Utilizing Photovoltaic Cells and Systems

(Nine Activities)

Grades: 5-8

Topic: Solar

Owner: National Renewable Energy Laboratory

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Utilizing Photovoltaic Cells and Systems

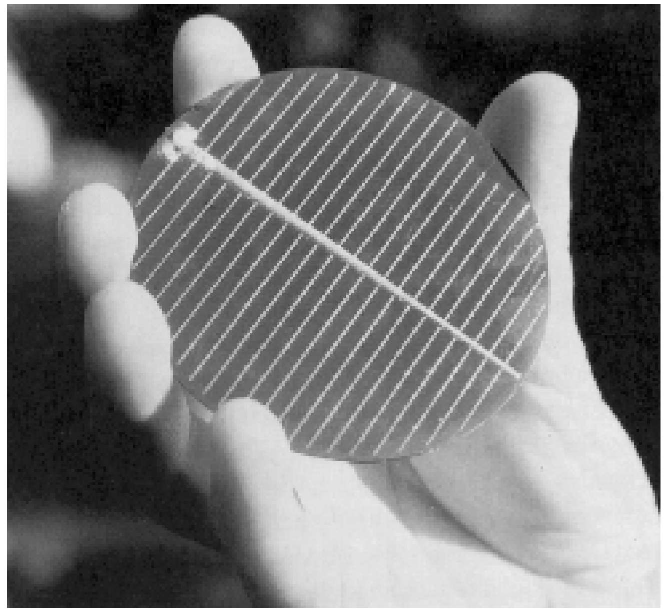
For the Teacher

As teachers, we want students to learn about energy, how we use it, and where it comes from. It is important that students become aware of both renewable and nonrenewable forms of energy resources so that as they grow into adults they can be informed citizens and can make good choices about the resources they use.

One renewable resource that many of us use today is solar energy. Solar energy is used in residential homes, industrial applications, central power stations, commercial buildings, and more. Students may know a little about solar energy, as some of their homes may use solar panels for heating or cooling purposes. The following projects allow students to set up their own investigations and manipulate variables surrounding photovoltaic cells. These projects can be easily integrated into a normal science classroom curriculum, or can be completed by students individually for science fair projects.

All of the projects listed will fit easily into classroom lessons surrounding scientific inquiry and the scientific method. The projects will also help illustrate concepts about electricity, light and color, velocity and gravity, chemistry and polarity, and could even lead to social studies or social action projects.

At NREL scientists are researching ways to make solar energy easier and less expensive to use. The authors of this section are studying different transparent conducting oxides (the



semiconductors on the surface of photovoltaic cells) to find the best possible materials for harnessing the sun's energy.

National Science Education Standards by the National Academy of Sciences

Science Content Standards: 5-8

Science As Inquiry

– Content Standard A:

"Abilities necessary to do scientific inquiry"

"Understandings about scientific inquiry"

Physical Science

– Content Standard B:

"Transfer of energy"

Earth and Space Science

– Content Standard D:

"Earth in the solar system"

Science and Technology

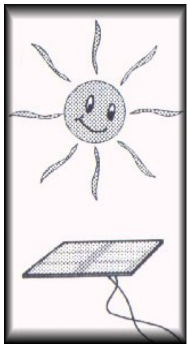
– Content Standard E:

"Abilities of technological design"

"Understandings about science and technology"

Science in Personal and Social Perspectives – Content Standard F:

"Science and technology in society"



Technology Description

In 1839, at age nineteen, French scientist Edmund Becquerel was the first person to observe an extraordinary and very useful phenomenon called the photovoltaic effect. The photovoltaic effect is the process that occurs when photons, or the particles of energy in a beam of sunlight, hit atoms in semiconductors and knock electrons loose, which makes electrical current possible.

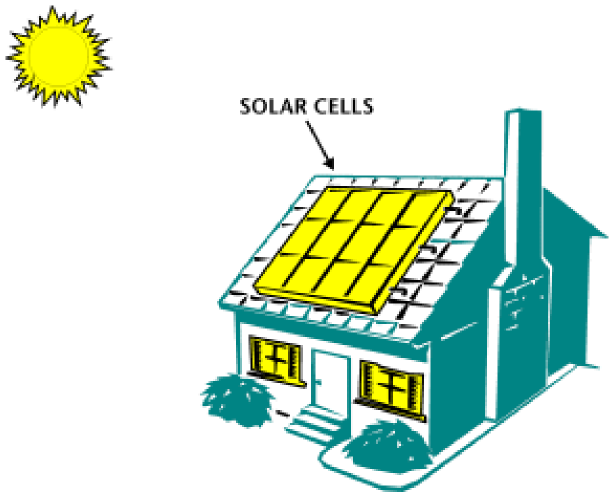
Semiconductors are materials that allow electric currents to flow through them under certain conditions. Semiconductors are neither excellent conductors (like copper wiring) nor are they excellent insulators (like glass or plastic), but have properties somewhere in the middle. Semiconductors are used in photovoltaic cells (sometimes referred to as PV cells or solar cells), computers, windows, and more.

Although Becquerel discovered the photovoltaic effect in the 1800s, solar cells were not produced until the mid 1950s. In 1954, the first crystalline silicon cell was created in Bell Laboratories in the United States. This cell was 4.5% efficient, which means that it only turned 4.5% of the sun's energy into electricity.

Today's PV cells are made of several layers of semiconductor material. On the bottom of the cell is a layer of a conductive metal and on the top is an additional conductive film. When sunlight strikes the upper semiconductor layer, photons excite electrons in the semiconductor, causing them to migrate to the next layer. As you probably know, electrons have a negative charge. When they move to the next layer, they leave a positively charged hole behind. When the excited electrons reach the surface of the cell, it moves through the external circuit and returns to the opposite layer to fill in the positively charged hole. This creates electricity.

You may have seen photovoltaic cells and modules on people's homes and businesses. These cells are capturing the sun's energy and changing it into electricity for us to use. Buildings are not the only place where photovoltaic cells are used. The sun powers illuminated warning signs on many highways and almost every American space satellite uses PV for its electric power!

You may be asking yourself why we would want to use the sun's light for electricity when we have so many other energy resources. The answer is that every day more solar energy falls to the Earth than the total amount of energy the planet's 6.1 billion inhabitants could consume in 27 years. In other words, there is plenty of sunlight to go around and we won't run out of it until the sun dies (which is not expected to happen for



another 4.5 billion years). This makes the sun a renewable resource.

Today's scientists continue the quest for an economical system for converting sunlight to electricity. Scientists want to make energy from the sun cheaper for us to use in our homes and businesses so that we can decrease our usage of non-renewable energy.

Resources:

U.S. Department of Energy PV Home Page
http://www1.eere.energy.gov/solar/photovoltaics.html

How Stuff Works
www.howstuffworks.com/solar-cell.htm

Florida Solar Energy Center
www.fsec.ucf.edu/pvt/

Roofus' Solar Home
http://www1.eere.energy.gov/kids/roofus/

Solar Energy
http://www.eia.doe.gov/kids/energyfacts/sources/renewable/solar.html

SunWind
http://sunwindsolar.com/

Resources for the following projects: PV and Electrical Measuring Supplies

PV cells: (Please note that when searching for PV cells on the internet, use key words "solar cells.")

www.scientificsonline.com (Click on the solar energy tab, then click on solar cells. (Contains low-cost solar cells to be assembled.))

http://www.solarnature.com/educational.html (Many choices at many prices)

Radio Shack stores or
www.radioshack.com

http://www.solar-world.com/default.htm
(Many choices – prices range from $8.00-$16.00)

***Resistors* (1 ohm to 1 megaohm):**

Radio Shack stores or
www.radioshack.com - Be sure to get a low watt resistor for safety purposes. (Cat#'s 271-1116 and 271-1108 are fine - they are $0.99 each)

***Voltmeters*:**

www.nebraskascientific.com (Use the site search option and type voltmeter - $15.95)

***Multimeters*:**

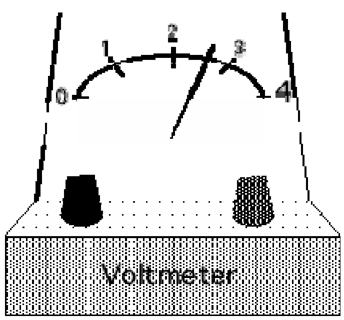
www.nebraskascientific.com (Use the site search option and type multimeter - $33.50)

www.cs-sales.com (Do a search on the site. Options range from $7.95-59.95)

Project Ideas

1 What is the output of a photovoltaic (PV) cell?

Learning Objective: You will be able to measure and find out for yourself just how much energy (voltage) a photovoltaic cell can create simply by placing it in front of a light source!



Controls and Variables: Light intensity, distance from PV cell to light source, load (resistor or light bulb)

Materials and Equipment:

***PV cells*:**
(See resource section.)

***Resistors* (1 ohm to 1 megaohm):**
(See resource section.)

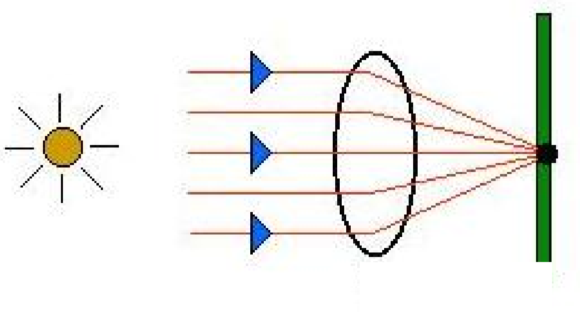
***25W-100W Light bulbs*:**
Grocery store ($0.75-$1.00 each)

***Voltmeter*:**
(See resource section.)

***Multimeter*:**
(See resource section. This equipment is not absolutely necessary for this project, but it allows you to measure both voltage *and* current.)

Safety and Environmental Requirements: Even if you wear sunglasses, *do not* look directly at the reflected image of the sun. Bulbs can get hot! The PV cell is most likely brittle; handle it with care. Also, be sure to follow all instructions on the voltmeter or multimeter carefully because you are dealing with electricity.

Suggestions: Connect the resistor and voltmeter (or multimeter) to PV cell leads (leads may have to be soldered on with low-temperature solder.) Try 25W, 40W, etc., bulbs at a fixed distance from the PV cell and record the voltages of each bulb. Then try one bulb at several distances. Also, try a fixed distance with one bulb, but hook up a load to be powered by the PV cell. Measure the voltage drop across the load and the current to the load. Calculate the power generated with: power = current X voltage (or power = voltage^2/resistance).



2 How does concentrating the sunlight affect the output from a solar cell?

Learning Objective: You will be able to determine for yourself whether concentrating light with mirrors and/or Fresnel lenses (special lenses used in car headlights, overhead projectors, and spotlights with a short focal length) affects the output of a solar cell.

Controls and Variables: Intensity of light, size of concentrating mirrors, angle of mirrors

Materials and Equipment:

PV cell: (See resource section.)

Mirrors or aluminum foil:
www.carolina.com (Search for mirrors and go to page 3 of 4. Prices range from about $5.00 to $18.00 for a set of mirrors.)

Voltmeter:
(See resource section.)

Multimeter:
(See resource section. This is not absolutely necessary for this project, but it allows you to measure voltage *and* current.)

Flashlight bulbs:
Hardware store (Prices vary.)

Fresnel Lens:
www.sciplus.com (Do a search for Fresnel lenses. A variety of lenses exist between $0.75 and $1.25.)

Safety and Environmental Requirements: Concentrated sunlight can be extremely dangerous to the naked eye. Even if you wear sunglasses, *do not* look directly at the reflected image of the sun. Also, light bulbs can get hot! The PV cell is most likely brittle; handle it with care. Also, be sure to follow all instructions on the voltmeter or multimeter carefully because you are dealing with electricity.

Suggestions: Measure the voltage (the amount of potential energy in the electricity) between cell connections from a plain solar cell placed in the sun. Next, put mirrors around the cell to reflect more light onto it. Try several positions and foil shapes. How is the voltage affected? Hook a flashlight bulb to the solar cell and see which combination of mirrors and foil causes the bulb to shine the brightest. Try a Fresnel lens to concentrate the sunlight.

(For information about Fresnel lenses, go to www.howstuffworks.com and do a search for Fresnel lenses.)

3 Does a tracking PV system collect more energy than a stationary system?

Learning Objective: For this project, you will be able to see whether tracking, or following the sun with your PV system, increases or decreases its energy output.

Controls and Variables: Tracking speed, tracking angle

Materials and Equipment:

PV cells:
(See resource section.)

Voltmeter:
(See resource section.)

Multimeter:
(See resource section. This is not absolutely necessary for this project, but it allows you to measure voltage *and* current.)

Resistors (1 ohm to 1 megaohm):
(See resource section.)

Tripod or other support system:
www.carolina.com (Do a search on the catalog for tripods. Prices range from $10.50 and up.)

Safety and Environmental Requirements: Even if you wear sunglasses, *do not* look directly at the sun. To aim the PV cell at the sun, point the cell towards the sun and adjust the cell until its shadow is as small as possible. The PV cell is most likely brittle; handle it with care. Also, be sure to follow all instructions on the voltmeter or multimeter carefully because you are dealing with electricity.

Suggestions: Connect a resistor (1-10 ohms) to the two wires of the PV cell. Measure the voltage drop across the resistor with each position of the tracker. Adjust the tracker periodically (every 15, 30, or 60 minutes) and see which way gives the most power. Compare this to a fixed PV cell. Remember, power (watts) = voltage^2/resistance. If you want, try making an automatic tracking device.

4 How long does the sun spend behind clouds each day?

Learning Objective: Using a PV cell, you will be able to tell your friends about how much time the sun spends behind clouds each day!

Controls and Variables: Size of PV cell, type of clock

Materials and Equipment:

Several PV cells of different sizes:
(See resource section.)

DC powered clock (any battery powered analog clock):

Grocery store (range of styles and prices)

Hardware store (range of styles and prices)

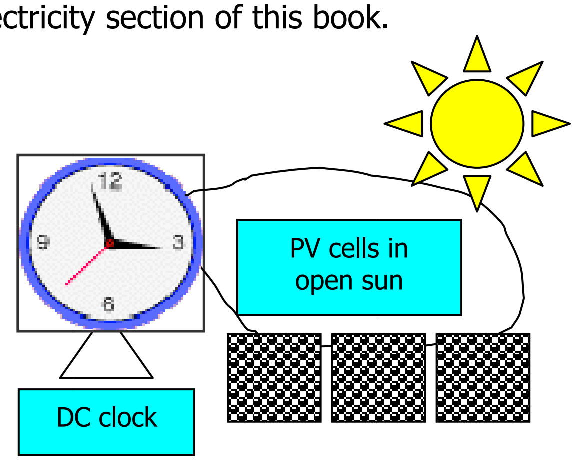
High Gauge Wire:

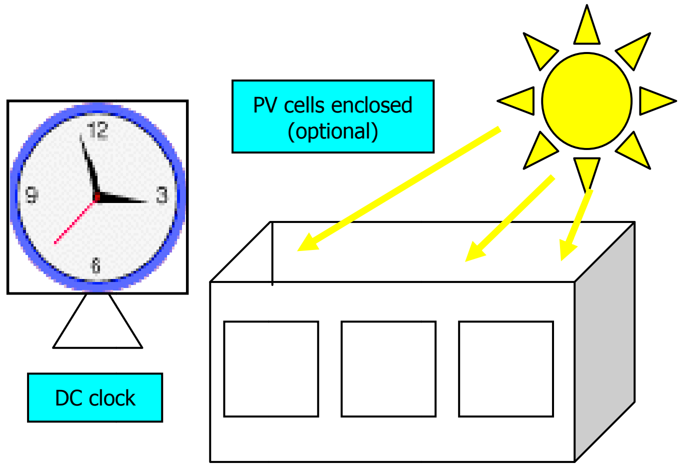
www.radioshack.com or RadioShack store.

Hardware store (range of styles and prices)

Safety and Environmental Requirements: Even if you wear sunglasses, *do not* look directly at the sun. To aim the PV cell at the sun, point the cell towards the sun and adjust the cell until its shadow is as small as possible.

Suggestions: Be sure to get a clock that requires only the voltage available from the PV cell. If you need more voltage, hook several PV cells together in a series. When the sun shines, the clock will run. If the clock runs when the sun is behind a cloud, try putting the PV cell(s) in the bottom of a tall tube or box and aiming it directly at sun. (See diagrams.) This will cut out indirect light. This sunshine time could be used in conjunction with some of the projects in the Process Heat and Electricity section of this book.





5 How fast can a solar powered car go?

Learning Objectives: You will be able to design and build a car powered only by the energy from the sun! Calculate the speed of your car. Compare it to a gravity-powered car.

Controls and Variables: Light intensity, weight of cars, size of the solar panel and motor.

Materials and Equipment:

Gears, rods and electric motor:
Junior Solar Sprint suppliers (http://www.solar-world.com/default.htm) have kits with wheels, gears, rods, and motors for your car.

- Gears Wheels and rod kit = $4.00
- Motor and accessories = $3.25

Balsa Wood & Glue (for the car frames):
Any crafts or hobby store.

PV cell:
Junior Solar Sprint suppliers (http://www.solar-world.com/default.htm) have PV cells especially built for make a solar car.

- PV cell = $28.00
- PV cell and motor = $30.00

Stopwatch:
Any sporting goods store = $5.00 - $10.00

Measuring tape:
Any hardware store

Safety and Environmental Requirements: None

Suggestions: Demonstrate the differences between a solar powered car and a gravity powered car by racing them from the top of a hill. Make sure the two cars weigh the same.

6 Is it practical to store the energy produced from a PV cell in a tank of water?

Learning Objectives: Design, build and test a water storage machine that uses the energy produced by a PV panel to indirectly power a light bulb or other electrical devices. (Wires from the PV panel cannot touch the electrical device).

Controls and Variables: Size and angle of the PV panel, height of water storage, and the resistance of the electrical device.

Materials and Equipment:

PV panel: Several PV cells connected in series to produce 50 W or greater. See resource section.

Small Electric Water Pump:
http://www.hobbylinc.com/
(Do a search for "water pump." $10.00)

Small Electric Generator:
(Electric motor hooked up backwards)
www.radioshack.com or RadioShack store

For the water Wheel attached to the Generator:

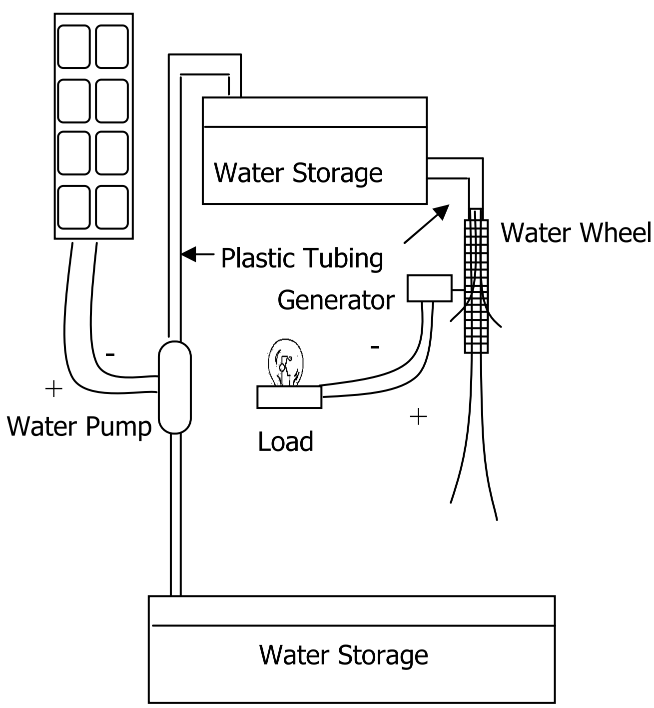
Two water storage tanks or buckets:
Any home improvement store

Plastic tubing:
Fish aquarium store

6m of 14 gauge electrical wire:
www.radioshack.com or Radio Shack store

Electric load (light bulb, radio, etc.):
www.radioshack.com or RadioShack store

Safety and Environmental Requirements: Even if you wear sunglasses, *do not* look directly at the sun. Be careful not to have any electrical wires touching the water. A short circuit will occur causing an electric shock. You can get hurt and your electrical devices could be damaged. Be careful of the sharp edges of the water wheel. Be careful not to over power any of the electrical devices (load). You can use a multimeter to check the voltage and current of the power supply. Compare the measurement to the load specification before connecting power supply to the load.



Suggestions: Try connecting the load directly to the PV panel, and then try connecting the load through the water wheel generator. Which way works the best and why? Try varying the height of the top water storage and the generator. Does it make a difference?

7 How does a photovoltaic (PV) solar cell respond to different wavelengths (colors) of light?

Learning Objective:
You will learn the effects of different colored light on PV cell output.

Controls and Variables:
Wavelength (color of light), voltage, current, resistance

Materials and Equipment:

Several types of PV cells:
(Crystalline silicon, amorphous silicon, copper indium diselenide, gallium arsenide if available. See resource section.)

Color filters:
Grocery store – colored plastic wrap

Hobby store – colored cellophane or polypropylene

www.papermart.com - click on the "film" section, go to the colored polypropylene section. (Prices range from $4.85 - $100.00, depending on how much you want)

Incandescent bulb:
Grocery store or Hardware store ($0.25-$1.00)

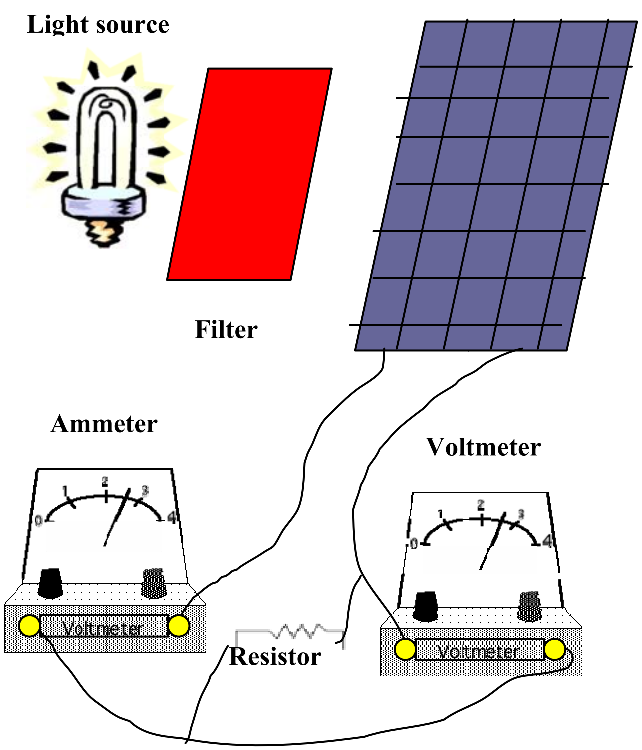
Fluorescent bulb:
Hardware store ($6.00-$8.00)

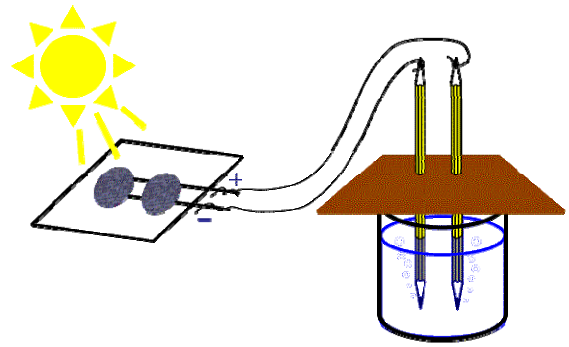
Voltmeter/ammeter/multimeter:
(See resource section.)

Resistors (1 ohm to 1 megaohm):
(See resource section.)

Safety and Environmental Requirements: Bulbs will be hot! Also, Even if you wear sunglasses, *do not* look directly at the sun!

Suggestions: Try different light sources and record the current (how many electrons pass by a point in a certain amount of time) and voltage output. Try several filters and record the current and voltage output. Try several resistors and record the current and voltage output. Try different types of solar panels, if available, and repeat the above three actions.





8 Can sunlight be used to split a water molecule and produce hydrogen?

Learning Objectives: Use the energy produced by a PV cell or panel to break up water molecules into oxygen and hydrogen. Test for and determine the ratio of oxygen to hydrogen produced.

Controls and Variables: Size and angle of the PV panel, and type of electrodes

Materials and Equipment:
PV cell or panel (A PV panel is just several PV cells connected in series to produce greater voltage)

Electrolysis kit:
(Kit must contain at least a set of electrodes and wires)
https://www1.fishersci.com/index.jsp
(Pack of two, $19.95)

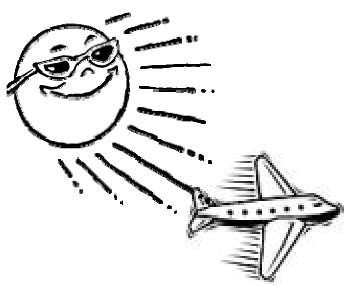
Beaker (if not part of electrolysis kit):
https://www1.fishersci.com/wps/portal/HOME (Pack of 12, 250m beakers, $44.75)

Two Test tubes (if not part of electrolysis kit):
https://www1.fishersci.com/wps/portal/HOME (Pack of 100, $28.00)

Popsicle sticks: Any discount store

Safety and Environmental Requirements: Even if you wear sunglasses, *do not* look directly at the sun! Always wear some type of eye protection when testing for flammability**.**

Suggestions: Use the PV cell/panel as the power source for the electrolysis kit. Test the flammability of the two gases formed with a lit or glowing Popsicle stick. Oxygen should make a glowing stick shine brighter. Hydrogen should ignite and make a popping sound with a lit stick.



9 Can an airplane be powered only by the energy from the sun?

Learning Objectives: You will be able to design, build and fly an airplane powered only by the energy from the sun! Test how long it can fly.

Controls and Variables: Light intensity, weight and size of airplane, size of the solar panel and motor.

Materials and Equipment:

Flying airplane model kit:
www.guilow.com **(**$7.00-$15.00)

PV panel or cell:
(See resource section.)

Electric motor:
www.radioshack.com or RadioShack store

Stopwatch:
Any sporting goods store ($5.00 - $10.00)

Safety and Environmental Requirements: **Be careful of the spinning propeller.**

Suggestions: Build a flying model airplane. Use the electrical motor instead of the motor from the kit. Attach a PV cell to the top of the wing and connect it to the electric motor. Try to keep the total weight of your airplane to a minimum.

More Project Ideas

How does the angle of the sun affect the output of a solar cell?

How does the magnification of a light source affect the electrical output of a solar cell?

What is the effect of temperature on a PV cell?

Which delivers more power to a motor: Two solar cells in a series or two solar cells in parallel?

Can a model boat be powered with energy from the sun?

References:

Science Projects in Renewable Energy and Efficiency, 1990

www.nrel.gov

Photo References:

http://www.nmsea.org/Curriculum/7_12/electrolysis/electrolysis.htm

www.shodor.org/succeed/projects/hi/skath

http://enrich.sdsc.edu/SE/opticsfresnel.html

www.solazone.com.au/tracker.htm

www.physics.emich.edu/phy110/circuits.htm

www.fcpud.com/images/energy%20bulb.gif