The positive terminal of the solar panel on the left goes to the positive terminal of the solar panel on the right and also to the positive end of the load. The negative terminal of solar panel on the left goes to the negative terminal of solar panel on the right and to the negative end of the load. The total solar panel voltage is equal to the nominal voltage for one panel. The total current is equal to the sum of the currents for both panels.



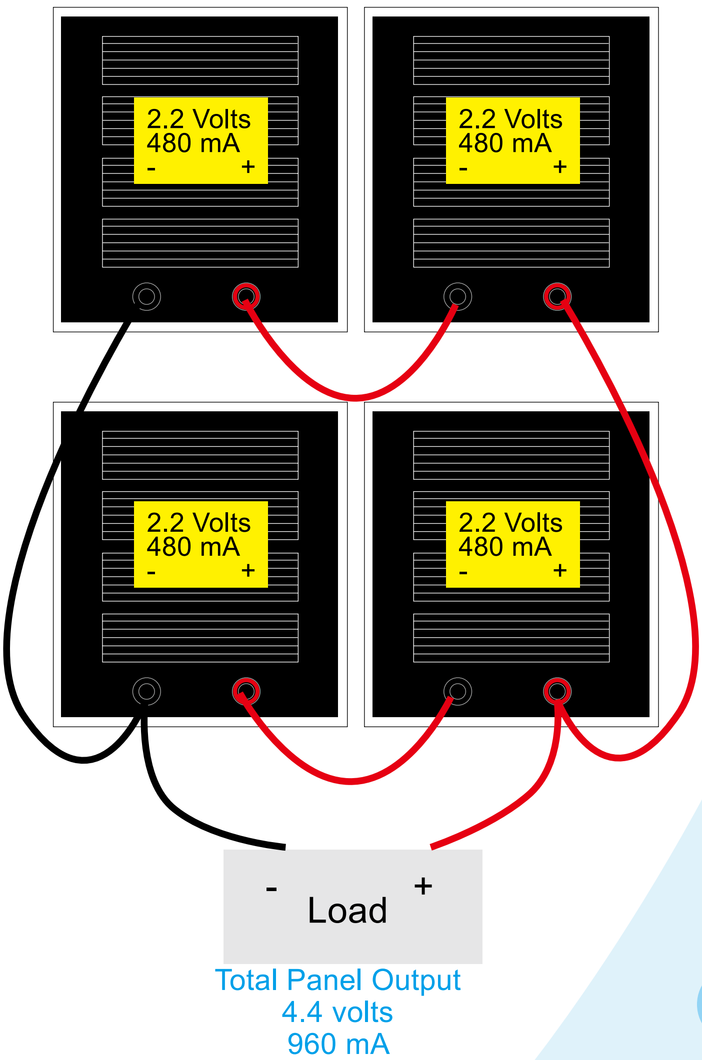
Series-Parallel Arrangement #1 with Four Solar Panels

Four solar panels are wired in a series-parallel arrangement such that the total voltage equals the nominal voltage of one panel while the total current is the sum of all four panels. The two panels on the top and bottom are wired in parallel and both sets of panels are wired in parallel.



Series-Parallel Arrangement #2 with Four Solar Panels

Four solar panels are wired in a series-parallel arrangement such that the total voltage equals twice the voltage of a single panel and the total current equals twice the current of a single panel. The two panels on the top and bottom are wired in series and both sets of panels are wired in parallel.

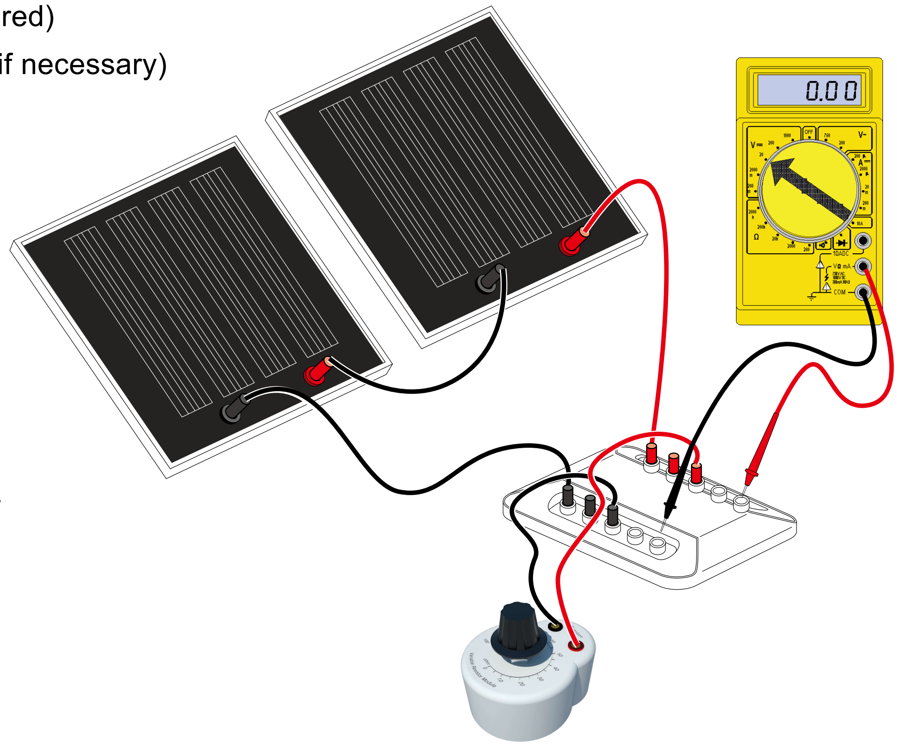


The Experiment with a Multimeter

Materials

2 - Solar panels (or more if desired)
1- Goose neck table lamp (two if necessary)
1 - Protractor
1 - 100 ohm potentiometer
3 – Red hookup lead
3 – Black hookup lead
1 – Circuit Board Module Base

Equipment Setup #1 - Series



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the potentiometer to 100 ohms.
2. Set the multimeter dial to DC Volts with a range of at least 10 VDC.
3. Place the solar panels flat on the table facing straight up.
4. Shine the table lamp directly on the solar panel.
5. Record the voltage.
6. Adjust the potentiometer for 50 ohms and measure the voltage.
7. Adjust the potentiometer for 30 ohms and measure the voltage.
8. Tilt the solar panels at a 45 degree angle to the table.
9. Repeat steps 1 through 7.

Preparing the Data for the Solar Panels in Series

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the indicated resistor load for each step. Refer to the **Experiment Guide** section for details on how to do this.

Solar Panels in Series - Flat

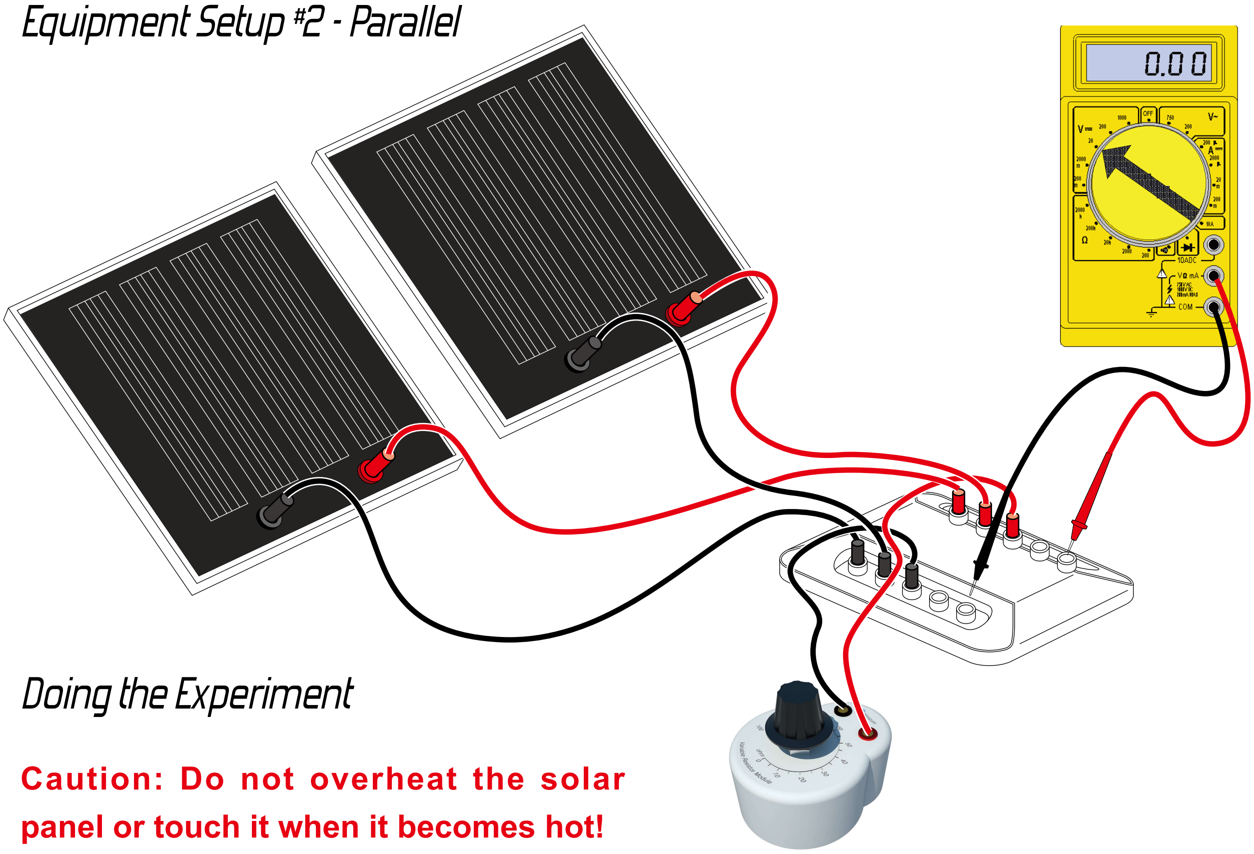
Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

Solar Panels in Series –At a 45^0 Angle

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

The Experiment with a Multimeter

Equipment Setup #2 - Parallel



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

10. Set the potentiometer to 100 ohms.
11. Set the multimeter dial to DC Volts with a range of at least 10 VDC.
12. Place the solar panels flat on the table facing straight up.
13. Shine the table lamp directly on the solar panel.
14. Record the voltage.
15. Adjust the potentiometer for 50 ohms and measure the voltage.
16. Adjust the potentiometer for 30 ohms and measure the voltage.
17. Tilt the solar panels at a 45 degree angle to the table.
18. Repeat steps 10 through 16.

Preparing the Data for the Solar Panels in Parallel

Have the students enter the voltage readings in the table below. Have them compute the current and power based on the indicated resistor load for each step. Refer to the **Experiment Guide** section for details on how to do this.

Solar Panels in Parallel - Flat

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

Solar Panels in Parallel –At a 45^0 angle

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

The Experiment with the Renewable Energy Monitor

Materials

2 - Solar panels (more if desired)
1- Goose neck table lamp (two if necessary)
1 - Protractor
1 - 100 ohm potentiometer
4 – Red hookup leads
4 – Black hookup leads
1 – Circuit Board Module Base

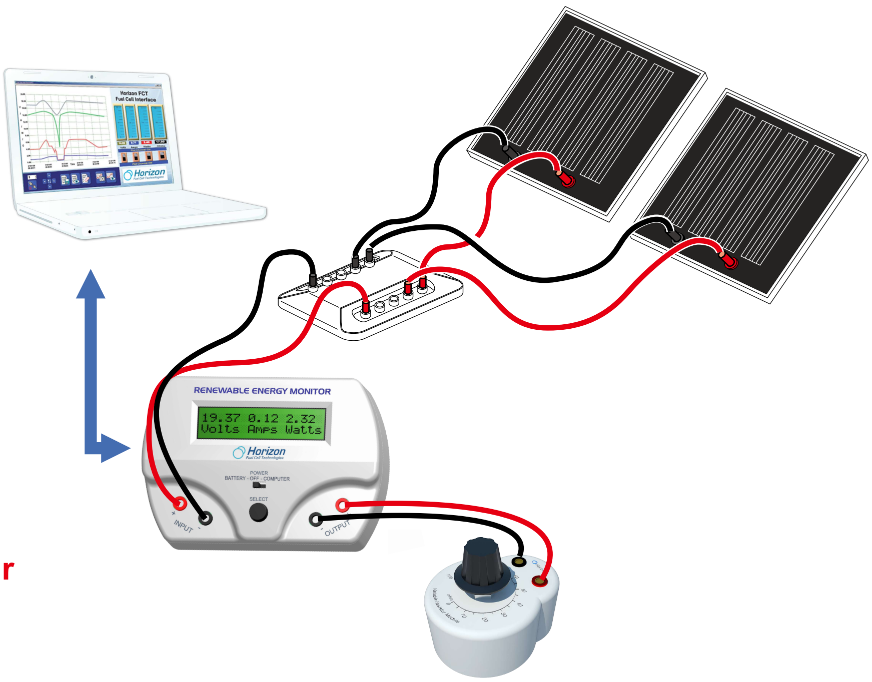
Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Ohms display appears

3. Adjust the potentiometer for 100 ohms. Light must be shining on the solar panels for this to occur.
4. Push the Select Button until the Volts Amps Watts display appears.
5. Place the solar panels flat on the table facing straight up.
6. Shine the table lamp directly on the solar panels.
7. Record the voltage, current and power.
8. Push the Select Button until the Ohms display appears.
9. Adjust the potentiometer for 50 ohms. Light must be shining on the solar panels for this to occur.
10. Push the Select Button until the Volts Amps Watts display appears.
11. Record the voltage, current and power.

Equipment Setup #1 - Series



12. Push the Select Button until the Ohms display appears.
13. Adjust the potentiometer for 30 ohms. Light must be shining on the solar panels for this to occur.
14. Push the Select Button until the Volts Amps Watts display appears.
15. Record the voltage, current and power
16. Tilt the solar panel at a 45 degree angle to the table.
17. Repeat steps 1 through 15.

Preparing the Data

Have the students enter the voltage, current and power data into the tables below:

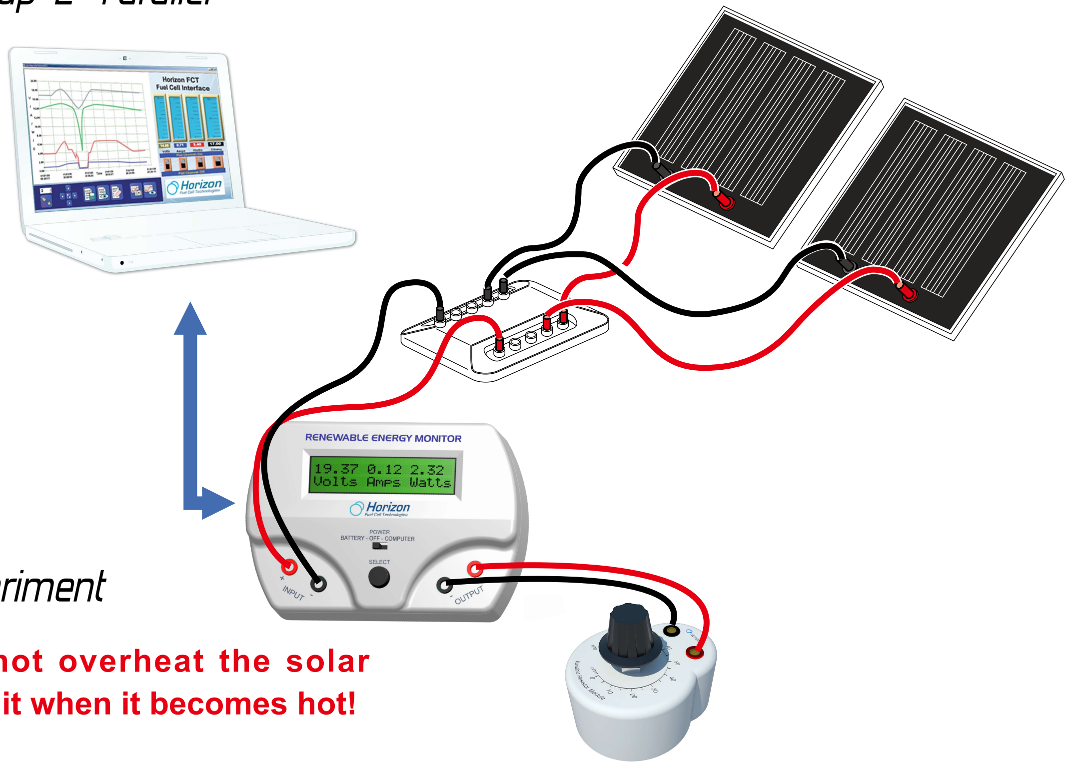
Solar Panels in Series - Flat

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

Solar Panels in Series –At a 45^0 Angle

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

Equipment Setup #2 - Parallel



Doing the Experiment

Caution: Do not overheat the solar panel or touch it when it becomes hot!

18. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
19. Push the Select Button until the Ohms display appears

20. Adjust the potentiometer for 100 ohms. Light must be shining on the solar panels for this to occur.
21. Push the Select Button until the Volts Amps Watts display appears.
22. Place the solar panels flat on the table facing straight up.
23. Shine the table lamp directly on the solar panels.
24. Record the voltage, current and power.
25. Push the Select Button until the Ohms display appears.
26. Adjust the potentiometer for 50 ohms. Light must be shining on the solar panels for this to occur.
27. Push the Select Button until the Volts Amps Watts display appears.
28. Record the voltage, current and power.
29. Push the Select Button until the Ohms display appears.
30. Adjust the potentiometer for 30 ohms. Light must be shining on the solar panels for this to occur.
31. Push the Select Button until the Volts Amps Watts display appears.
32. Record the voltage, current and power
33. Tilt the solar panel at a 45 degree angle to the table.
34. Repeat steps 18 through 32.

Preparing the Data

Have the students enter the voltage, current and power into the tables below:

Solar Panels in Parallel - Flat

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

Solar Panels in Parallel –At a 45^0 Angle

Resistance	Volts	Amps	Watts
100 ohms			
50 ohms			
30 ohms			

Analyzing the Results

The following data were recorded for the above conditions.

For the solar panels in series notice that the current stayed reasonably steady while the voltage varied with additional resistor loads. This is as predicted for solar panels in series. The only differences were when the solar panels were tilted to a 45 degree angle placing them closer to the light source. This cased the overall voltage and current to increase; however, the current again stayed constant while the voltage varied.

Solar Panels in Series - Flat

Resistance	Volts	Amps	Watts
100 ohms	3.194	0.032	0.102
50 ohms	1.708	0.034	0.057
30 ohms	1.173	0.035	0.040

Solar Panels in Series –At a 45^0 Angle

Resistance	Volts	Amps	Watts
100 ohms	4.076	0.041	0.166
50 ohms	1.513	0.045	0.067
30 ohms	1.234	0.044	0.054

For the solar panels in parallel the opposite happened. Notice that the voltage stayed the same while the current varied with different resistor loads. Placing the panels at a 45 degree angle did not alter the readings very much due to the characteristics of the parallel arrangement.

Solar Panels in Parallel - Flat

Resistance	Volts	Amps	Watts
100 ohms	2.486	0.025	0.061
50 ohms	2.340	0.047	0.109
30 ohms	2.124	0.063	0.133

Solar Panels in Parallel –At a 45^0 Angle

Resistance	Volts	Amps	Watts
100 ohms	2.548	0.026	0.066
50 ohms	2.465	0.050	0.122
30 ohms	2.332	0.070	0.162

What If ???

Have students speculate on the following hypothetical question.

What if your class decided to build a large model solar farm? How would you arrange the solar panels in series and parallel to power or charge up the following types of devices?

- An IPod
- A Cell Phone
- A Large Portable Radio (Boom Box)
- A Laptop Computer

Assume that each solar panel is rated at 3 volts and 0.100 amps (100 milliamps). You are allowed to have as many panels as you want, but you will be judged on the minimum number of panels you use, so don't use more than you need.

You are allowed to go a little over the needed voltage and current without the thought of damaging the equipment that the solar panels are powering or charging.

The goal is to find the best series-parallel arrangement for each application. There can be more than one answer.

Once you think you know the answer you are to sketch it on paper and describe in writing with some math to support it as to why it will work.

NOTE: The figures for power and charging stated below are for example only. They may not be the actual voltage and currents needed for the actual devices. **DO NOT ATTEMPT TO POWER THESE DEVICES WITHOUT AN APPROVED POWER UNIT. THE FOLLOWING IS SIMPLY AN EXERCISE.**

Solar Farm Problem #1 – Charging Your IPod

A typical IPod (of any model) requires 6 volts and 0.2 amps (200 milliamps) for charging. How many solar panels and in what series-parallel configuration will you need to charge it?

Solar Farm Problem #2 – Charging Your Cell Phone

A typical cell phone requires 9 volts and 0.4 amps (400 milliamps) for charging. How many solar panels and in what series-parallel configuration will you need to charge it?

Solar Farm Problem #3 – Powering a Large Portable Radio (Boom Box)

Because a Boom Box is so loud it takes a good deal of battery power when it's ON. Assume that it requires 15 volts and 0.8 amps (800 milliamps) to keep it blasting out your favorite tunes. How many solar panels and in what series-parallel configuration will you need to charge it?

Solar Farm Problem #4 – Powering a Laptop Computer

A neat thing to do would be to keep your laptop computer fully charged at all times so that you could use it to surf the web or Twitter to your friends without its battery going dead. Assume that your laptop needs 12 volts at 1.2 amps (1200 milliamps) to stay fully charged at all times. How many solar panels and in what series-parallel configuration will you need to charge it and keep it charged?

Sketch your answers below

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 35 – Powering a House Using Solar Power

Page 35 – Solving Solar Powered Issues

Web Links

http://community.gogreensolar.com/video/wiring-solar-panels-in-series
http://www.californiasolarcenter.org/fste/fste.html

Do More Research

Have students do research on the following topic – concentrating solar arrays:

The newest and most advanced form of generating solar energy on a mass scale is through the use of concentrating solar arrays. One form of solar concentrators focuses the sun using parabolic dish arrays on a single point of PV solar material where the concentrated sunlight produces far more power than flat panel arrays.

Figure 2 – Solar Concentrating Arrays

Another solar concentrating system uses focused mirrors that are directed to the top of a tower where "salt" is heated to a molten state. The heat from the molten salt is used to generate steam from water which, in turn, powers conventional electrical generators. The advantage of this system is that the molten salt retains most of its heat at night so electrical power can be generated all day and all night.

Figure 3 – Solar-Thermal Farm

Build a Wind F arm

LESSON OVERVIEW

This lesson demonstrates methods to arrange model wind turbines in series and parallel configurations in order to study the voltage, current and power generated. It is designed to be a simulation of a commercial wind farm in model scale where students learn the potential of wind power as a mass energy source. This is the same wind turbine that comes with the Horizon Hydro-Wind Kit.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn how to wire wind turbines in series and parallel.
- Students will learn to calculate energy.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the model wind turbines can be arranged in series and parallel configurations to produce the desired levels of voltage and current outputs.

Students come to understand that:

1. Wind turbines in series generate more voltage with the same amount of current.

2. Wind turbines in parallel generate more current with the same amount of voltage.

3. The energy used to generate hydrogen is far more than the energy produced by a fuel cell to power a motor-propeller load.

STUDENT ACTIVITIES

Students use two model wind turbines with six long blades. They first wire two wind turbines in series and measure the voltage, current and power going into an electrolyzer unit. They connect a motor-propeller to the electrolyzer to see how long the motor-propeller can spin. This is followed by wiring the same wind turbines in parallel and repeating the measurements. They measure the time that each wiring configuration generates and consumes hydrogen. Data are taken at each step for later analysis.

SAFETY

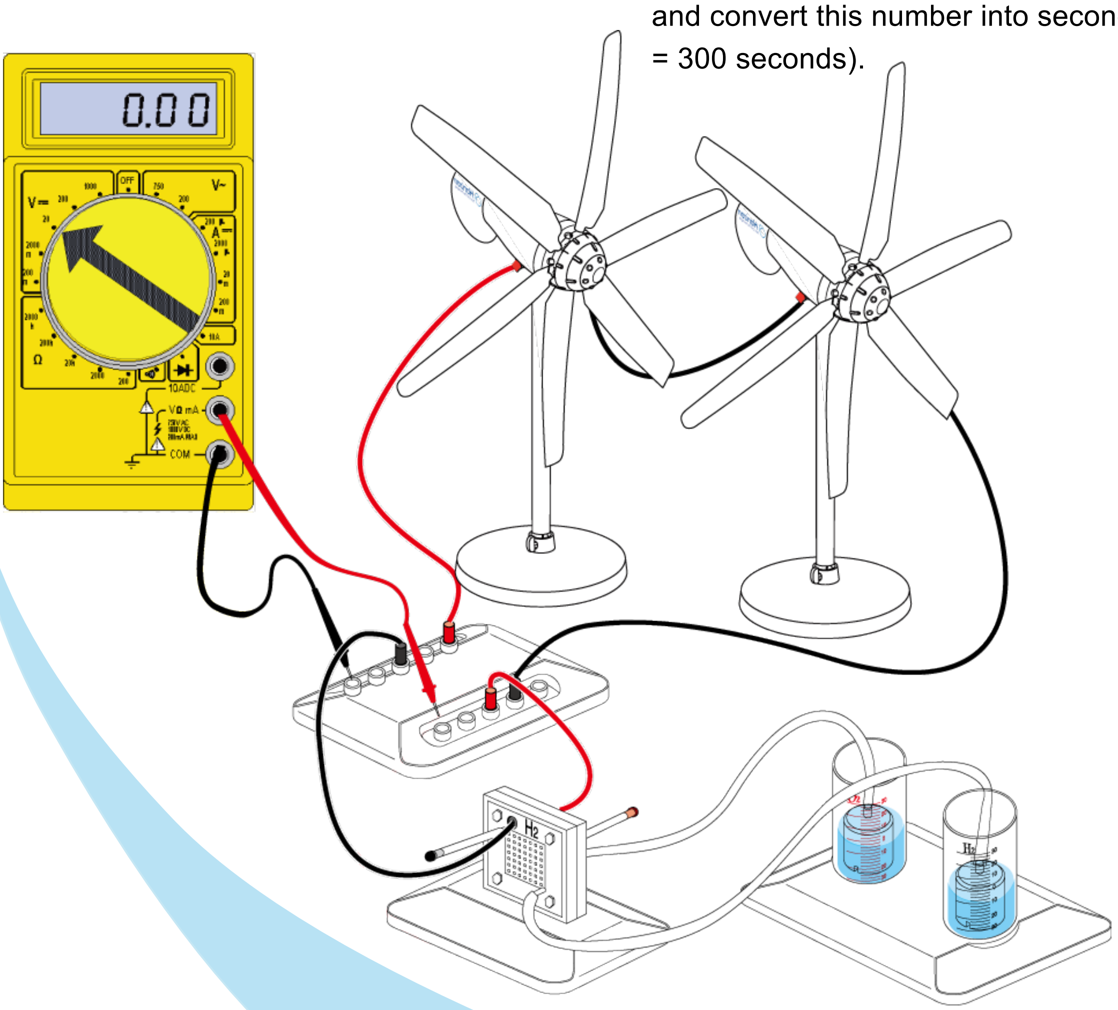
Be sure NOT to touch the spinning blades as potential injury may result. Also, be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

Materials

2 – Model wind turbines with 6 blades
1 – Large 20” diameter (minimum) floor fan
1 – Fuel Cell
1 – Motor and propeller
1 – Clock, watch or stopwatch
1 – Electrolyzer unit with gas storage containers
3 – Red hookup leads
3 – Black hookup leads
1 – Circuit Board Module Base
1 – Fuel Cell Base

Equipment Setup #1
Two Wind Turbines with 6 Blades Wired in Series



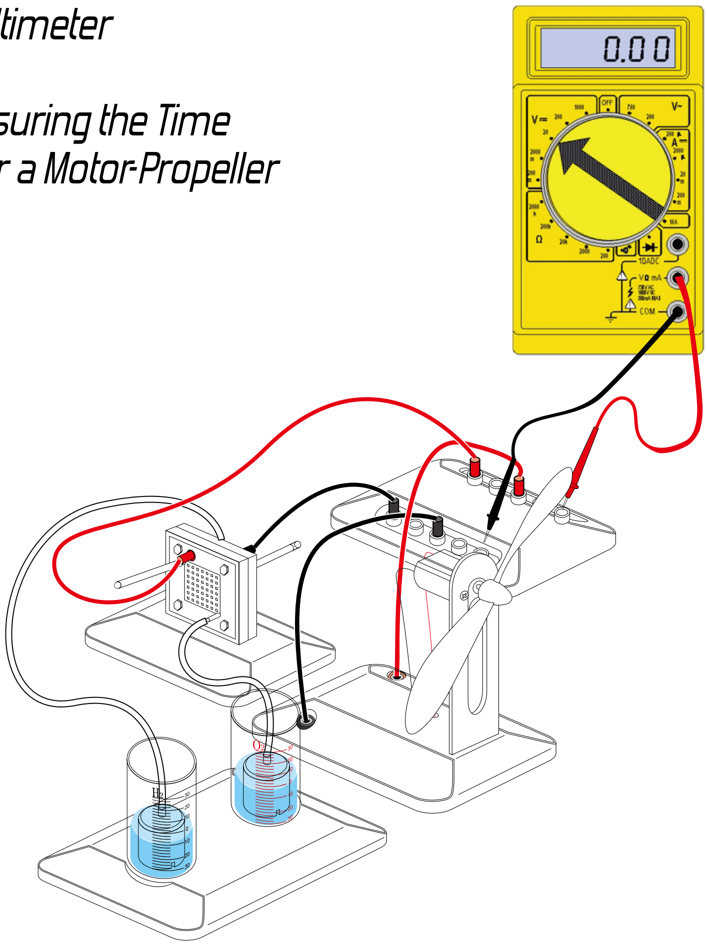
Doing the Experiment

Part 1:

1. Setup the equipment as in Equipment Setup #1.
2. Set the multimeter dial to DC Volts with a range of at least 5 VDC.
3. Fill both the hydrogen and oxygen cylinders to the 0 ml marks with distilled water. Make sure to fill the inner containers, as well.
4. Place the floor fan directly in front of the wind turbines and set it to its highest speed setting.
5. Note the time on the clock or watch. Allow the floor fan and wind turbine to run for 5 minutes.
6. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.
7. Turn the floor fan OFF after 5 minutes and convert this number into seconds (5 x 60 = 300 seconds).

The Experiment with a Multimeter

Equipment Setup #2 Measuring the Time and Energy Used to Power a Motor-Propeller



Part 2:

8. Remove the wind turbines from the setup and replace it with the motor-propeller as illustrated in Experiment Setup #2.

9. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

10. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the Experiment Guide for help.

11. Allow the motor to run until the hydrogen is used up.

12. Note the time when the motor-propeller stops turning.

13. Subtract the start time in step 9 from the stop time in step 12 and convert this number into seconds.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this.

Parts 1 and 2 - Our Data

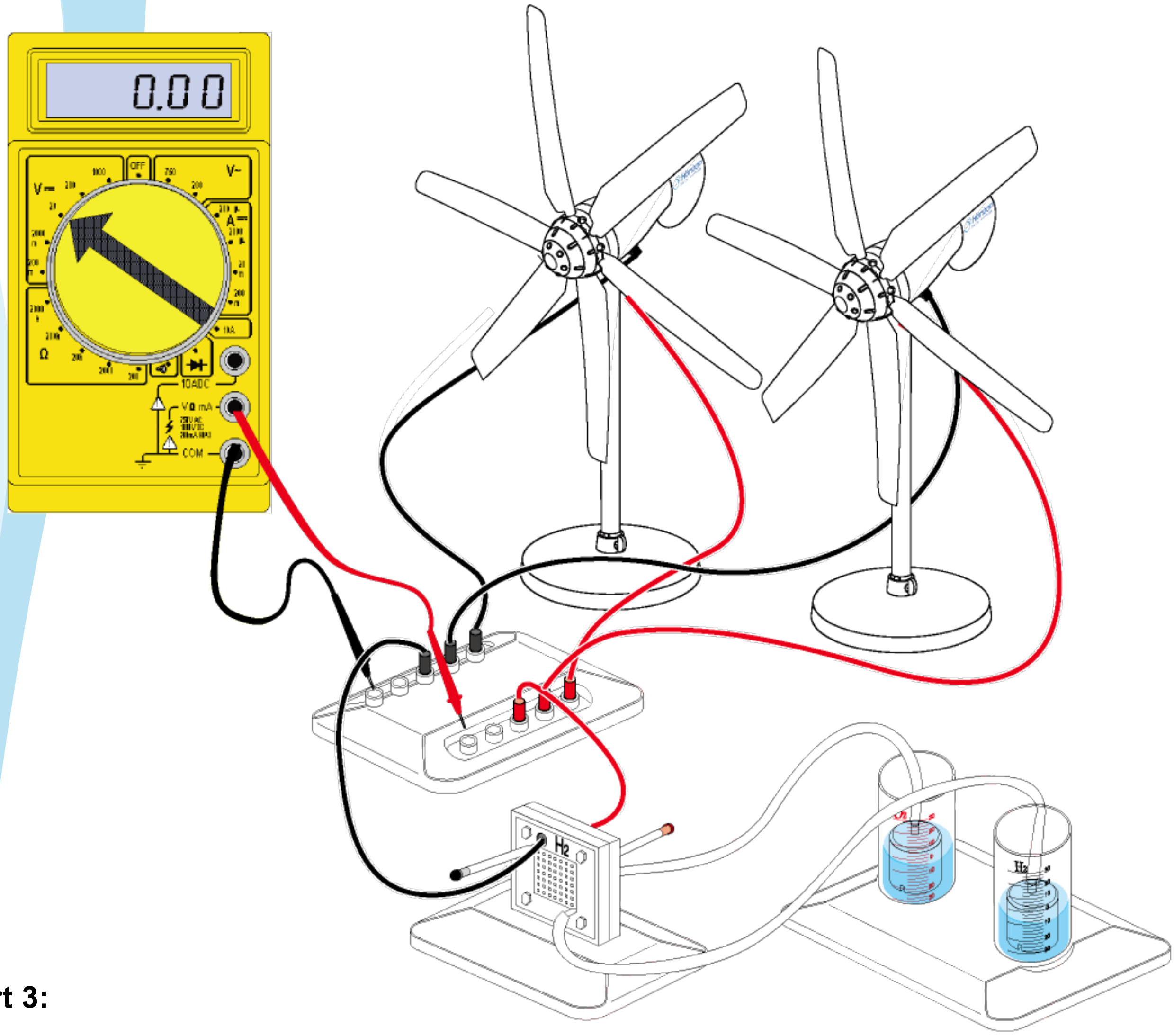
	Seconds	Volts	Amps	Watts
Part 1	300	1.572	0.083	0.130
Part 2	38	0.73	0.38	0.277

Parts 1 and 2 - Your Data

	Seconds	Volts	Amps	Watts
Part 1				
Part 2				

The Experiment with a Multimeter

Equipment Setup #3 Two Wind Turbines with 6 Blades Wired in Parallel



Part 3:

14. Setup the equipment as in **Equipment Setup #3.**

15. Set the multimeter dial to DC Volts with a range of at least 5 VDC.

16. Fill both the hydrogen and oxygen cylinders to the 0 ml marks with distilled water. Make sure to fill the inner containers, as well.

17. Place the floor fan directly in front of the wind turbines and set it to its highest speed setting.

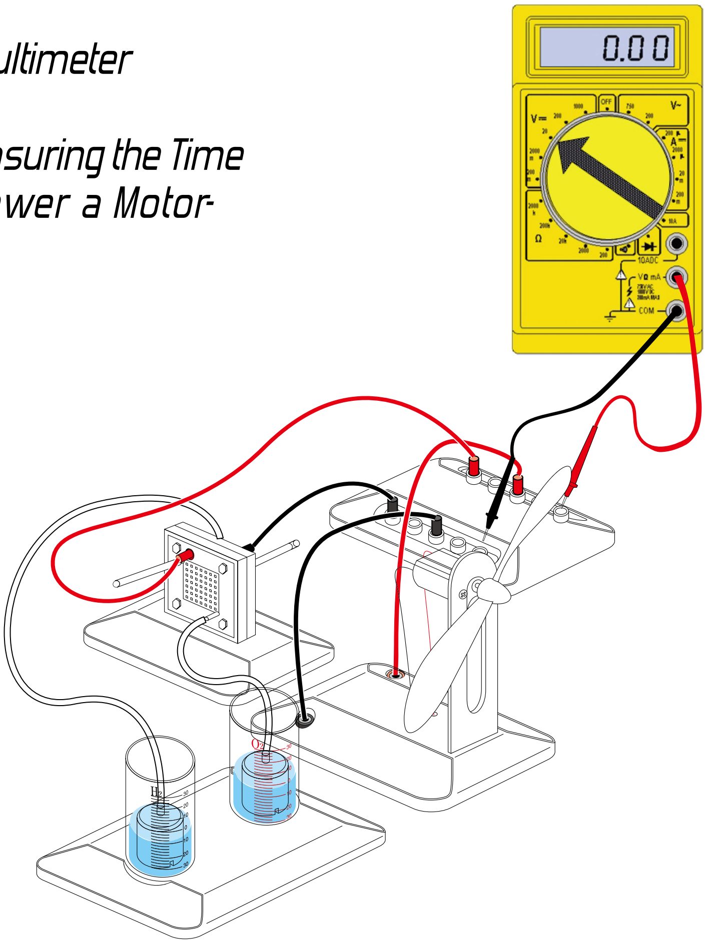
18. Note the time on the clock or watch. Allow the floor fan and wind turbine to run for 5 minutes.

19. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.

20. Turn the floor fan OFF after 5 minutes and convert this number into seconds (5 x 60 = 300 seconds).

The Experiment with a Multimeter

Equipment Setup #4 Measuring the Time and Energy Used to Power a Motor-Propeller



Part 4:

21. Remove the wind turbines from the setup and replace it with the motor-propeller connected to the fuel cell as illustrated in Experiment Setup #4. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details.

22. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

23. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.

24. Allow the motor to run until the hydrogen is used up.

25. Note the time when the motor-propeller stops turning.

26. Subtract the start time in step 22 from the stop time in step 25 and convert this number into seconds.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this.

Parts 3 and 4 - Our Data

	Seconds	Volts	Amps	Watts
Part 3	300	1.646	0.137	0.226
Part 4	60	0.703	0.378	0.266

Parts 3 and 4 - Your Data

	Seconds	Volts	Amps	Watts
Part 3				
Part 4				

The Experiment with the Renewable Energy Monitor

Materials

2 – Model wind turbines and 6 blades
1 - Large 20” diameter (minimum) floor fan
1 – Fuel Cell
1 – Motor and propeller
1 – Clock, watch or stopwatch
1 – Electrolyzer unit with gas storage containers
4 – Red hookup leads
4 – Black hookup leads
1 – Circuit Board Module Base
1 – Fuel Cell Base

Wind Turbine Blades

Setup the wind turbine hub with six curved blades supplied with the kit. Use combinations of the BP-28, NCAA 44 or NCAA 63 blades.

Equipment Setup #1
Two Wind Turbines with Six Blades Wired in Series

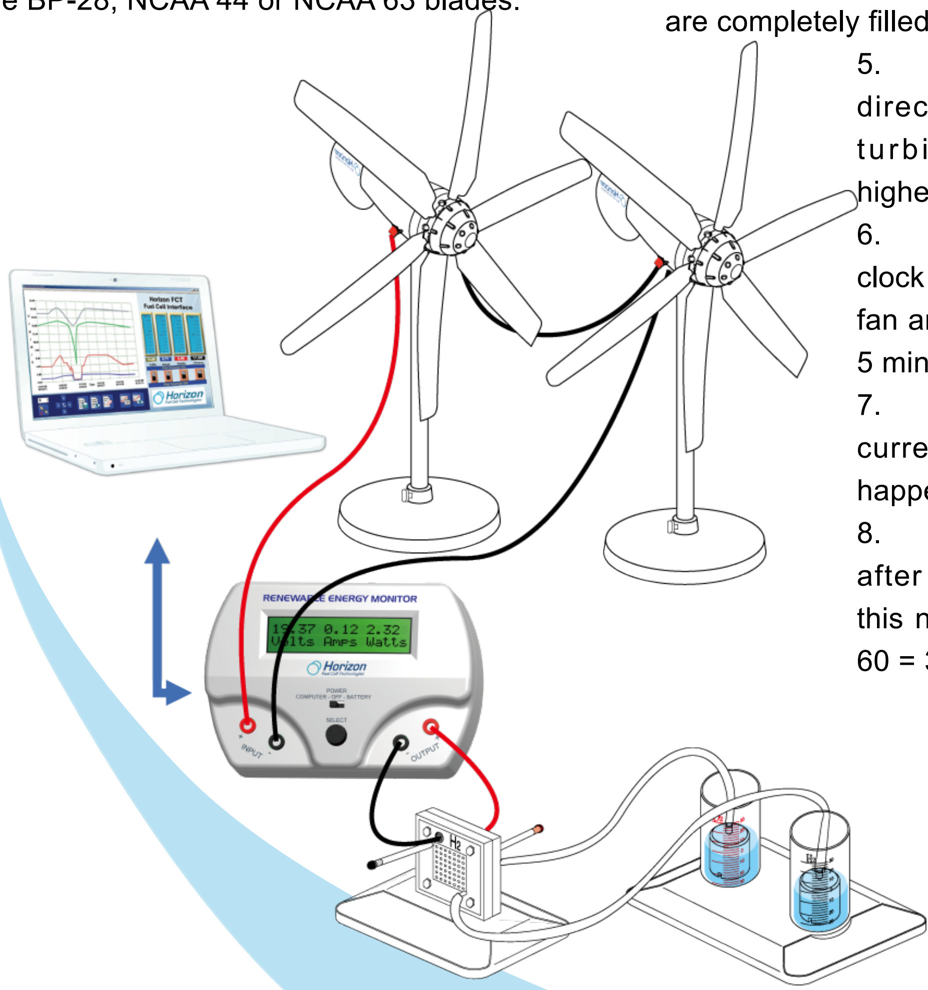
Doing the Experiment

Caution: Be careful not to touch the spinning blades and wear safety glasses to prevent eye injury!

Part 1:

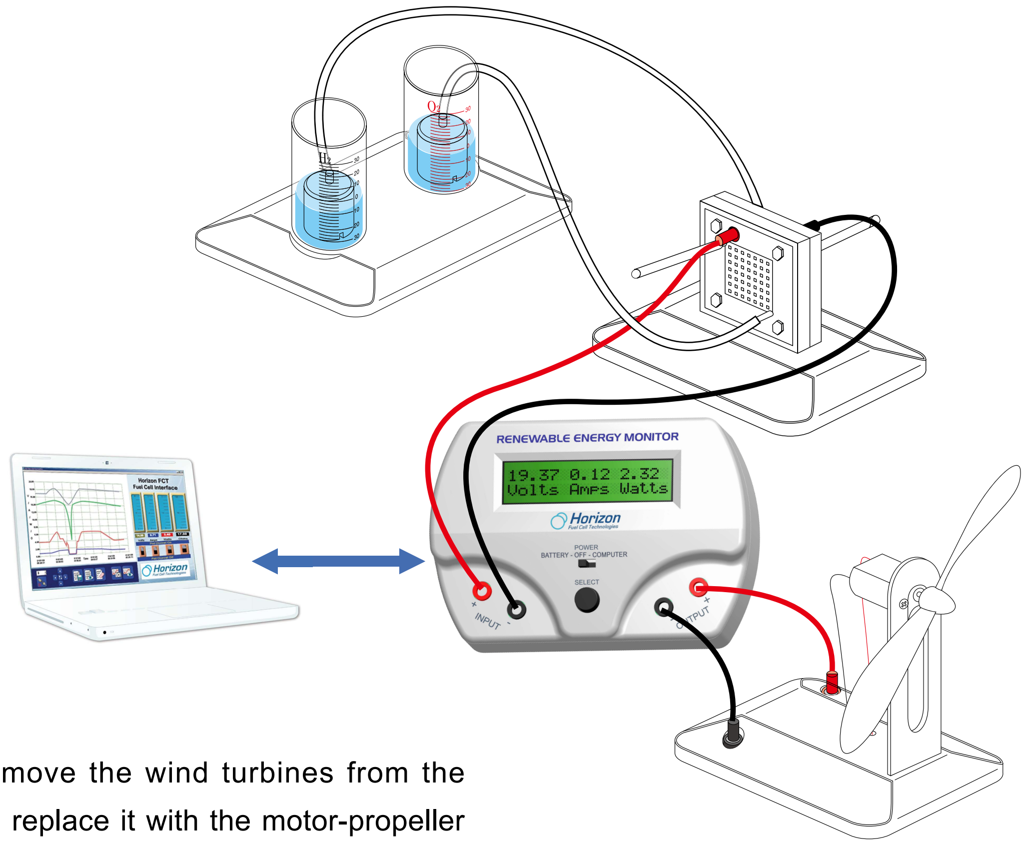
1. Setup the equipment as in Equipment Setup #1.
2. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
3. Push the Select Button until the mV-mA-mW display appears.

4. Fill both the hydrogen and oxygen cylinders to the 0 ml marks with distilled water. Make sure that the inner containers are completely filled with water.
5. Place the floor fan directly in front of the wind turbines and set it to its highest speed setting.
6. Note the time on the clock or watch. Allow the table fan and wind turbine to run for 5 minutes – no longer!
7. Record the voltage, current and power as this is happening.
8. Turn the table fan OFF after 5 minutes and convert this number into seconds (5 x 60 = 300 seconds).



The Experiment with the Renewable Energy Monitor

Equipment Setup # 2 Measuring the Time and Energy Used to Power a Motor-Propeller



Part 2:

9. Remove the wind turbines from the setup and replace it with the motor-propeller connected to the fuel cell as illustrated in Experiment Setup #2. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the Experiment Guide for details.

10. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

11. Record the voltage, current and power as this is happening.

12. Allow the motor to run until the hydrogen is used up.

13. Note the time when the motor-propeller stops turning.

14. Subtract the start time in step 8 from the stop time in step 10 and convert this number into seconds.

Preparing the Data

Have the students enter the voltage, current and power data into the table below. As an example we entered our data.

Parts 1 and 2 - Our Data

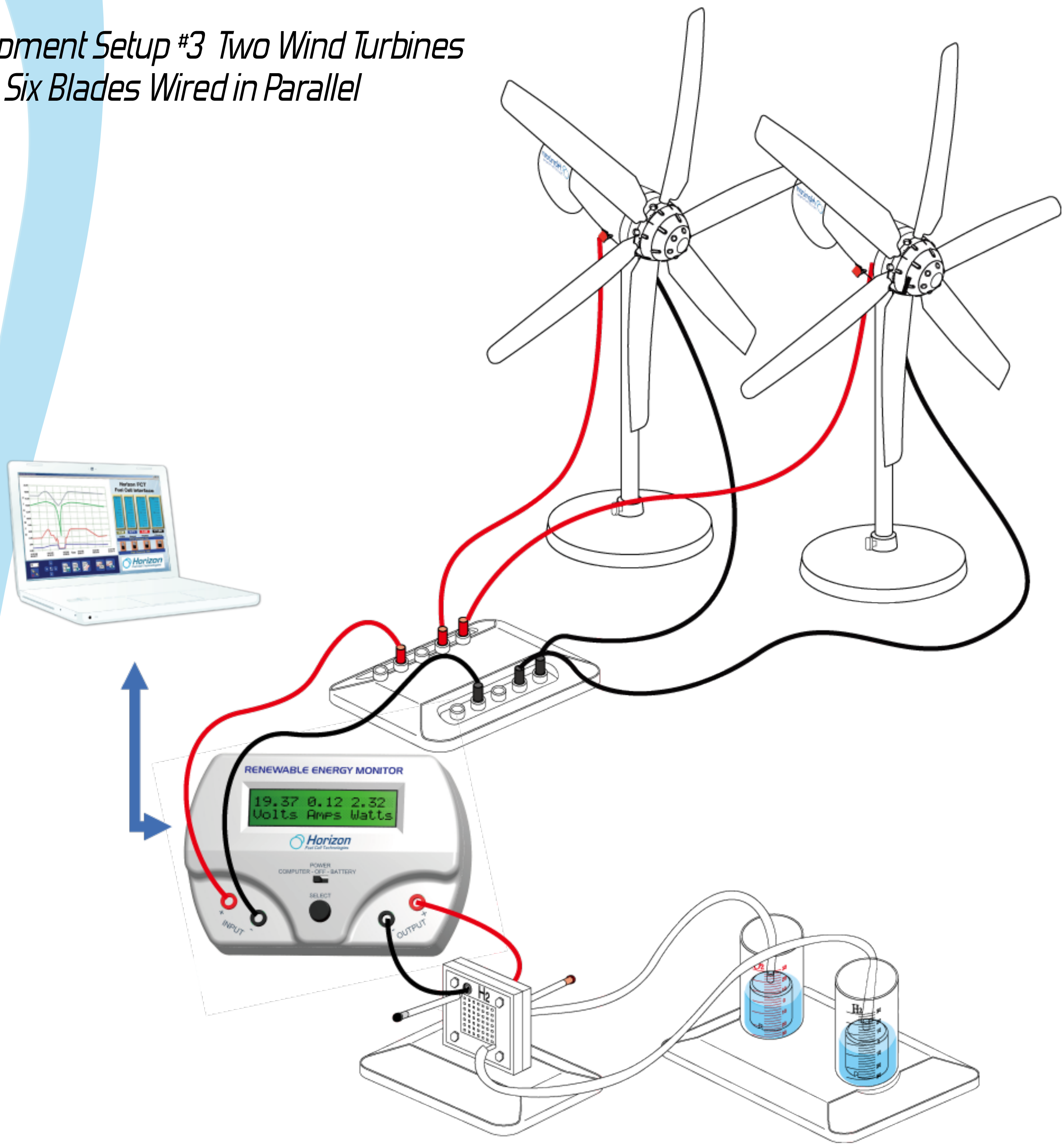
	Seconds	mV	mA	mW
Part 1	300	1572	83	130
Part 2	38	73	380	277

Parts 1 and 2 - Your Data

	Seconds	mV	mA	mW
Part 1				
Part 2				

The Experiment with the Renewable Energy Monitor

Equipment Setup #3 Two Wind Turbines with Six Blades Wired in Parallel



Part 3:

15. Setup the equipment as in Equipment Setup #3.

16. Fill both the hydrogen and oxygen cylinders to the 20 ml marks with distilled water. Make sure that the inner containers are completely filled with water.

17. Place the floor fan directly in front of the wind turbines and set it to its highest speed setting.

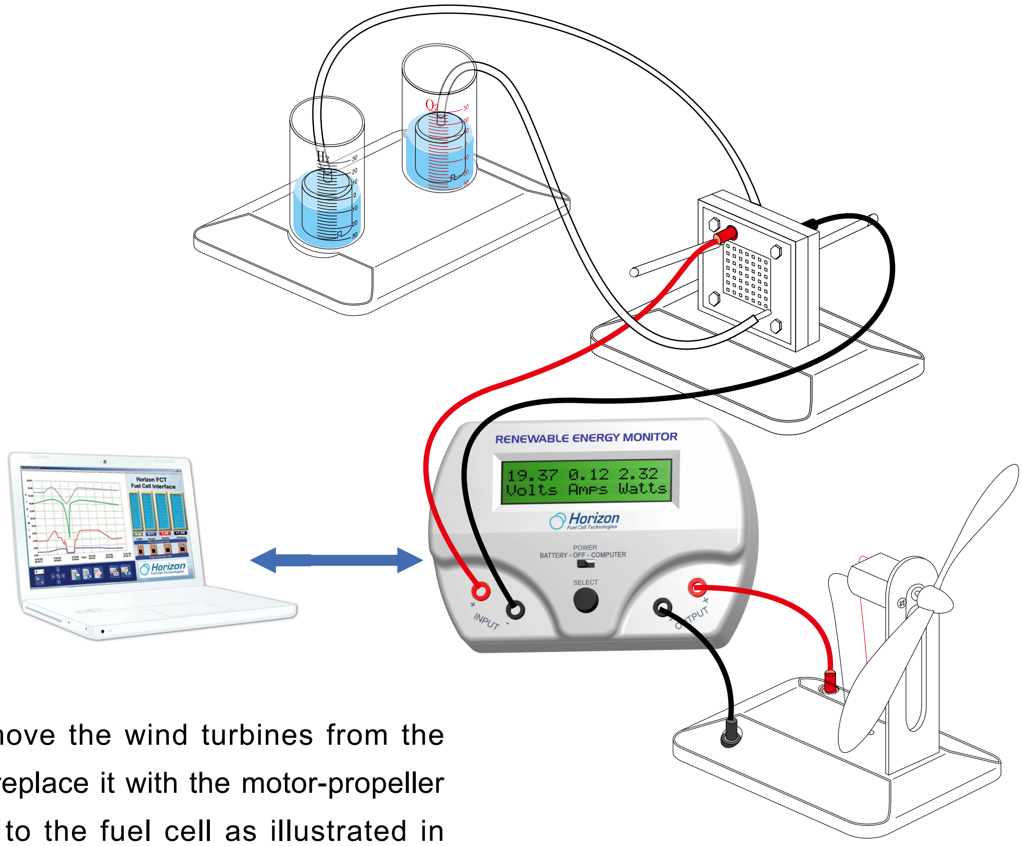
18. Note the time on the clock or watch. Allow the table fan and wind turbine to run for 5 minutes – no longer!

19. Record the voltage, current and power as this is happening.

20. Turn the table fan OFF after 5 minutes and convert this number into seconds (5 x 60 = 300 seconds).

The Experiment with theRenewable Energy Monitor

Equipment Setup # 4 Measuring the Time and Energy Used to Power a Motor-Propeller



Part 4:

21. Remove the wind turbines from the setup and replace it with the motor-propeller connected to the fuel cell as illustrated in Experiment Setup #4. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the Experiment Guide for details.

22. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

23. Record the voltage, current and power as this is happening.

24. Allow the motor to run until the hydrogen is used up.

25. Note the time when the motor-propeller stops turning.

26. Subtract the start time in step 19 from the stop time in step 21 and convert this number into seconds.

Preparing the Data

Have the students enter the voltage, current and power data into the table below. As an example we entered our data.

Parts 3 and 4 - Our Data

	Seconds	mV	mA	mW
Part 3	300	1646	137	226
Part 4	60	703	378	266

Parts 3 and 4 - Your Data

	Seconds	mV	mA	mW
Part 3				
Part 4				

Analyzing the Results

Using the data in the table recorded for **Part 1** and **Part 3** compute the energy used to generate hydrogen with the wind turbines wired in series and parallel, respectively. Energy is computed as power times time. As an example, using the values for our data in **Part 1** and **Part 3** the energy values are computed as follows:

Energy Input for Wind Turbines in Series

E1 = Power x Time

E1 = 300 x 0.130

E1 = 39.00 watt-seconds or Joules

Energy Input for Wind Turbines in Parallel

E3 = Power x Time

E3 = 300 x 0.226

E3 = 67.8 watt-seconds or Joules

Based on the recorded data the wind turbines in parallel generated more power and thus energy as they were used to electrolyze water into hydrogen and oxygen.

Now compare the input energy to the output energy.

Using the data in the table recorded for Part 2 and Part 4 compute the energy consumed by the motor and spinning propeller. As an example, using the values for our data in Part 2 and Part 4 the energy values are computed as follows:

Energy Output for Wind Turbines in Series

E2 = Power x Time

E2 = 38 x 0.277

E2 = 10.53 watt-seconds or Joules

Energy Output for Wind Turbines in Parallel

E4 = Power x Time

E4 = 60 x 0.266

E4 = 15.96 watt-seconds or Joules

If you used a **Renewable Energy Monitor** you probably experienced plots similar to the ones in Figure 1 and Figure 2 for wind turbines in series and parallel, respectively.

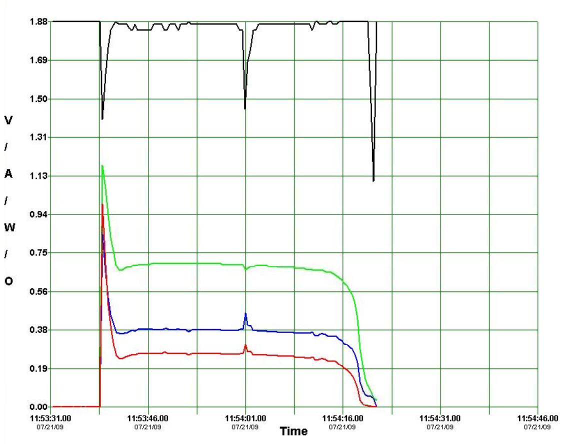


Figure 1 – Plot of Motor Electrical Parameter from H2 Generated by Wind Turbines in Series

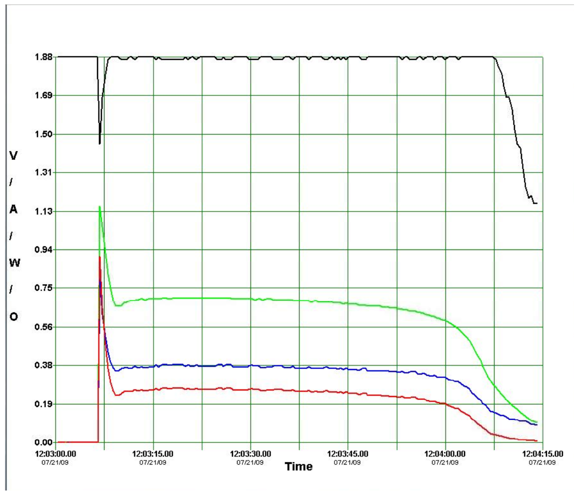


Figure 2 – Plot of Motor Electrical Parameter from H2 Generated by Wind Turbines in Parallel

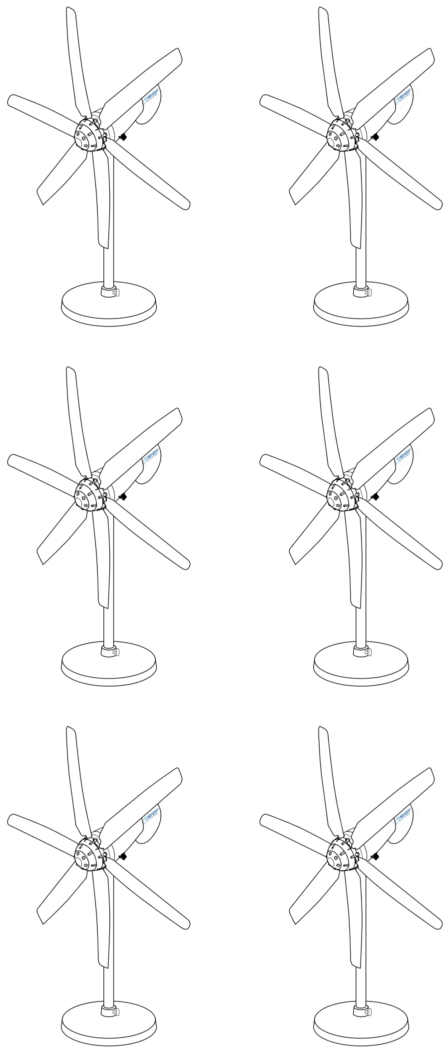
As the two plots clearly show the wind turbines in parallel (Figure 2) produced more hydrogen and oxygen than the wind turbines in series (Figure 1).

The main reason for this is the wind turbine's limited ability to electrolyze water without sufficient current and voltage. Notice in Part 3 that the voltage and current generated by the wind turbines to electrolyze water were GREATER than in Part 1. Arranging the wind turbines in parallel allowed more current to flow from each turbine into the electrolyzer thus lessening the load and actually allowing the voltage to increase

What If ???

Have students speculate on the following hypothetical question.

What if your class decided to build a large model wind farm using the wind turbines from the experiment? Assuming that each wind turbine developed 1.5 volts at 0.100 amps (100 milliamps) into a load how would you wire them in series-parallel to power a motor that takes 3 volts at 200 ma. There can be several answers to this arrangement. Use the wind turbine illustrations below to make a series-parallel hookup. You can use as many wind turbines as you think you need for the hookup; only use as many as are really necessary.



Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 43 – Aerodynamics of Wind Turbines
Page 49 - Energy and Power in the Wind
Page 49 - Potential of Wind Power
Page 49 - Distribution of Wind Speed

Figure 3 – Wind Farm in Calm Sea

Web Links

To learn more about where wind turbines should be located to acquire the most wind look here..

http://www.nrel.gov/gis/wind.html

Wind farms are gaining popularity. Here are links to some of the most popular types:

http://en.wikipedia.org/wiki/Wind_farm

http://www.capewind.org/

Do More Research

Have students do research on the following topic – wind farms:

Excerpted from the RE Science Educational Manual – page 51 "In locations with high winds, multiple turbines can be installed in a wind farm, or wind park. The advantages of wind farms include centralized access, reduced site development costs, and easy connections to transmission lines.

Wind turbines cannot be located too close together because they will interfere with the amount of wind received by those located close by."

Wind farms are popular on land and sea and some are even [thought about] being placed in the air like high-flying kites.

Figure 4 – Sky WindPower Concept

Credit for the above photo and the following text goes to Sky WindPower of San Diego, CA.

"If it ever seems windy where you live, be thankful you do not live 10km up in the air. At that height, the jet-stream winds blow stronger and more constantly than ground level winds, carrying up to a hundred times more energy. Just as oil companies are drilling deeper and in more remote locations in search of new reserves, pioneer wind-power engineers are looking higher in the sky for new sources of energy. Conventional turbines will not take them there--the highest to date is just over 200 meters tall. So they are trying to invent a whole new technology for harvesting wind: electricity generators that fly."

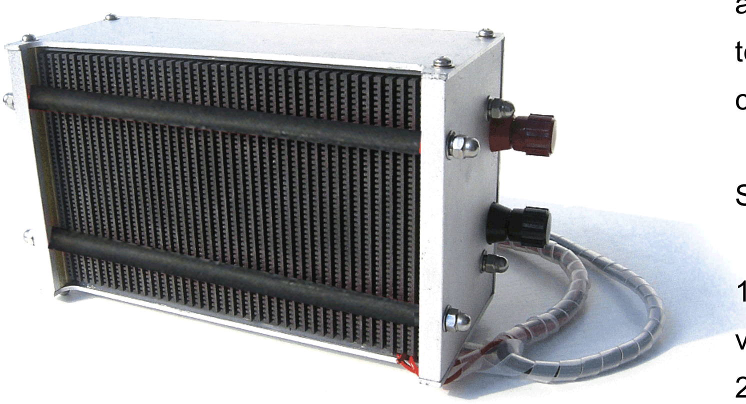
While somewhat fanciful more practical wind farm designs are taking place on land and at sea.

Figure 5 – Palm Springs, CA Wind Farm

Figure 6 – Large Wind Farm at Sea

Have students research these intriguing projects to generate ideas of their own on how clean, non-polluting wind power can supplement our electrical supply and make us less dependent on fossil fuels.

Build a Fuel Cell Stack



LESSON OVERVIEW

This lesson demonstrates methods to arrange two PEM fuel cells in series and parallel configurations in order to study the voltage, current and power generated. It is designed to be a simulation of a commercial fuel cell stack in model scale where students learn the potential of fuel cells as substitute for rechargeable batteries in both home and industrial applications.

LESSON OBJECTIVES

- Students will use the Scientific Process to perform the experiment.
- Students will collect and analyze data.
- Students will learn how to wire fuel cells in series and parallel.
- Students learn to compute energy.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that the fuel cells can be arranged in series and parallel configurations to produce the desired levels of voltage and current outputs.

Students come to understand that:

1. Fuel cells in series generate more voltage with the same amount of current.
2. Fuel cells in parallel generate more current with the same amount of voltage.
3. The energy used to drive a motor-propeller load with fuel cells in parallel is different than with fuel cells in series.

STUDENT ACTIVITIES

Students first electrolyze “two” 10 ml water units into hydrogen and oxygen using” two separate electrolyzer apparatus” and in doing so they measure the voltage, current, power and time in order to compute input energy. They then wire two fuel cells in series and connect a motor-propeller to the fuel cells to see how long the motor-propeller can spin. This is followed by electrolyzing water again and wiring the same fuel cells in parallel and repeating the measurements. Data are taken at each step for later analysis.

SAFETY

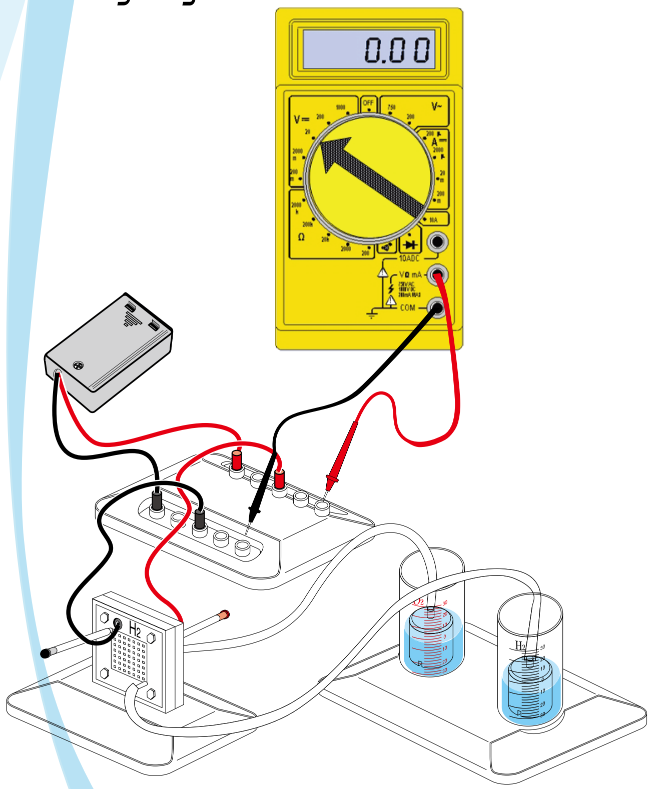
Be sure to wear safety glasses at all times to protect eyes from injury.

The Experiment with a Multimeter

Materials

2 – Fuel Cells
2 – Battery Pack (3 volt battery with switch)
1 – Motor and propeller
1 – Clock, watch or stopwatch
2 – Electrolyzer unit with gas storage containers
3 – Red hookup leads
3 – Black hookup leads
1 – Circuit Board Module Base
2 – Fuel Cell Base
4– Red hookup leads
4 – Black hookup leads

Equipment Setup #1
Electrolyzing Water



Doing the Experiment

Part 1:

1. Setup the equipment as in Equipment Setup #1.
2. Set the multimeter dial to DC Volts with a range of at least 5 VDC.
3. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers are completely filled with water.
4. Set the ON-OFF switch on the battery pack to ON.
5. Note the time on the clock or watch to begin timing how long it takes for the hydrogen to fill to the 10ml level on the hydrogen cylinder.
6. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.
7. Set the battery switch to OFF when the hydrogen cylinder reaches the 10ml mark.
8. Note the time it took to create this level of hydrogen and enter it into the table below. Convert this time into seconds.
9. Repeat steps 1 through 8 for the other electrolyzer apparatus.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this. As an example we entered our data.

Part 1 - Our Data

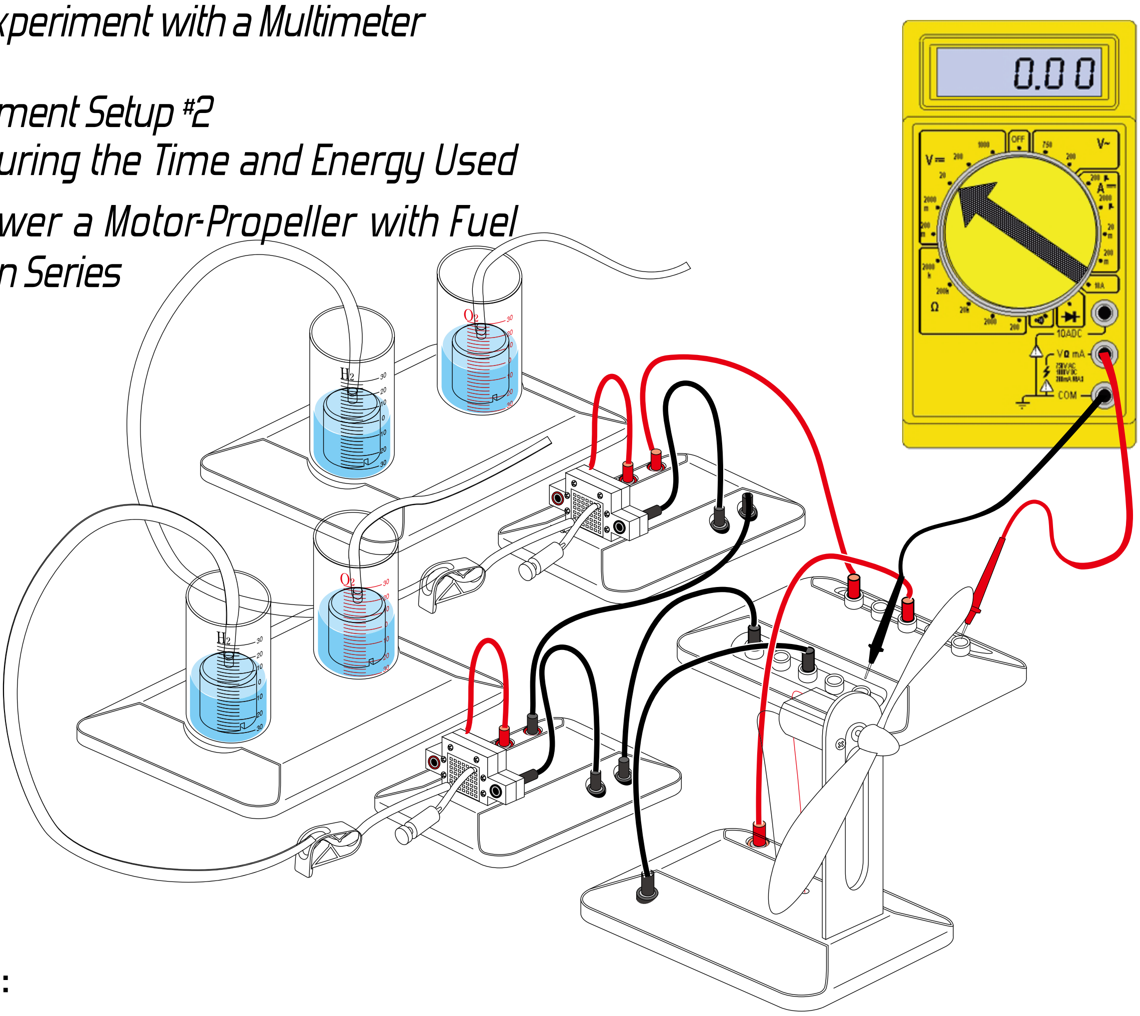
	Seconds	Volts	Amps	Watts
EL 1	175	2.227	0.594	1.348
EL 2	194	2.202	0.551	1.113

Part 1 - Your Data

	Seconds	Volts	Amps	Watts
EL 1				
EL 2				

The Experiment with a Multimeter

Equipment Setup #2
Measuring the Time and Energy Used to Power a Motor-Propeller with Fuel Cells in Series



Part 2:

10. Setup the equipment as in Equipment Setup #2. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details.

11. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

12. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.

13. Allow the motor to run until the hydrogen is used up.

14. Note the time when the motor-propeller stops turning.

15. Subtract the start time in step 11 from the stop time in step 14 and convert this time into seconds.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this.

Part 2 - Our Data

	Seconds	Volts	Amps	Watts
Part 2	90	1.041	0.560	0.580

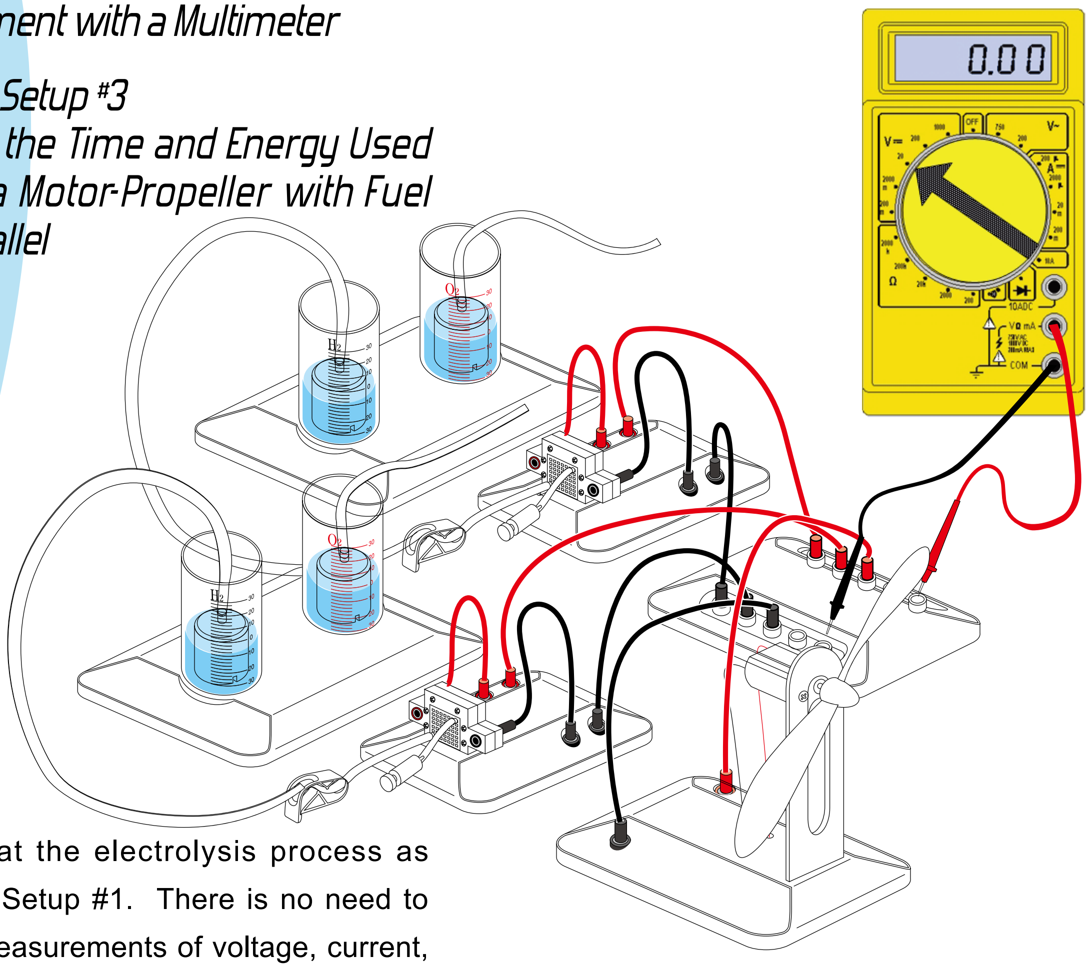
Parts 2 - Your Data

	Seconds	Volts	Amps	Watts

Proceed to Part 3 of the experiment on the following page.

The Experiment with a Multimeter

Equipment Setup #3
Measuring the Time and Energy Used to Power a Motor-Propeller with Fuel Cells in Parallel



Part 3:

16. Repeat the electrolysis process as described in Setup #1. There is no need to repeat the measurements of voltage, current, power and time; data from the first exercise will suffice.

17. Setup the equipment as in Equipment Setup #3. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details.

18. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger being careful not to allow the rotating blade to cause injury.

19. Record the voltage and current as this is happening. You will need to place the multimeter in both parallel (voltage) and series (current) wiring configurations for this step. Refer to the **Experiment Guide** for help.

20. Allow the motor to run until the hydrogen is used up.

21. Note the time when the motor-propeller stops turning.

22. Subtract the start time in step 18 from the stop time in step 21 and convert this time into seconds.

Preparing the Data

Have the students enter the time, voltage and current readings in the table below. Have them compute the power based on the recorded voltage and current. Refer to the **Experiment Guide** section for details on how to do this.

Part 3 - Our Data

	Seconds	Volts	Amps	Watts
Part 3	120	0.718	0.378	0.271

Parts 3 - Your Data

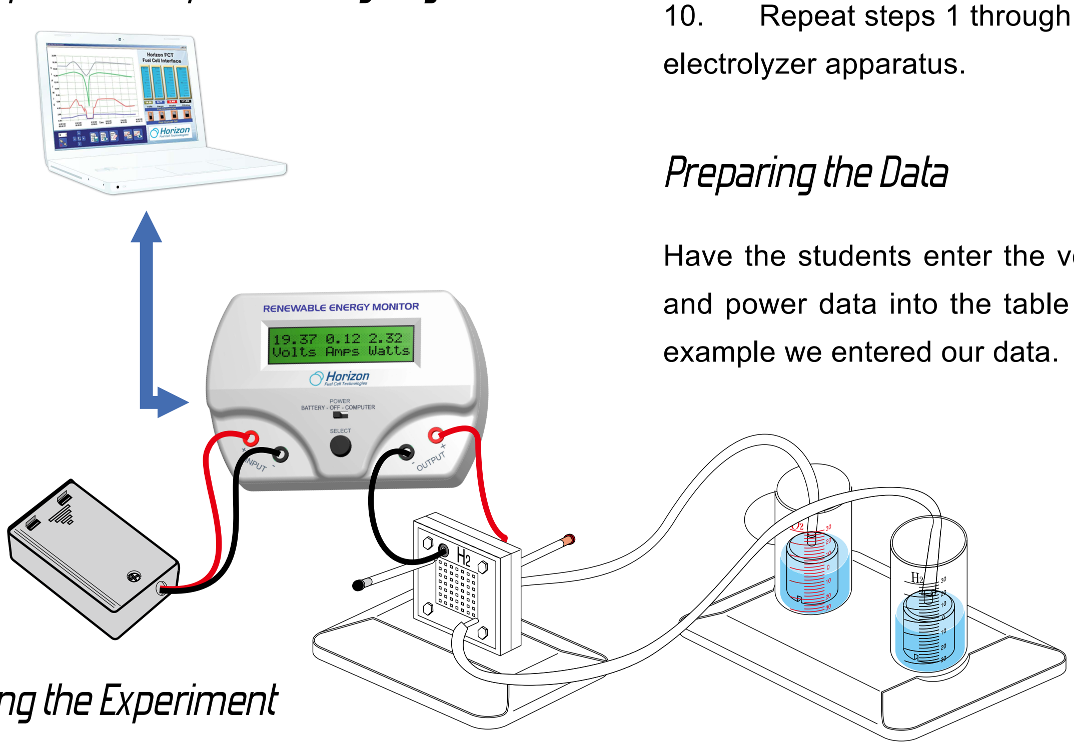
	Seconds	Volts	Amps	Watts
Part 3				

The Experiment with the Renewable Energy Monitor

Materials

2 – Fuel Cells
2 – Battery Pack (3 volt battery with switch)
1 – Motor and propeller
1 – Clock, watch or stopwatch
2 – Electrolyzer unit with gas storage containers
4 – Red hookup leads
4 – Black hookup leads
1 – Circuit Board Module Base
2 – Fuel Cell Base
5 – Red hookup leads
5 – Black hookup leads

Equipment Setup #1 Electrolyzing Water



Doing the Experiment

Part 1:

1. Set the Renewable Energy Monitor switch to Battery or Computer depending on your hookup.
2. Push the Select Button until the Volts – Amps- Watt display appears

3. Setup the equipment as in Equipment Setup #1
4. Fill both the hydrogen and oxygen cylinders to the 0ml marks with distilled water. Make sure that the inner containers are completely filled with water.
5. Set the ON-OFF switch on the battery pack to ON.
6. Note the time on the clock or watch to begin timing how long it takes for the hydrogen to fill to the 20ml level on the hydrogen cylinder.
7. Record the voltage, current and power.
8. Set the battery switch to OFF when the hydrogen cylinder reaches the 10ml mark.
9. Note the time it took to create this level of hydrogen and enter it into the table below. Convert this time into seconds.
10. Repeat steps 1 through 9 for the other electrolyzer apparatus.

Preparing the Data

Have the students enter the voltage, current and power data into the table below. As an example we entered our data.

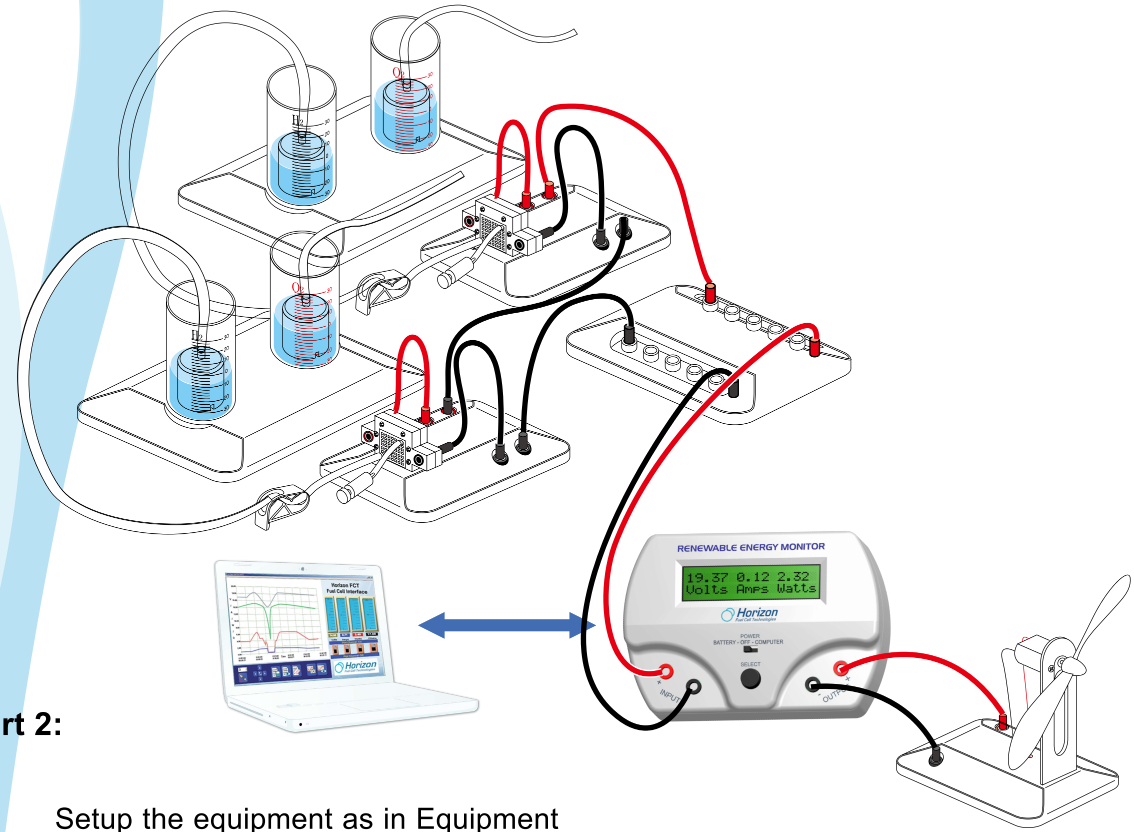
Part 1 - Our Data

	Seconds	Volts	Amps	Watts
EL1	175	2.227	0.594	1.348
EL2	194	2.202	0.551	1.113

Part 1 - Your Data

	Seconds	Volts	Amps	Watts
EL1				
EL2				

Equipment Setup # 2 Measuring the Time and Energy Used to Power a Motor-Propeller with Fuel Cells in Series



Part 2:

11. Setup the equipment as in Equipment Setup #2. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details.

12. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger **being careful not to allow the rotating blade to cause injury.**

13. Record the voltage, current and power.

14. Allow the motor to run until the hydrogen is used up.

15. Note the time when the motor-propeller stops turning.

16. Subtract the start time in step 12 from the stop time in step 15 and convert this time into seconds.

Preparing the Data

Have the students enter the voltage, current and power into the table below. As an example we entered our data.

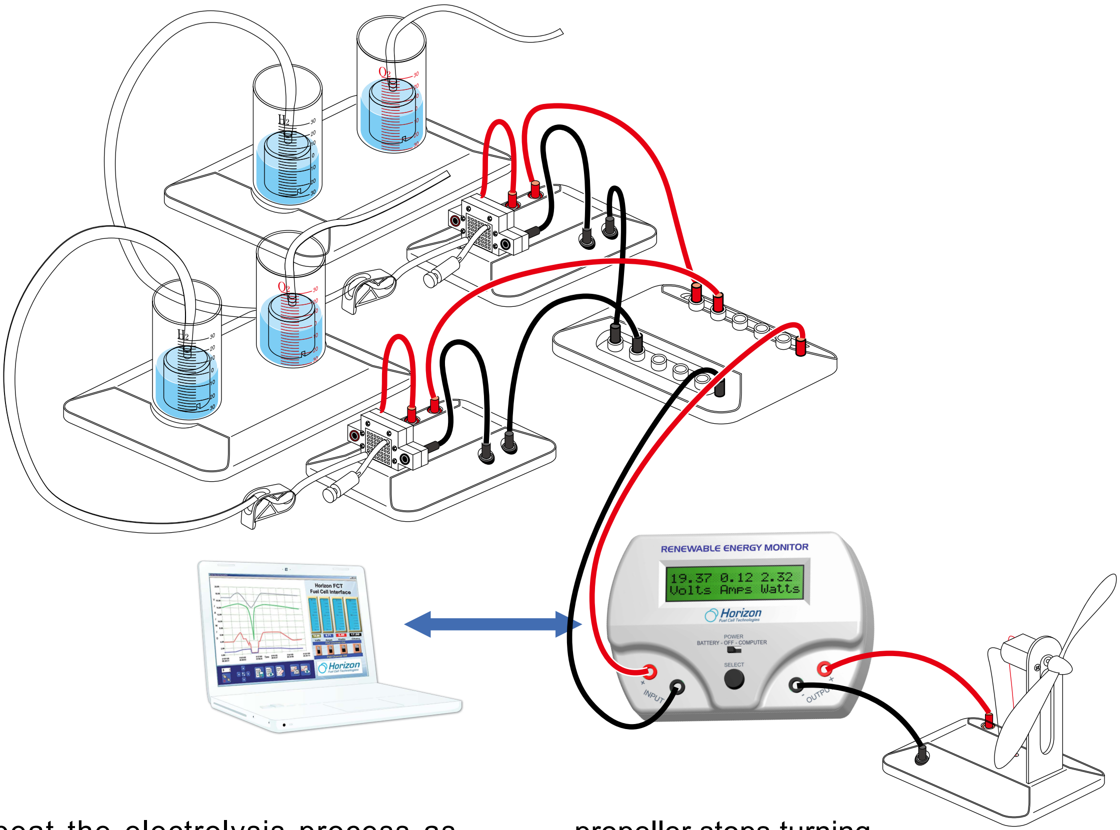
Part 2 - Our Data

	Seconds	Volts	Amps	Watts
Part 2	90	0.041	0.560	0.580

Parts 2 - Your Data

	Seconds	Volts	Amps	Watts
Part 2				

Equipment Setup # 3 Measuring the Time and Energy Used to Power a Motor-Propeller with Fuel Cells in Parallel



Part 3:

17. Repeat the electrolysis process as described in Setup #1. There is no need to repeat the measurements of voltage, current, power and time; data from the first exercise will suffice.

18. Setup the equipment as in Equipment Setup #3. Be sure not to release any of the stored hydrogen and oxygen to the air. Refer to the **Experiment Guide** for details.

19. Connect the red wire from the fuel cell to the Circuit Board Module Base and note the time on the clock or watch. If the motor doesn't immediately start spinning, give the blade a push with your finger **being careful not to allow the rotating blade to cause injury.**

20. Record the voltage, current and power.

21. Allow the motor to run until the hydrogen is used up.

22. Note the time when the motor-propeller stops turning.

23. Subtract the start time in step 19 from the stop time in step 22 and convert this time into seconds.

Preparing the Data

Have the students copy the voltage, current and power into the table below. As an example we entered our data.

Part 3 - Our Data

	Seconds	Volts	Amps	Watts
Part 3	120	0.718	0.378	0.271

Parts 3 - Your Data

	Seconds	Volts	Amps	Watts
Part 3				

Analyzing the Results

Using the data in the table recorded for Part 1 compute the energy used to generate hydrogen for each fuel cell. Energy is computed as power times time. As an example, using the values for our data in Part 1 the energy values are computed as follows:

Energy Input for Fuel Cell #1

E1 = Power x Time

E1 = 1.348 x 175

E1 = 235.9 watt-seconds or Joules

Energy Input for Fuel Cell #2

E2 = Power x Time

E2 = 1.113 x 194

E2 = 215.9 watt-seconds or Joules

Now compare the input energy to the output energy.

Using the data in the table recorded for Part 2 and Part 3 compute the energy consumed by the motor and spinning propeller. As an example, using the values for our data in **Part 2 and Part 3** the energy values are computed as follows:

Energy Output for Fuel Cells in Series

Es = Power x Time

Es = 0.580 x 90

Es= 52.2 watt-seconds or Joules

Energy Output for Fuel Cells in Parallel

Ep = Power x Time

Ep = .271 x 120

Ep = 32.52 watt-seconds or Joules

If you used a **Renewable Energy Monitor** you probably experienced plots similar to the ones in Figure 1 and Figure 2 for fuel cells in series and parallel, respectively.

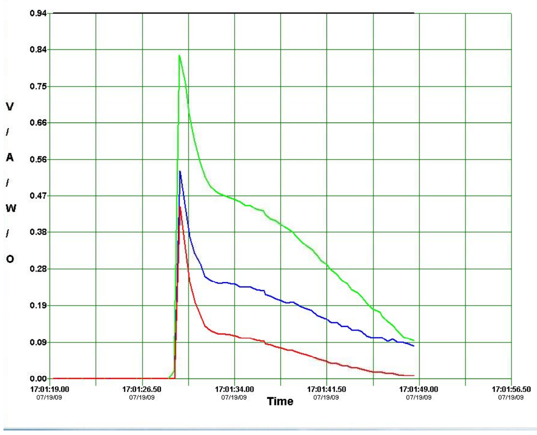


Figure 1 – Plot of Motor Electrical Parameter from H_2 Generated by Fuel Cells in Series

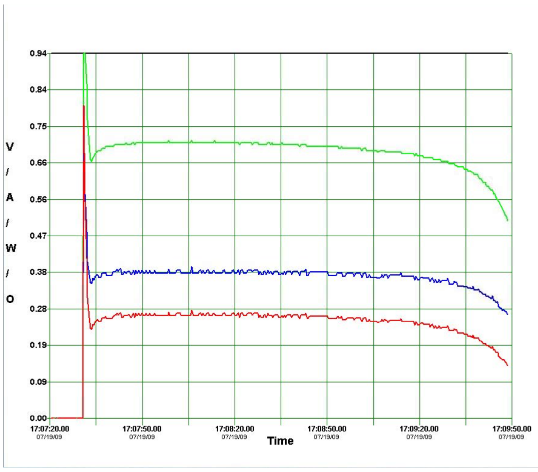


Figure 2 – Plot of Motor Electrical Parameter from H_2 Generated by Fuel Cells in Parallel

As can be seen the fuel cells in series produced more power but didn't last as long as the same fuel cells in parallel. The series arrangement produced a higher voltage which ran the motor-propeller faster; however, the parallel arrangement spread the power output over more time. Even so, the energy figures at the left show more energy was produced by fuel cells in series. The important issue is to perform the experiment in the best way possible to obtain results that you can explain.

What If ???

Have students speculate on the following hypothetical question.

Now that you know something about putting fuel cells in series and parallel you really know about how fuel cell stacks are constructed in principle. They're really like batteries that are stacked together to generate more voltage and current; that's why they call them "stacks" because individual fuel cells are stacked together like slices of bread in a sandwich.

What if you needed to add power to your bicycle in order to climb hills faster or just ride on flat ground without peddling so much? You could add an electric motor connected to a fuel cell stack to help you do this.

The question is...how would you hookup an electric motor and fuel cell stack to power it?

And how big of a motor and fuel cell stack would you need?

The answers depend on your particular bicycle and where you intend to ride it. Do some research on this subject and come up with a design to do it.

Links to the Renewable Energy Science Education Manual

Have students examine the information on the following pages in order to prepare to do more research on the experiment.

Page 79 – How Do Fuel Cells Work

Page 81 – Stack Design and Construction

Web Links

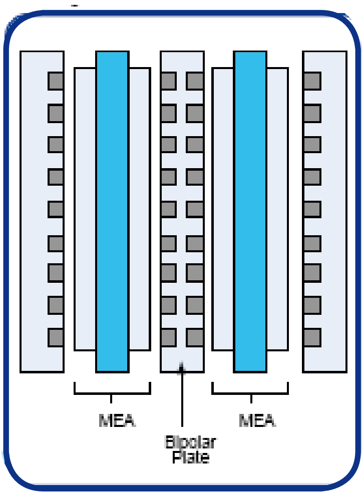
To learn more about fuel cell stacks look here..

http://en.wikipedia.org/wiki/Fuel_cell
http://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/fuel-cell.htm

Do More Research

Have students do research on the following topic – fuel cell stacks:

Excerpted from the RE Science Educational Manual – page 81 "In the traditional bipolar stack design, the fuel cell stack has many cells in series, and the cathode of one cell is connected to the anode of the next cell. The MEAs, gaskets, bipolar plates and end plates are the typical layers of the fuel cell. The cells are usually clamped together. The most common fuel cell configuration is shown here.



Each cell (MEA) is separated by a plate with flow fields to distribute the fuel and oxidant. The majority of fuel cell stacks are of this configuration regardless of fuel cell size, type or fuel used. Fuel cell performance is dependent upon the flow rate of the reactants. Uneven flow distribution can result in uneven performance between cells. Reactant gases need to be supplied to all cells in the same stack through common manifolds"

Ultra Cool Experiment - Running Your School with Hydrogen

Photo credit – www.futurepredictions.com

LESSON OVERVIEW

This lesson describes a hypothetical model for students to consider in terms of powering their school completely, or in part, with hydrogen that is generated by their (hypothetical) solar panels and wind turbines. A hypothetical fuel cell is used to generate the electricity. It illustrates the energy that lighting and typical electrical appliances use during a normal day and causes students to consider how much energy in the form of stored hydrogen is required to run them. The lesson also demonstrates the amount of polluting materials (NOX, SOX, CO2) that are saved by using strictly hydrogen instead of power from the electric grid.

LESSON OBJECTIVES

- Students will research the amount of energy used by electrical appliances
- Students will compute the amount of pollution they can save by using hydrogen.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that stored hydrogen can be a substitute for electricity from the power grid.

Students come to understand that:

1. The correct amount of stored hydrogen can power their school's lighting, heating and other electrical functions without producing pollution.
2. Using stored hydrogen for electrical power can reduce pollution and reduce global warming.
3. A compromise of stored hydrogen making power and grid power can be achieved more easily than completely powering the school with independent solar power.

STUDENT ACTIVITIES

Students do an energy audit of their classroom to determine the amount of energy used for lighting, heat, air conditioning, computers and other electrical appliances. This exercise can also be extended to other parts of the school building, as well. Students then determine the total amount of stored hydrogen that is needed to provide the power they determined in their energy audit. This is followed by them listing how much pollution in terms of CO2, NOX and SOX emissions are saved.

To Do List

Choose the area within your school building that you would like to have student's assess in terms of the following criteria:

1. Energy Audit
2. Hydrogen Storage Requirements
3. Pollution Saved

Energy Audit

Have students find out or make a reasonable guess at the amount of electrical energy used by the following devices:

________ watts	Overhead lights
_________watts	Air Conditioning
_________watts	Heat (all furnaces use electricity)
_________watts	Classroom computer(s)
_________watts	Classroom television
_________watts	Table Fan
_________watts	Gooseneck Lamp
_________watts	__________________
_________watts	__________________
_________watts	__________________
_________ watts	Total Energy Load

Hydrogen Requirements

Each "hypothetical" hydrogen storage tank is capable of producing 500 watts for eight hours (a normal school day) from a fuel cell.

Have students compute the number of hydrogen tanks and fuel cells that will be necessary to supply this amount of power. Ask them for a justification of why they chose their particular amount of hydrogen storage tanks and fuel cells.

Pollution Primer

Air pollution caused by using fossil fuels like coal and natural gas to generate electrical power comes from the following categories of what are all called "Greenhouse Gasses":

CO_2 - Carbon Dioxide
CH_4 - Methane
N_2O - Nitrous Oxide
SF_6 - Sulfur Hexafluoride

While this is not a complete list of all Greenhouse Gasses it will serve as a basis for students to do research into their sources and outcomes in creating pollution. The net effect of these and other similar gasses is now called your "Carbon Footprint" or the amount of carbon-based pollution that is generated by an individual, building, city, state or any other entity.

Pollution Saved

Have students use the following links to compute the pollution saved by using solar panels in lieu of electricity from the grid. Most of these are designed for home use, so feel free to substitute numbers of people and home square footage to match your school's profile. Choose the one that is best for your particular situation.

http://www.carbonfootprint.com/calculator.aspx

http://www.climatecrisis.net/takeaction/carboncalculator/

Have students compute the pollution saved by substituting hydrogen fuel cells for normal electrical power.

Web Links

To find out how much electrical energy your appliances use, look here:

http://michaelbluejay.com/electricity/howmuch.html

http://www1.eere.energy.gov/consumer/tips/appliances.html

http://www.windsolarenergy.org/Solar-wind-power-just-one-appliance.htm

http://www.ouc.com/power/usage.htm

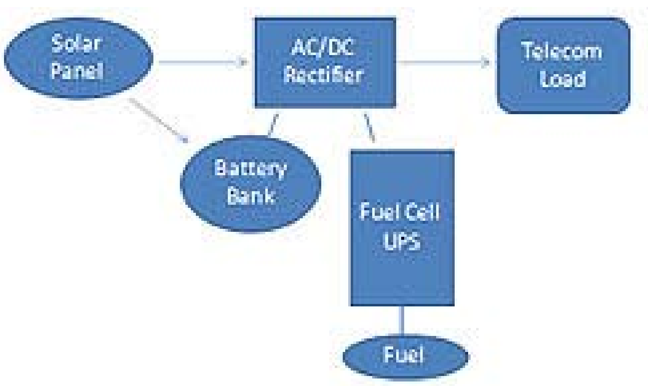
http://www.ourplanet.org.uk/about-solar-energy.asp

Do More Research

Have students research in the following areas:

Fuel Cell UPS (Uninterruptable Power Supply). A Fuel Cell UPS is really a combination hydrogen storage tank connected to a fuel cell that keeps the power flowing when the regular power fails.

- Key advantages of Horizon's fuel cell UPS:
- Immediate response to power interruptions
- Longer back-up time for less amount of space
- Higher system reliability and network availability
- Lower maintenance and operating cost
- Silent, reliable operation with zero emissions
- Robust, weatherproof, anti-corrosion casing
- Remote monitoring capability
- Can be integrated with solar panels for off-grid locations



Ultra Cool Experiment - *Running Your School with Solar Power*

Photo credit - Faith Cathcart/The Oregonian

LESSON OVERVIEW

This lesson describes a hypothetical model for students to consider in terms of powering their school completely, or in part, with solar power. It illustrates the energy that lighting and typical electrical appliances use during a normal day and causes students to consider how much energy in the form of solar panels is required to run them. The lesson also demonstrates the amount of polluting materials (NOX, SOX, CO2) that are saved by using strictly solar energy instead of power from the electric grid.

LESSON OBJECTIVES

- Students will research the amount of energy used by electrical appliances
- Students will determine the effectiveness of solar power at their geographical location.
- Students will compute the amount of pollution they can save by using solar power.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that solar power can be a substitute for electricity from the power grid.

Students come to understand that:

1. The correct amount of solar panels can power their school's lighting, heating and other electrical functions without producing pollution.
2. Using solar panels for electrical power can reduce pollution and reduce global warming.
3. A compromise of solar power and grid power can be achieved more easily than completely powering the school with independent solar power.

STUENT ACTIVITIES

Students do an energy audit of their classroom to determine the amount of energy used for lighting, heat, air conditioning, computers and other electrical appliances. This exercise can also be extended to other parts of the school building, as well. Students then determine the total amount of solar panels that are needed to provide the power they determined in their energy audit. This is followed by them listing how much pollution in terms of CO2, NOX and SOX emissions are saved.

To Do List

Choose the area within your school building that you would like to have student's assess in terms of the following criteria:

1. Energy Audit
2. Solar Panel Requirements
3. Pollution Saved

Energy Audit

Have students find out or make a reasonable guess at the amount of electrical energy used by the following devices:

________ watts	Overhead lights
_________watts	Air Conditioning
_________watts	Heat (all furnaces use electricity)
_________watts	Classroom computer(s)
_________watts	Classroom television
_________watts	Table Fan
_________watts	Gooseneck Lamp
_________watts	____________________
_________watts	____________________
_________watts	____________________
_________ watts	Total Energy Load

Solar Panel Requirements

Each "hypothetical" solar panel is capable of producing 1000 watts in full sunlight and 300 watts on an overcast day.

Have students compute the number of solar panels that will be necessary to supply this amount of power. Tell them that the sun does not shine all the time and that they need to add more to their estimate to account for this – without going overboard. Ask them for a justification of why they chose their particular amount of solar panels. Have them consider the time of year and their geographical location in their choice (see Web Links and Do More Research for a solar map).

Pollution Primer

Air pollution caused by using fossil fuels like coal and natural gas to generate electrical power comes from the following categories of what are all called "Greenhouse Gasses":

CO_2 - Carbon Dioxide
CH_4 - Methane
N_2O - Nitrous Oxide
SF_6 - Sulfur Hexafluoride

While this is not a complete list of all Greenhouse Gasses it will serve as a basis for students to do research into their sources and outcomes in creating pollution. The net effect of these and other similar gasses is now called your "Carbon Footprint" or the amount of carbon-based pollution that is generated by an individual, building, city, state or any other entitly.

Pollution Saved

Have students use the following links to compute the pollution saved by using solar panels in lieu of electricity from the grid. Most of these are designed for home use, so feel free to substitute numbers of people and home square footage to match your school's profile. Choose the one that is best for your particular situation.

http://www.carbonfootprint.com/calculator.aspx

http://www.climatecrisis.net/takeaction/carboncalculator/

Have students compute the pollution saved by substituting solar energy for normal electrical power.

Web Links

To find out how much electrical energy your appliances use, look here:

http://michaelbluejay.com/electricity/howmuch.html

http://www1.eere.energy.gov/consumer/tips/appliances.html

http://www.windsolarenergy.org/Solar-wind-power-just-one-appliance.htm

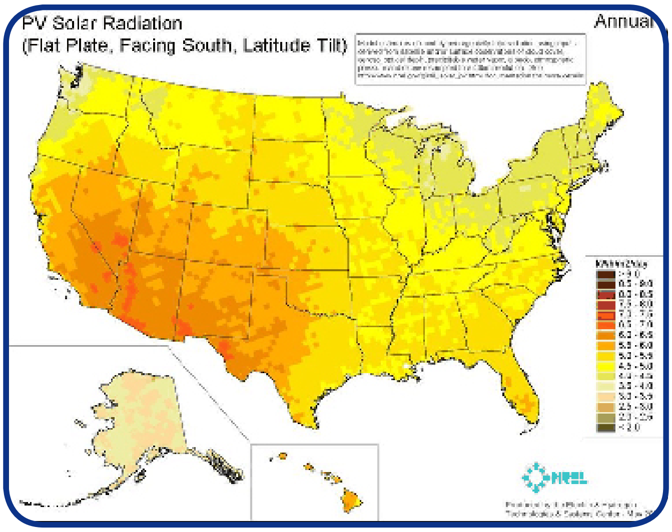
http://www.ouc.com/power/usage.htm

http://www.ourplanet.org.uk/about-solar-energy.asp

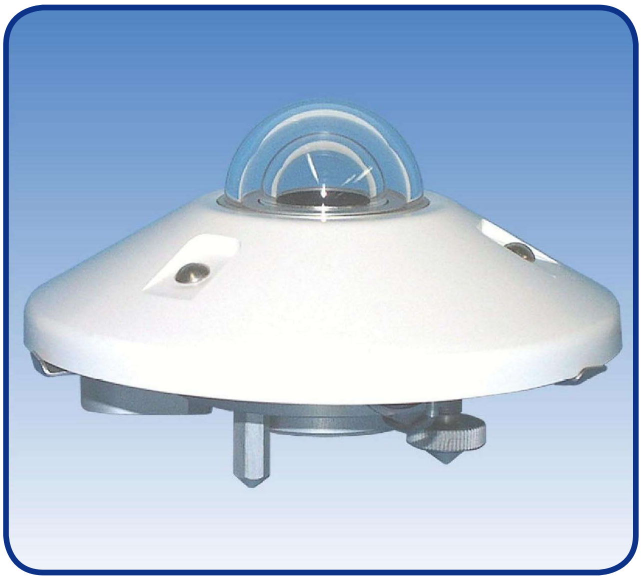
Do More Research

Have students research in the following areas:

Solar Maps – find out how much of the sun's energy falls on your school.



http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/



Solar Energy – find out how to measure the energy from the sun using a device called a pyranometer.

http://en.wikipedia.org/wiki/Pyranometer

Ultra Cool Experiment- *Running Your School with Wind Power*

Photo credit – www.greenpeace.org

LESSON OVERVIEW

This lesson describes a hypothetical model for students to consider in terms of powering their school completely, or in part, with wind power. It illustrates the energy that lighting and typical electrical appliances use during a normal day and causes students to consider how much energy in the form of wind turbines is required to run them. The lesson also demonstrates the amount of polluting materials (NOX, SOX, CO2) that are saved by using strictly wind power instead of power from the electric grid.

LESSON OBJECTIVES

- Students will research the amount of energy used by electrical appliances
- Students will determine the effectiveness of wind power at their geographical location.
- Students will compute the amount of pollution they can save by using wind power.
- Students will use the Internet to research lesson related topics.

LEARNING OUTCOMES

Students are shown that wind power can be a substitute for electricity from the power grid.

Students come to understand that:

1. The correct amount of wind turbines can power their school's lighting, heating and other electrical functions without producing pollution.
2. Using wind turbines for electrical power can reduce pollution and reduce global warming.
3. A compromise of wind turbines and grid power can be achieved more easily than completely powering the school with independent solar power.

STUDENT ACTIVITIES

Students do an energy audit of their classroom to determine the amount of energy used for lighting, heat, air conditioning, computers and other electrical appliances. This exercise can also be extended to other parts of the school building, as well. Students then determine the total amount of wind turbines that are needed to provide the power they determined in their energy audit. This is followed by them listing how much pollution in terms of CO2, NOX and SOX emissions are saved.

To Do List

Choose the area within your school building that you would like to have student's assess in terms of the following criteria:

1. Energy Audit
2. Wind Power Requirements
3. Pollution Saved

Energy Audit

Have students find out or make a reasonable guess at the amount of electrical energy used by the following devices:

________ watts	Overhead lights
________ watts	Air Conditioning
________ watts	Heat (all furnaces use electricity)
________ watts	Classroom computer(s)
________ watts	Classroom television
________ watts	Table Fan
________ watts	Gooseneck Lamp
________ watts	____________________
________ watts	____________________
________ watts	____________________
________ watts	Total Energy Load

Wind Turbine Requirements

Each "hypothetical" wind turbine is capable of producing 1000 watts in full wind and 300 watts in light wind.

Have students compute the number of wind turbines that will be necessary to supply this amount of power. Tell them that the wind does not blow all the time and that they need to add more to their estimate to account for this – without going overboard. Ask them for a justification of why they chose their particular amount of wind turbines. Have them consider the time of year and their geographical location in their choice (see Web Links and Do More Research for a wind map).

Pollution Primer

Air pollution caused by using fossil fuels like coal and natural gas to generate electrical power comes from the following categories of what are all called "Greenhouse Gasses":

CO_2 - Carbon Dioxide
CH_4 - Methane
N_2O - Nitrous Oxide
SF_6 - Sulfur Hexafluoride

While this is not a complete list of all Greenhouse Gasses it will serve as a basis for students to do research into their sources and outcomes in creating pollution. The net effect of these and other similar gasses is now called your "Carbon Footprint" or the amount of carbon-based pollution that is generated by an individual, building, city, state or any other entity.

Pollution Saved

Have students use the following links to compute the pollution saved by using solar panels in lieu of electricity from the grid. Most of these are designed for home use, so feel free to substitute numbers of people and home square footage to match your school's profile. Choose the one that is best for your particular situation.

http://www.carbonfootprint.com/calculator.aspx

http://www.climatecrisis.net/takeaction/carboncalculator/

Have students compute the pollution saved by substituting wind power for normal electrical power.

Web Links

To find out how much electrical energy your appliances use, look here:

http://michaelbluejay.com/electricity/howmuch.html

http://www1.eere.energy.gov/consumer/tips/appliances.html

http://www.windsolarenergy.org/Solar-wind-power-just-one-appliance.htm

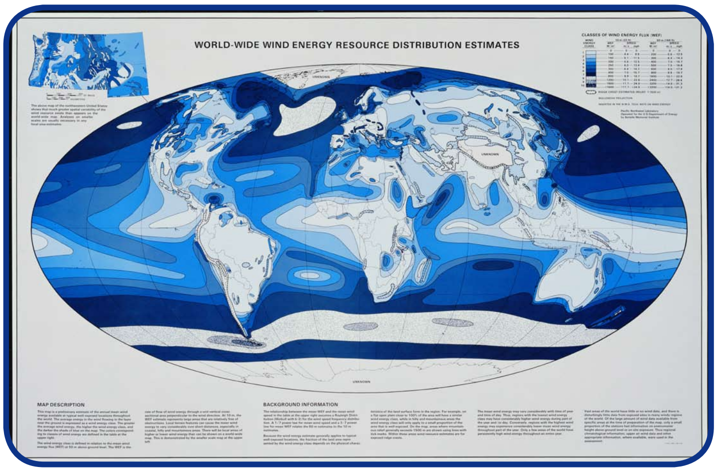
http://www.ouc.com/power/usage.htm

http://www.ourplanet.org.uk/about-solar-energy.asp

Do More Research

Have students research in the following areas:

Wind Maps – find out how much wind energy is available in your area.



http://www.geni.org/globalenergy/library/renewable-energy-resources/wind.shtml

Weather Instruments – find out about weather instruments that measure wind speed and direction.

http://www.weatherinstruments.us/

About the Author

John Gavlik is the founder and president of LearnOnLine, Inc., (www.learnonline.com) a company dedicated to promoting the application of online teaching and learning to the mediums of the Internet and World Wide Web. Mr. Gavlik is a degreed electronic engineer who, with his technical training, early on recognized the potential of these new mediums for effective distance education. This is especially true in the case of collaborative learning that involves individuals and groups that are geographically separated.

One such collaborative project is the Renewable Energy Education Lab, or REEL Power, which uses renewable energy devices such as solar panels, wind turbines and fuel cells to help teach math and science. Designed by Mr. Gavlik, REEL Power provides students and teachers with both classroom and Internet-based teaching aids that allow them to do experiments in class and reach out to other schools, worldwide, to share their activities using YouTube, Skype, Twitter, Google Earth and other Internet tools.

Mr. Gavlik's other professional work experience includes over 35 years of digital hardware, software and embedded firmware design for leading commercial and aerospace companies including Bendix Electrodynamics, Burroughs, Litton Guidance & Control, Jet Propulsion Laboratory, RCA Avionics, Sonatech, Hayes Microcomputer Products, National Semiconductor Corporation and Aerovironment.

In 1989 John co-founded MapTech, Inc., which was the first maritime electronic mapping company to put nautical charts on CDROMs and linked them to GPS to make navigation easier and safer for mariners of all sizes of boats. Maptech still maintains its dominant position in the field of electronic mapping.

Mr. Gavlik is a graduate of the California Polytechnic State University (Cal Poly) with a BSEE degree in Electronic Engineering. For more information about John and LearnOnLine, please visit http://www.learnonline.com.