Advanced Manufacturing & Materials

Warm Home Solar Style

Grade Level: 9th – 12th

Academic Content Areas: Science, Technology, Engineering, & Mathematics

Topics: Science and Technology; Scientific Ways of Knowing; Number, Number Sense and Operations; Measurement; Data Analysis & Probability

Essential Question

How can we use the sun to warm our homes?

Summary

Students will investigate and explore the use of solar energy as a means to heat a home. In order to understand how solar energy can be harnessed, students will define solar energy, explore photovoltaic cells, and investigate passive solar energy. After gaining understanding about the concepts of solar energy, students will build a solar-heated model home that is warm and comfortable based on the data analysis of the previous sections. This unit is applicable for high school students in grades nine through twelve with a variety of learning styles.

Big Ideas / Focus

On planet Earth, sunlight is the most important form of energy. Solar energy travels through space in the form of infrared radiation, ultraviolet light, and visible light. Some of this energy enters the Earth's atmosphere where it warms our planet's surface, drives ocean currents, and winds, and is used by plants to make food. Life on Earth is dependent on the sun.

Solar energy and materials can be combined to provide comfortable, environmentally friendly, and inexpensive heat. Solar energy can be stored during the day for later use. Solar energy can also be used to make electricity. This electricity can be stored in deep cycle rechargeable batteries.

The deep cycle batteries used with solar arrays must be able to discharge and recharge again many times. They contain thicker lead plates than automotive starting batteries. They are also usually larger, heavier, and more expensive than starting batteries. The solar cells can also be hooked to an electric grid instead of batteries.

Besides solar panels and rechargeable batteries, modern photovoltaic systems are usually equipped with some kind of electronic charge controller. The main job of the charge controller is to feed electricity from the solar panel to the battery in the most efficient manner without overcharging and damaging the batteries.

In many cases, people need the electricity stored in the rechargeable batteries to operate normal household appliances. Most of those appliances require 110 volts of alternating current (110V AC), whereas the battery puts out only direct current (DC), usually at a much lower voltage. A power inverter solves this problem by converting the battery's low-voltage direct current to 110 volts of alternating current. Modern charge controllers often come equipped with their own built-in power inverters.

Prerequisite Knowledge

Students should have a basic understanding of solar energy and heat energy transfer.

Students should also have a basic understanding of how electricity flows.

If students know how to use MS Excel they can graph and interpret data they collected.

Standards Connections

Content Area: Science

Science and Technology Standard

Students recognize that science and technology are interconnected and that using technology involves assessment of the benefits, risks and costs. Students should build scientific and technological knowledge, as well as the skill required to design and construct devices. In addition, they should develop the processes to solve problems and understand that problems may be solved in several ways.

Grade 9 - Benchmark A: Explain the ways in which the processes of technological design respond to the needs of society.	2. Identify a problem or need, propose designs and choose among alternative solutions for the problem.
Grade 11 - Benchmark A: Predict how human choices today will determine the quality and quantity of life on Earth	2. Predict how decisions regarding the implementation of technologies involve the weighing of trade-offs between predicted positive and negative effects on the environment and/or humans.

Scientific Ways of Knowing Standard

Students realize that the current body of scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world. This includes demonstrating an understanding that scientific knowledge grows and advances as new evidence is discovered to support or modify existing theories, as well as to encourage the development of new theories. Students are able to reflect on ethical scientific practices and demonstrate an understanding of how the current body of scientific knowledge reflects the historical and cultural contributions of women and men who provide us with a more reliable and comprehensive understanding of the natural world.

Grade 9 - Benchmark B: Explain how scientific inquiry is guided by knowledge, observations, ideas and questions.	6. Explain that inquiry fuels observation and experimentation that produce data that are the foundation of scientific disciplines. Theories are explanations of these data.
Grade 10 - Benchmark A: Explain that scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world.	3. Recognize that science is a systematic method of continuing investigation, based on observation, hypothesis testing, measurement, experimentation, and theory building, which leads to more adequate explanations of natural phenomena.

Grade 11 - Benchmark A: Explain how scientific evidence is used to develop and revise scientific predictions, ideas or theories.	3. Demonstrate that scientific explanations adhere to established criteria, for example a proposed explanation must be logically consistent, it must abide by the rules of evidence and it must be open to questions and modifications.
Grade 12 - Benchmark A: Explain how scientific evidence is used to develop and revise scientific predictions, ideas or theories.	4. Analyze a set of data to derive a principle and then apply that principle to a similar phenomenon (e.g., predator-prey relationships and properties of semiconductors).

Content Area: Mathematics

Number, Number Sense and Operations Standard

Students demonstrate number sense, including an understanding of number systems and operations and how they relate to one another. Students compute fluently and make reasonable estimates using paper and pencil, technology-supported and mental methods.

Grade 9 – Benchmark J: Compute probabilities of compound events, independent events, and simple dependent events.	4. Demonstrate fluency in computations using real numbers.

Measurement Standard

Students estimate and measure to a required degree of accuracy and precision by selecting and using appropriate units, tools and technologies.

Grade 9 - Benchmark H: Use counting techniques, such as permutations and combinations, to determine the total number of options and possible outcomes.	2. Use unit analysis to check computations involving measurement.

Data Analysis and Probability Standard

Students pose questions and collect, organize, represent, interpret and analyze data to answer those questions. Students develop and evaluate inferences, predictions and arguments that are based on data.

Grade 9 - Benchmark K: Make predictions based on theoretical probabilities and experimental results.	10. Use theoretical and experimental probability, including simulations or random numbers, to estimate probabilities and to solve problems dealing with uncertainty; e.g., compound events, independent events, simple dependent events.
Grade 11 Benchmark D. Solve problem situations involving derived measurements; e.g., density, acceleration	1. Design a statistical experiment, survey or study for a problem; collect data for the problem; and interpret the data with appropriate graphical displays, descriptive statistics, concepts of variability, causation, correlation and standard deviation.

Preparation for activity

Make photocopies of each of the labs as well as key vocabulary terms and other solar information sections. Encourage students to keep a folder or portfolio of their investigation. Students should bring their folder/portfolio to class every day.

Setting up the lamps can be time consuming. Attaching the lamp to a table edge might be preferred over the ring stands. If you use a table edge you may need to use a box (such as for printer paper) placed upside down on the floor as a platform for the other equipment in that section of the lab.

Setting up the graphing calculators and temperature probes can also be time consuming.

If you are not familiar with voltmeters and ammeters Fluke has an online tutorial.

Critical Vocabulary

absorption – process of light energy being changed into heat energy when light hits an object

active solar energy – solar energy provided by equipment such as photovoltaic cells or solar collectors that require electricity to move the collected heat.

alternative fuel – any fuel that is not petroleum based such as solar, electric, compressed natural gas, or hydrogen

ampere (amp) – unit of measure of the number of electrons flowing through a wire per unit of time

angle of incidence – the angle of the sun in relation to a normal line drawn perpendicular to level ground or the collector surface. The angle of incidence varies according to location (latitude) and time of day.

charge controller – a piece of equipment that channels electricity from the solar panel to the battery in a way that prevents the solar panel from overcharging the battery

current – rate of flow of electric charge

electricity – flow of electrons

energy source – object or material that produces energy by changing it from one form to another

load – a device to which power is delivered

nonrenewable energy source – source of energy that is either unable to be replaced naturally or is naturally replaced very slowly such as fossil fuels or nuclear fuels

orientation – set in any definite position with reference to the points of the compass

passive solar design – construction technique that uses structural elements of a building to collect heat in the cold weather and deflect heat in hot weather; includes materials, eaves, landscape, and windows. Orientation to the sun is also considered.

photovoltaic (PV) – the effect of producing electric current using light; from photo meaning light and voltaic meaning to produce direct electric current by chemical action

photovoltaic array – a group of solar cells put together.

photovoltaic cell – device that converts solar energy directly into electricity

solar cell – photovoltaic (PV) cell

solar energy – energy derived from the sun

solar thermal energy – using the sun to directly heat air or water; the simplest type of solar technology

volt – the unit used to measure the potential energy per electron in a circuit.

watt – the standard unit used to measure electric power, specifically the rate at which electrical energy is consumed.

Timeframe

Day	Time Allotment	Activities
1	1 class period (~50 minutes)	Pre-Test Introductory video from How Stuff Works Selection of Student Engineering Teams (SETs)
2	1-2 class periods	Lab One – Photovoltaic Lab
3	1-2 class periods	Lab Two – Passive Solar Energy Lab – Angle of Incidence
4	3-4 class periods	Lab Three – Basic House Plan Lab

Materials & Equipment

Materials for Photovoltaic Cell Lab:

photovoltaic (solar) cell
voltmeter
ammeter
LED's
6 identical lamps with the same type and wattage of light bulbs (60-150 watts)
insulated wires with alligator clips (same lengths)
protractor
ruler
calculator
modeling clay
stopwatches
cardboard (to make shade)

Materials for Passive Solar Energy – Color Lab:

6 thermometers or temperature probes with graphing calculators
6 identical lamps with the same type and wattage of light bulbs (60-150 watts)
6 flasks*
6 stoppers with one-hole
scissors
plastic wrap
6 stop watches
water
*Black construction paper
*White construction paper
*Yellow construction paper
*Red construction paper
*Blue construction paper
*Green construction paper
* Metal water bottles of various colors could be used instead of using flasks and construction paper.

Materials for Passive Solar Energy – Angle of Incidence Lab:

lamp (light fixture on ring stand can be used)
shoe box
transparency sheets
colored construction paper (see above)
stopwatch
tape

Materials for Basic House Plan Lab:

solar panels
motors
fans for motors
LED's
card board or wood
insulation
batteries
glass or plastic
additional supplies as determined by student design

Safety & Disposal

Be careful not to touch any wires or areas that might be carrying current and cause you to be shocked.

Do not touch hot lamp reflector or bulb.

Pre-Activity Discussion

One of the How Stuff Works solar energy videos might serve as a reference for class discussion.

Additionally, students' experiences with heating or powering their own homes might be used for class discussion.

Discussion or Research Questions:

What is the source of heat for your homes?
How do animals get warm?
How can someone heat their home without electricity?
What is the largest source of energy for our planet?

Solar Energy

On planet Earth, sunlight is the most important form of energy. Solar energy travels through space in the form of infrared, ultraviolet light, and visible light. Some of this energy enters the Earth's atmosphere where it warms our planet's surface, drives ocean currents, and winds, and is used by plants to make food. Life on Earth is dependent on the sun.

Photovoltaic Cells

Visible light can be converted directly to electricity by a photovoltaic cell or solar cell. Most photovoltaic cells are made from silicon. Solar cells are usually made by using two thin layers or wafers of silicon. Wires are positioned on the layers. The wires enable electrons to travel between the layers. When sunlight strikes the solar cell, electrons move from one layer to the other through the wires.

How Photovoltaic Panels Work:
The Pembina Institute

Photovoltaic cells are marvels of sub-atomic physics. They are constructed by layering special materials called semiconductors into thin, flat sandwiches, called solar cells. These are linked by electrical wires and arranged on a panel of a stiff, non-conducting material such as glass. The panel itself is called a module.

A ray of light consists of a stream of photons – tiny packets of light energy – moving along at around 300,000 kilometers per second. When these energy packets strike the top layer of a solar panel, they bump electrically charged particles called electrons away from their "parent" atoms. These electrons are collected by another layer in the sandwich and passed along through wires that may connect to storage batteries to run household appliances. The amount of electricity the panel can produce depends on the intensity of the light.

Assignment of Student Roles and Responsibilities:

Students will share the responsibility of performing experimental tests. Additionally, students will assume the following roles:

Member	***Role Name***	***Brief Description***
1	Manager	Responsible for organizing team and keeping team on task to meet goals and deadlines. Will also serve as team spokesperson, if one is required.
2	Tester	Responsible for manipulating equipment properly.
3	Safety Officer	Responsible for making sure team observes all safety measures during experimentation.
4	Technical Writer	Responsible for recording data during experimentation and overseeing the writing of results and conclusions.

Activity

Teacher instructions:

Comparison of data will be possible if the equipment is set up exactly the same way (same wattage bulb, same distance from light to collector, same incidence angle) from lab group to lab group. Additionally, students should be advised to record their equipment details so that if more than one class period is needed equipment set-up can be duplicated the next time lab is scheduled.

Photovoltaic Cell Lab

In this activity students will explore how photovoltaic cells work under four conditions:

(1) Students will experiment to determine how the position of the sun relative to the array affects the electricity produced by the array.
(2) Students will investigate the effect of shade on the amount of power produced by the photovoltaic array.
(3) Students will explore how the length of time photovoltaic cells are exposed to the sun or a light source affects electrical production.
(4) Students will compare the amount of power produced by one photovoltaic panel versus two or more panels.

After students have explored how photovoltaic cells work they will determine if the photovoltaic system is a viable option for heating a home.

Preparation:

Caution students not to touch any wires or areas that might be carrying current and cause them to be shocked.

a. Set up your system by attaching a wire to each of the photovoltaic cell wires.

b. In order to obtain quantitative measurements of current, connect an ammeter and a LED in series with the photovoltaic cell.

c. In order to obtain quantitative measurements of the voltage, connect a voltmeter to the photovoltaic cell by attaching the red wire of the voltmeter to the red wire of the photovoltaic cell and the black wire of the voltmeter to the black wire of the photovoltaic cell.

d. Students can test the photovoltaic cell for current and voltage by shining a light on it or, at the teacher's discretion, taking it outside in the sunlight.

e. If no readings are present on the meters, check your connections first, then the equipment.

f. Power (P) is equal to current (I) multiplied by voltage (V) or P= IV and is measured in Watts (W).

Part 1: Position of the Sun *(The term angle of incidence refers to the angle formed between the normal line and the light striking the solar cell. The normal line is a line that strikes the surface of a solar cell at a 90° angle.)*

1. Predict (record your predictions):
   a. At which angle of incidence do you expect to have the greatest amount of power?
   b. At which angle of incidence do you expect to have the least amount of power?
   c. Rank the amount of power possible at each of incidence from greatest to least.
2. Position the photovoltaic cell at various angles (minimum of five different angles). Teacher can allow students to select angles or provide angles for them.
3. Place an LED on the back of the photovoltaic cell between the posts. (Circuit requires a load.)
4. Use a protractor to measure the test angles.
5. Modeling clay could be used to maintain the position of the photovoltaic cell at the designated angles.
6. Create an appropriate data table and record your findings. Students who are unable to create their own data table may be provided with this one:

Prediction Ranking*	Angle of Incidence	Current (Amps)	Voltage (Volts)	Power (Watts)
	0°			
	30°			
	45°			
	60°			
	90°			

*For the prediction ranking: 1= highest and 5 = lowest

7. Were your predictions correct? Explain.
8. Graph your results, power versus angle of incidence.

Analysis

9. Does the angle of the photovoltaic cell in relationship to the sun impact the amount of available solar power?
10. At which angle of incidence were you able to gain the most solar energy?
11. How would this influence the use of solar energy in Ohio or in your area?
12. How does this influence the global use of solar energy?

Part 2: Cloudy Days (*Have students write a response to this question in their notebooks/journals:)*

Do clouds and other methods of blocking sunlight impact the production of solar energy?

1. Block the amount of light reaching the panel with different amounts of cardboard.
2. Determine the surface area of the solar panel and divide it into fourths. Allow students to come up with their own ideas on how to do this. If they are having difficulties, offer one or more of these suggestions:
   a. Calculate the surface area using length x width; then divide by four. Each fourth represents 25% of the surface area.
   b. An alternate method is to cut a piece of cardboard the exact size of the area of the array. Fold the cardboard into half and then into half again. Each portion of the cardboard is 25% of the surface area.
3. Prediction: Predict the impact of the "shade". For your prediction use a percentage of reduction to represent each amount of coverage or "shade". For example, "With 25% of the array shaded, I predict the amount of solar power will decrease by 10%." Record your predictions.
   a. Will the amount of solar energy be greatly reduced by a small amount of shade?
   b. Will the amount of solar energy only be reduced a little by a small amount of shade?
4. Test the ***change in solar power*** for each one-fourth of the array that is shaded.
5. Create an appropriate data table and record your findings. Students who are unable to create their own data table may be provided with this one:

Predictions (Percentage of Power)	**Shaded** Collector Area	Current (Amps)	Voltage (Volts)	Power (Watts)	Percentage of Power
	0%				
	25%				
	50%				
	75%				
	100%				

6. Calculate power and enter the values in your data table. (Power = Amps x Volts = Watts)

7. Calculate the percentage of power and enter the values in your data table.
8. Were your predictions correct? Explain.
9. Graph the results of your observations: Power versus Collector Area.

Analysis

10. How does blocking parts of the solar cell impact the amount of available solar power?
11. How would this influence the use of solar energy in Ohio or in your area?
12. How does this influence the global use of solar energy?

Part 3: What about short days and long nights?

In this section students will explore the impact of the amount of time in the "sun" or length of day on the amount of solar power possible. Students should use the angle of incidence that produced the most solar energy from Part 1.

1. Prediction (written response required): How much energy do you expect to yield for:
   a. 10 minutes
   b. 20 minutes
   c. 30 minutes
   d. 40 minutes
2. Place the solar cell in the light.
3. Create an appropriate data table and record readings after each of the time intervals. Students who are unable to create their own data table may be provided with this one:

Prediction	Time (min)	Current (Amps)	Voltage (Volts)	Power (Watts)	Energy (Joules)
	10				
	20				
	30				
	40				

4. Calculate energy and enter the values in your data table.
   Energy = Power x time = (Current x Voltage) x time = (Amps x Volts) x seconds = Joules.
5. Were your predictions correct? Explain.
6. Graph your results as Temperature versus Time.

Analysis

7. Does length of time of the solar cell is exposed to the sun effect the amount of solar energy collected?
8. How would this influence the use of solar energy in Ohio or in your area?
9. How does this influence the global use of solar energy?

Part 4: If one solar panel is good how good would three solar panels be?

1. Prediction (record your predictions):
   a. How much power do you expect to yield from one solar panel?
   b. How much power do you expect to yield from two solar panels?
   c. How much power do you expect to yield from three solar panels?
2. Use the angle with the best yield of power for all of the tests.
3. Set up your photovoltaic system with one solar panel.
4. Create an appropriate data table and record readings of the current and the voltage for one panel. Students who are unable to create their own data table may be provided with this one:

Prediction: Power (Watts)	Number of Solar Panels	Current (amps)	Voltage (volts)	Power (Watts)
	1			
	2			
	3			

5. Calculate power and enter the values in your data table. (Power = Amps x Volts = Watts)
6. Set up your photovoltaic system with two solar panels in series.
7. Record readings of the current and voltage for two panels.
8. Calculate power and enter the values in your data table. (Power = Amps x Volts = Watts)
9. Carefully connect three solar panels in a series.
10. Also connect the meters to get readings of the current and voltage.
11. Calculate power and enter the values in your data table. (Power = Amps x Volts = Watts)
12. Were your predictions correct?
13. Graph your results, power versus number of panels.

Analysis

1. How many solar cells would you need to have enough electricity to power your home?

   Appliance electric usage charts are available at Otter Tail Power Company, Appliance Energy Usage www.otpco.com/SaveEnergyMoney/applianceEnergyUsage.asp or the Energy Usage Chart at http://www.psnh.com/sharePDFs/Residential/EnergyusageChart.pdf

2. How would this influence the use of photovoltaic cells to heat your home?

3. Is there another type of solar energy that would be more effective to heat your home?

Extension: *For additional analysis enter the results of all four parts of the lab into an Excel spreadsheet. Are there any correlations?*

Teacher should show HowStuffWorks Videos: "Invention Nation: Solar Panels"

Begin a discussion on Storage of Solar Energy

Storing Electricity

Solar energy must be stored during the day for later use. The usual storage device is a rechargeable battery.

The battery bank used with solar arrays must be able to discharge and recharge again many times. They are also usually heavier and more expensive than car starter batteries.

Besides solar panels and rechargeable batteries, modern photovoltaic systems are usually equipped with an electronic charge controller. The main job of the charge controller is to supply electricity from the solar panel to the battery in the most efficient manner and to prevent the solar panel from overcharging and damaging the batteries.

People need the electricity stored in rechargeable batteries for use with normal household appliances. Most appliances require 110 volts of alternating current (110V AC). Battery puts out only direct current (DC), usually at a much lower voltage. A power inverter converts the battery's low-voltage direct current to 110 volts of alternating current. Modern charge controllers often come equipped with their own built-in power inverters.

Passive Solar Energy Lab

Passive Solar Energy - Color
In this activity students will investigate the use of passive solar energy to warm a container. Students will explore how the color of the solar collector affects temperature. Students will use air and water to test the impact of color on the solar energy collected.

Part One - Air

1. Prediction:
   a. Which color do you think will create the highest temperature reading?
   b. Which color do you think will create the lowest temperature reading?
   c. Rank the colors in order from lowest to highest temperature.
2. Cut each piece of construction paper to form a paper skirt to fit around the flasks.
3. Assemble the flasks with a stopper and thermometer or temperature probe with graphing calculator.
4. Place a lamp near each flask in the same position relative to each piece of construction paper.
5. Be sure to get an initial temperature reading before turning on the lamps.

Table One:

Prediction	Color	Initial Temperature 0 minutes	Temperature after 5 minutes	Temperature after 10 minutes	Temperature after 15 minutes	Temperature after 20 minutes	Temperature after 25 minutes
	yellow						
	red						
	blue						
	black						
	white						
	green						

Part Two - Water

1. Prediction:
   a. Which color do you think will heat up the fastest with water added to the flask?
   b. Which color do you think will be the slowest to increase temperature?
   c. Rank the colors in order from fastest to slowest increase in temperature.
2. Add 100 milliliters of water to each of the flasks.
3. Repeat the experiment.

Table Two:

Prediction	Color	Initial Temperature 0 minutes	Temperature after 5 minutes	Temperature after 10 minutes	Temperature after 15 minutes	Temperature after 20 minutes	Temperature after 25 minutes
	yellow						
	red						
	blue						
	black						
	white						
	green						

4. Were your predictions correct?
5. Graph your results for Table One and Table Two temperature versus time.

Analysis:

1. How does color of the solar collector affect the rate that the air and water heated? Explain your answer.
2. How can you use the data you gathered to design a solar heated house?

3. How would the location of the sun (lamp) change the temperature?
4. Design a lab to test your answer to question three.

Passive Solar Energy – Angle of Incidence
In this section students will build a model solar "house" based on the analysis of the data from the previous section. Use one of the colors you tested for the model house. Explain why you picked that color.

Change the angle of incidence and measure the temperature.

1. Prediction:
   a. Which angle do you think will cause the most increase in temperature in your solar energy house?
   b. Rank the angles from most temperature gain to least temperature gain.
2. Draw and label a design for your house.
3. What kinds of things are important for using passive solar energy?
4. Use the shoe box, transparencies, tape, and colored construction paper to build your "house".
5. Position the lamp to represent various angles of the sun.
6. Record the starting temperature.

Table Three:

Prediction	Angle of Incidence	Temperature
	30^{o}	
	45^{o}	
	60^{o}	
	90^{o}	

7. Were your predictions and rankings correct?

Analysis

1. At which angle did you have the highest temperature?
2. At which angle did the temperature increase the fastest?
3. How would you use this data to design a passive solar energy system in your home?

Basic House Plan Lab
In this activity students will design a model of a home that is warm and comfortable and heated with solar energy.

Questions to consider:
1. How can we use the information we learned in the photovoltaic cell lab and passive solar energy lab to design a model of a solar heated house? *Students might want to build a model with only passive solar energy, only solar cells, or use a combination of passive solar energy and photovoltaic cells.*

2. What materials would be used to make a home energy efficient? *Insulation; wood; brick; glass; solar panels; solar energy system, fan, motor*

3. What other issues need to be taken into consideration? *Orientation to the sun; size and location of windows; landscape; shade; location*

Possible Procedure:

1. Draw and label a design for your model.

2. Decide how to test your model. *Students can build a model and use either a lamp or sunlight as an energy source to heat their model. Temperature probes can be placed in the house to observe temperature change. If photovoltaic cells are used students might want to attach a voltmeter and ammeter to see how much power their system generates. However, if the students' main point is to heat a home the temperature reading may suffice.*

3. Build and test your model.

Analysis:

1. Were you able to heat your model home with solar energy?

2. How could you improve your model?

Student instructions:

Caution: Do not touch any wires or areas that might be carrying current.

Note: After set-up, record the details of your equipment (i.e. identification numbers) so that if more than one class period is needed equipment set-up can be duplicated the next time lab is scheduled.

Photovoltaic Cell Lab

1. Set up your system by attaching a wire to each of the photovoltaic cell wires.

2. In order to obtain quantitative measurements of current, connect an ammeter and a LED in series with the photovoltaic cell.

3. In order to obtain quantitative measurements of the voltage, connect a voltmeter to the photovoltaic cell by attaching the red wire of the voltmeter to the red wire of the photovoltaic cell and the black wire of the voltmeter to the black wire of the photovoltaic cell.

4. Test the photovoltaic cell for current and voltage by shining a light on it.

5. If no readings are present on the meters, check your connections first, then the equipment.

6. Power (P) is equal to current (I) multiplied by voltage (V) or P= IV and is measured in Watts (W).

Part 1: Position of the Sun *(The term angle of incidence refers to the angle formed between the normal line and the light striking the solar cell.)*

1. Predict:

    a. At which angle do you expect to produce the greatest amount of power?
    b. At which angle do you expect to produce the least amount of power?
    c. Rank the amount of power possible at each angle from greatest to least.

2. Position the photovoltaic cell at various angles (minimum of five different angles).

3. Place an LED on the back of the photovoltaic cell between the posts. (Circuit requires a load.)
4. Use a protractor to measure your test angles.
5. Modeling clay could be used to maintain the position of the photovoltaic cell at the designated angles.
6. Create an appropriate data table and record your findings (including your predictions).

Background Information

Provide background content information for the teacher to assist in implementing this activity/unit.

Black absorbs light.

White reflects light.

The size of the photovoltaic arrays will impact the results of the labs.

Place an LED on the back of the photovoltaic cell between the posts. (Circuit requires a load. A small red LED works well.)

Instructional tips

Some parts of the unit can be eliminated depending on the prior knowledge and experience of the students.

Colored felt can be used instead of colored paper for the Passive Solar Energy – Color Lab.

Student Engineering Teams (SETs) should be comprised of a variety of learners. To begin the model process, each member of the team should generate a labeled drawing of their ideas for the model. After everyone finishes their drawing, the group should collaborate and arrive at a consensus for the chosen drawing. Students should keep a journal of their daily work on their model.

Give students specific goals for the day. Having goals for the day will encourage students to stay on task and move forward in their design process. To monitor student progress have scheduled times for progress reports. During the progress reports have students alternate presenting. Each group member should take a turn serving as presenter in these brief updates. This will keep all members actively engaged in the process as well as prepare the students for their final presentation.

Formative Assessments

Students will maintain a portfolio throughout their investigation. The portfolio is an artifact that allows students to follow their investigation and observe the progress of their discovery.

Brief progress reports to state progress on the design construction will verify student learning. Each member of the group will take turns presenting a progress briefing to the facilitator/ teacher.

Post-Activity Discussion

As evidence of understanding the concepts, students will present a solar powered product (home model) to their class as if they are a company representative at a Green Earth Trade Show. The Trade Show is a real world application of an assessment method. Student Engineering Teams or SETs (lab groups) will present their product to potential consumers (the rest of the class). SETs will be expected to demonstrate their understanding of how well their home is warmed with solar energy and why their design works. The consumers can ask questions and make suggestions for product improvements that meet consumer demands. Each member of the SET should have a role in the presentation.

Extension: Students can complete this mathematics lesson as an extension of their investigation of solar energy.

Standards:

Patterns, Functions and Algebra Standard

9th Grade

2. Generalize patterns using functions or relationships (linear, quadratic and exponential), and freely translate among tabular, graphical and symbolic representations.

3. Describe problem situations (linear, quadratic and exponential) by using tabular, graphical and symbolic representations.

7. Use formulas to solve problems involving exponential growth and decay.

13. Model and solve problems involving direct and inverse variation using proportional reasoning.

10th Grade

10. Solve real-world problems that can be modeled using linear, quadratic, exponential or square root functions.

11. Solve real-world problems that can be modeled, using systems of linear equations and inequalities.

11th Grade

1. Identify and describe problem situations involving an iterative process that can be represented as a recursive function; e.g., compound interest.

2. Translate a recursive function into a closed form expression or formula for the *n*th term to solve a problem situation involving an iterative process; e.g., find the value of an annuity after 7 years.

12th Grade

1. Analyze the behavior of arithmetic and geometric sequences and series as the number of terms increases.

When is it worth it to convert to solar power?

I. Introduction

From SolarHome.org

Here are several important steps to take and factors to consider when it comes to building a solar power home:

- Determine how much power is required to supply your home energy needs. This includes finding out the wattage used by each and every appliance and accessory used. Calculate the voltage multiplied by the daily hours of use.
- Once the necessary amount of wattage is determined, the next step is to compare various solar systems offered by reputable companies.

- Select a system which comes with some sort of guarantee. It is not uncommon to see at least five-year warrantees; some warrantees may even extend up to twenty-five years.
- A home powered by solar energy requires top quality UL listed products and solar modules.
- Installation can be tricky. Most full systems require professional installation, or at least come with a very detailed instruction book.

Having a solar power home is not impossible; it can, however, be expensive. The savings on energy bills, reimbursements from energy companies, and tax credits which some states offer help offset the initial cost. Most owners of solar homes find that they have indeed saved money over the long run.

II. Initial questions and important points to remember:

What in your home determines the amount of electricity you use?
Answer: A common misconception about energy efficiency is that it linked to the size of your home. This is not necessarily true. How you use electricity within the home determines the efficiency. You could have a smaller home that uses more electricity than a home much larger. The amount of electricity a home uses is based on the efficiency of appliances, heating and cooling systems, water heaters, etc. and the number of hours these items are being used.

What factors would affect the efficiency of a solar power system in your home?
Answer: The amount of sunlight you receive daily, the geographic location of your home, the efficiency of your appliances, and the amount of electricity you use will all have an impact on the efficiency of a solar power system in your home.

III. Main Question: Is an investment in a solar power system for your home worth it? Explain your reasoning.

A. Determining the Cost

Determine the start up cost installing a new system without appliances.

According to www.solar-electric.com the cost for converting your home to 100% solar power can be determined using the following method.

1. Determine the watts of solar panels needed.

$$\text{watts of solar panels needed} = \frac{\text{monthly electric usage (in KWH)}}{30} \div (\text{avg. \# of full sun hrs. per day}) \times 1.15$$

You can find the information for your location by conducting a search on the internet. Searching "Ohio utility rate survey" on Google provide a report with latest usage information from the top 8 cities in Ohio. This information is calculated based on an average monthly usage of 750KWH. This can be used in the calculation or students can bring in an electricity statement from home with parents' permission.

Finding the average hours of daylight can be found by going to http://www.rssweather.com/dir/North%20America/United%20States. On this site find your location by selecting the state, county, and city you are in. Once in the city webpage, you can click on the state climate. This page will give the sunshine hours by a percentage of the day by month. To find the average per day, average the months' percentages and multiply this number by .01 (to convert the percent to decimal) and then by 24 hours.

For Dayton, Ohio this number would be: $53.42(0.01)(24) = 12.82 \text{ hours}$.

You should now have enough information to calculate your watts of solar panels needed.

If you used the information from above for Dayton, Ohio you should obtain

$$\text{watts of solar panels needed} = \frac{750\text{K}WH}{30} \div (12.82) \times 1.15 = \frac{750{,}000WH}{30} \div (12.82) \times 1.15 = 2242.6W$$

According to Northern Arizona Wind and Sun, the average cost of installation of solar panels is $7/watt (if you do it yourself) or $9/watt by professional. These prices include panels, mounts, inverters, wire, mounts, and other hardware but do not include inspections, permits, or extra meters by the electric company.

So for our solar powered home in Dayton, Ohio will total $7(2242.6) = \$15698.137$ if we do it ourselves and $9(2242.6) = \$20183.31$ if we have a professional install it, but this does not include any appliance upgrades.

2. (Optional) Determine which appliances are worth replacing.
Efficient appliances are recommended to cut energy usage. Are their appliances that are worth converting to solar power? Explain your reasoning.

www.solarhome.org has an extensive list of efficient appliances. Students can explore different appliances and specifics on these appliances to determine which would be worth replacing in their home.

Solar water heaters can return around $40 per month on a monthly electric bill. Students should strongly consider these up front costs which can be reduced through incentive and rebate plans discussed in the next section.

Answers for this question may vary based on the routine and usage of these appliances from household to household.

3. Find incentive plans and rebates offered by Federal, state, and local agencies for converting to solar power.
The website www.dsireusa.org provides a list of Federal, state, and local rebates and tax incentives for your area that can reduce the cost up to 50%. Click on Ohio and See All Summaries to get a list of all incentives and rebates with a relatively small summary.

Students can select different incentives and rebates to reduce their initial cost and increase their savings. Many incentives and rebates are listed. Some only apply to businesses or rural development, but there are a number of incentives and rebates for homeowners.

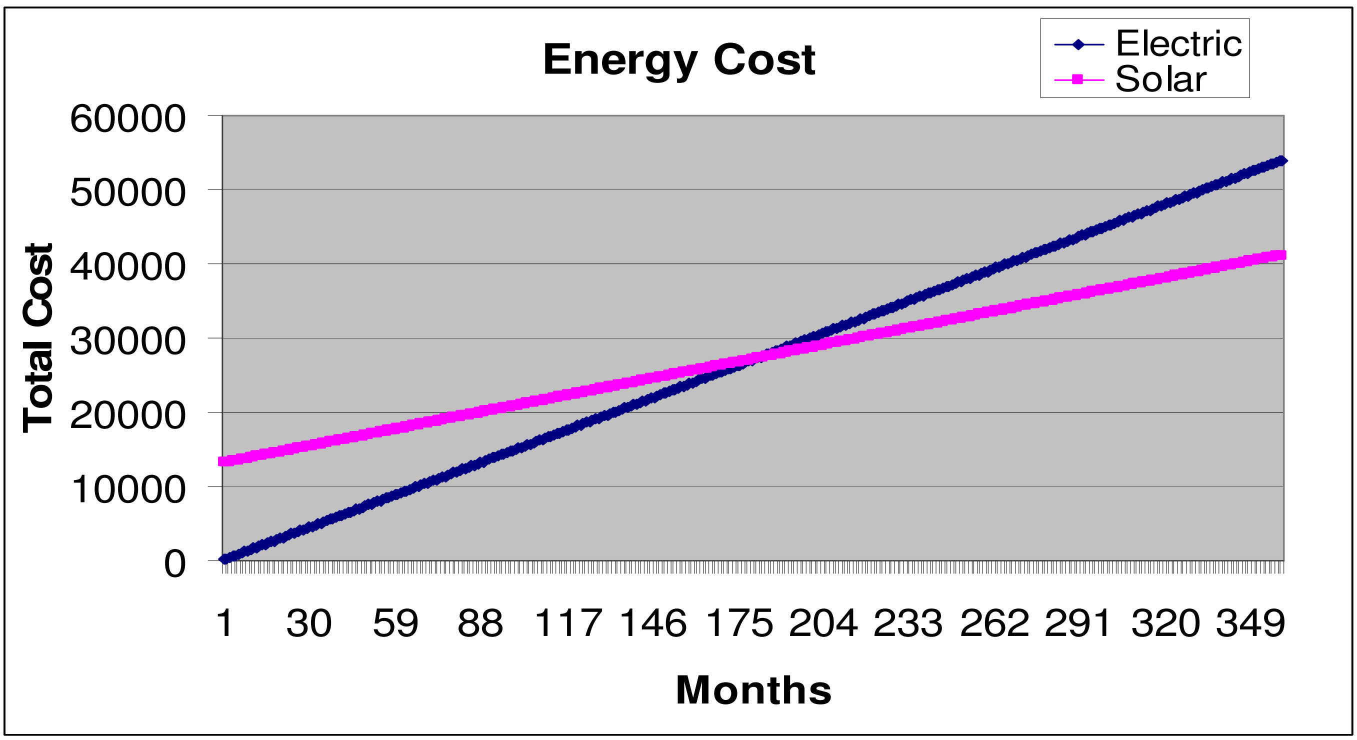
For example The Sierra Club, Green Energy Ohio is giving a rebate of $30 per kBtu/day with a maximum of $2,400 for solar water heating. This could factor into the whether students purchase an energy efficient water heater. A State Grant Program is listed that could possibly pick up 50% of the cost of the system.

Students should investigate the effect on the value of the home after installing a solar power system. Most websites will say that for every $1000 saved annually on an electric bill, the home value will increase $20,000.

4. How long will it take for you to see savings if you invest in a solar powering system for a home with an average monthly electricity usage of 750 KWH?
One way to determine this would be to graph the cost of not switching to solar and compare it to the long term cost of converting to solar. This could be represented on a cumulative line graph.

According to the Ohio utility rate survey found earlier the average monthly utility bill for residents in Dayton, Ohio is $150.06. The cumulative cost could be represented by the cost would be $y = 150.06x$ where x is the number of months. This is a simple model of the average monthly billing. For more advanced students, students should investigate the 3-7% annual increase in the average electric bill. This becomes more difficult to model but is a more realistic model.

Let's assume that we receive the State Grant Program picks up 50% of the cost of the system. Our start up cost will then be $0.5(20183.31) = 10091.65$. Students should explore electricity cost savings using a 2.2 kW solar energy system. Most websites will estimate savings to be around $32 per month. If students install a solar water heater they can save an additional $40 per month. With certain incentives this may only add $3000 to the initial cost. With the solar panels and the new water heater the monthly electric bill will then be $\$150.06 - \$72 = \$78.06$. Considering all of this, the cumulative solar power cost could then be represented by $y = 78.06x + 13091.65$.



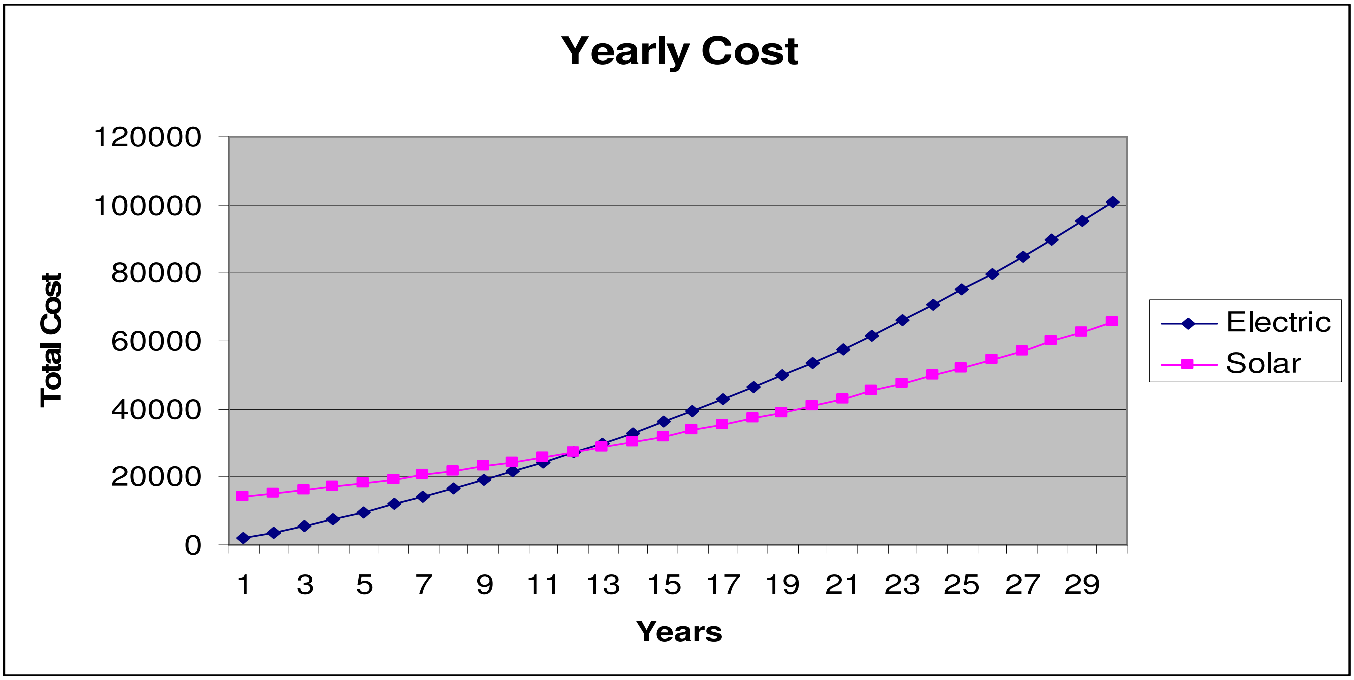
According to this model, in the 181st month the solar power system will have paid for itself and would begin saving money monthly over the electric system.

Modeling the situation with the 3-7% annual increase in the electric bill would probably be done more easily considering the cost in terms of years. This can be done by multiplying the average monthly bill by 12. Using our example, $12(150.06) = 1800.72$. Our annual bill with the solar power system would be $12(78.06) = 936.72$. To model the electric bill without changing the system, students will have to account for the percent increase (let's assume that it is 4% for this model) which they could do in the following way

$$y = 1800.72 + 1800.72(1.04) + 1800.72(1.04)^2 + 1800.72(1.04)^3 + \ldots = 1800.72\left(\frac{1-1.04^x}{1-1.04}\right)$$. This model is based off the formula for the sum of a geometric series.

For the solar powered system, the cumulative cost model would be

$$y = 13091.65 + 936.72 + 936.72(1.04) + 936.72(1.04)^2 + 936.72(1.04)^3 + \ldots$$
$$= 13091.65 + 936.72\left(\frac{1-1.04^x}{1-1.04}\right)$$



In this model students can see that in year 12 the solar powered system will start saving them money.

It is important to note that many states will allow home owners with very efficient systems that yield a surplus of energy to sell their surplus back to the energy companies. This is another item for students to consider.

B. Revisiting the Main Question
Is an investment in a solar power system for your home worth it? Explain your reasoning.

The answer to this question can vary. Students can base their decision on the amount of time they believe that they will occupy the home, their sense of responsibility to the environment, initial financial concerns, or various other issues.

Long term, converting to solar power will save the home owner money, increase their property value without increasing property tax because these improvements are tax exempt, and will potentially bring in income if their system is highly efficient and their state has a policy for buying back their surplus.

The Dayton Regional STEM Center Science, Technology, Engineering and Math

Post-Activity Rubric

Distinguished - Student Engineering Team (SET) presents design information and defense of design choices in logical, interesting sequence which audience can follow. The Team's model home reaches and maintains a warm, comfortable* temperature. The team selects quantifiable experimental data to defend their design choices. The quantifiable factors and/or units chosen for the design are effectively displayed with graphs with correctly labeled axes and tables. Data is presented to the reader in text as well as graphic forms. All components of the display have appropriate labels with correct units. All members of the Student Engineering Team contribute to the Trade Show presentation.

Excellent - Student Engineering Team (SET) presents design information and defense of design choices in logical, interesting sequence which audience can follow. The Team's model home reaches but does not maintain a warm, comfortable* temperature. The Team has ideas about the reasons for not maintaining the warm, comfortable temperature in the model. Although the temperature is not maintained, the students demonstrate an understanding of contributing concepts. The team selects quantifiable experimental data to defend their design choices. The quantifiable factors and/or units chosen for the design are effectively displayed with graphs with correctly labeled axes and tables. Data is presented to the reader in text as well as graphic forms. All components of the display have appropriate labels with correct units. All members of the Student Engineering Team contribute to the Trade Show presentation.

Satisfactory - Student Engineering Team (SET) presents design information and defense of design choices in logical, interesting sequence which audience can follow. The Team's model home reaches but does not maintains a warm, comfortable* temperature. The team selects quantifiable experimental data to defend their design choices. The Team explains possible reasons for not being able to maintain the warm, comfortable temperature in the model but only partially explains their ideas. The quantifiable factors and/or units chosen for the design are effectively displayed with graphs with correctly labeled axes and tables. Data are not presented to the reader in text as well as graphic forms. Most components of the display have appropriate labels with correct units. All members of the Student Engineering Team contribute to the Trade Show presentation.

Needs Improvement - Student Engineering Team (SET) presents design information and defense of design choices in logical, interesting sequence which audience can follow. The Team's model home does not reach or maintain a warm, comfortable* temperature. The Team can not explain possible reasons for not being able to reach and maintain the warm, comfortable temperature in the model. The team selects some quantifiable experimental data to defend their design choices. The quantifiable factors and/or units chosen for the design are not effectively displayed with graphs with correctly labeled axes and tables. Data is not presented to the reader in text as well as graphic forms. All tables or graphs do not have appropriate labels with correct units. Not all members of the Student Engineering Team contribute to the Trade Show presentation. The Team needs to reflect on work completed and look for ways to improve their final product.

** Comfortable condition will be a temperature determined by the class prior to design.*

The Warm Home Model is an authentic assessment for the Warm Home Solar Style unit. Point value for each category may be determined by teacher.

Pre-Test / Post-Test

1. Electricity is provided when photons of light strike a solar cell and _____ are freed from the atom.
    a. neutrons
    b. protons
    c. electrons

2. Most of the electricity in the United States is generated from
    a. wind power.
    b. nuclear power plants.
    c. coal power plants.
    d. hydroelectric power plants.
    e. solar power.

3. What is a photovoltaic array?
    a. Camera equipment
    b. Solar cells in a group
    c. Computer software
    d. A meter to measure electricity

4. List at least two appliances in your home, school, or neighborhood that have a photovoltaic cell or array on them. *Answers may vary but could include calculators, watches, and lights.*

5. What are the advantages of solar electricity over electricity generated from fossil fuels or nuclear fuels (list at least two)? *Solar energy is a clean, renewable resource.*

6. List at least four problems or disadvantages of solar electricity. *Answers may vary. Storage of solar energy can be a problem. Other disadvantages include no sunlight available at night and clouds or dust blocking the sun. Location of the home may also be a problem. You might need a back-up system to supply power for your house.*

7. Identify three major parts of a solar electric generating system. *Solar cell array, battery bank, inverter.*

8. If you were designing a solar electric system for your home, identify at least four variables you would need to consider. *Answers may vary and include day length; orientation to sun; power needs; average amount of sunlight; clouds, buildings, or trees blocking the sun; collector; etc.*

9. What type of solar energy would be most cost effective for heating a home? Why? *Passive solar energy is often used to heat homes because it is more efficient and solar electric systems can be expensive.*

10. What is the most important form of energy on Earth? Justify your answer. *Solar Energy. Life on Earth is dependent on the sun.*

Pre-Test / Post-Test Rubric

Q #1	Correct multiple choice response = C	1 point
Q #2	Correct multiple choice response = C	1 point
Q #3	Correct multiple choice response = B	1 point
Q #4	Provide examples of solar powered appliances – min. of 2	2 points
Q #5	List advantages of solar-generated electricity over others – min. of 2	2 points
Q #6	List disadvantages of solar-generated electricity over others – min. of 4	4 points
Q #7	List at least 3 of the following: solar cell, solar array, battery bank, and inverter	3 points
Q #8	Identify at least 4 of the following: day length; orientation to sun; power needs; average amount of sunlight; objects blocking the sun; or collector. Other responses need to be verified for correctness.	4 points
Q #9	Identify passive solar energy as the most cost effective for 1 point and the explanation is worth the other point.	2 points
Q #10	Correct response is Solar Energy for 1 point. Justification of answer is worth the other point.	2 points
		22 poss

Technology Connection

The **ADISC** Model of technology created by ITEL

Integration Model	***Application Description***
Technology that supports students and teachers in **adjusting, adapting, or augmenting** teaching and learning to meet the needs of individual learners or groups of learners	HowStuffWorks Video "Heat: Solar Energy" HowStuffWorks Video "Solar Farm" HowStuffWorks Video "Solar Panel Manufacturing" HowStuffWorks Video "Solar Panel Factory" HowStuffWorks Video "Invention Nation: Solar Panels" HowStuffWorks Video "Solar Power Comeback" HowStuffWorks Video "Energy: Solar Energy"
Technology that supports students and teachers in **dealing effectively with data**, including data management, manipulation, and display	MS Excel; Fluke (or other brand of multi-meter) online tutorial

Technology that supports students and teachers in **simulating** real world phenomena including the modeling of physical, social, economic, and mathematical relationships	Refer to attached video of a solar home.

Interdisciplinary Connection

Many skills can be developed and strengthened in this unit about solar energy. Students have the opportunity to use academic skills for written expression, mathematics, and science while working on team building skills.

Home Connection

Students could ask their parents about the heating system used in their homes.

Students can also ask parents to help them define ways that passive solar energy is used in their homes.

Students may even be able to encourage their families to make their own homes warm and comfortable solar style.

Differentiated Instruction

Collaborative Learning Groups: Organize student groups with a variety of learners. Each group member should have a job or position in which they can be successful. Divide labs and assignments into smaller segments that are more manageable for students with learning challenges.

Extension

If you were designing a school, how could you use your knowledge about solar energy in your school design?

Students should use drawings, a narrative, and an oral explanation to address the question.

Career Connection

Environmental Scientist or Environmental Engineer

Additional Resources

Resources:	***Purpose and Application:***
http://www.fsec.ucf.edu/en/education/k-12/curricula/use/index.htm	Florida Solar Energy Center
http://www.energyquest.ca.gov/story/chapter15.html	The Energy Story
http://www.globallearningnj.org/index.htm	Global Learning Inc
http://videos.howstuffworks.com/search.php?terms=solar+energy+power+storage&media=video&x=37&y=16	How Stuff Works

http://www.sunwindsolar.com/a_solar/solar_energy_links.html	Solar Energy Links from SunWind
http://www.planete-energies.com/site/en/homepage.html	Planete-energies.com
http://www.re-energy.ca/t-i_solarelectricity.html	Alternative energy

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Teacher Reflections

- Were students focused and on task throughout the lesson? *Insert answer here.*
- If not, what improvements could be made the next time this lesson is used? *Insert answer here.*
- Were the students led too much in the lesson or did they need more guidance? *Insert answer here.*
- Did the students learn what they were supposed to learn? *Insert answer here.*
- How do you know? *Insert answer here.*
- How did students demonstrate that they were actively learning? *Insert answer here.*
- Did you find it necessary to make any adjustments during the lesson? *Insert answer here.*
- What were they? *Insert answer here.*
- Did the materials that the students were using affect classroom behavior or management? *Insert answer here.*
- What were some of the problems students encountered when using the …? *Insert answer here.*
- Are there better items that can be used next time? *Insert answer here.*
- Which ones worked particularly well? *Insert answer here.*

Additional Comments