Solar Technology Curricula

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REFERENCE PAGES

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OHSU-EP-1517

Introduction

Sunlight is a renewable source of energy for Earth. The demand for cleaner energy sources and the development of strategies to harness the sun's energy has led to an explosion of solar technology applications worldwide. In 2013 Ohio Sea Grant's Stone Laboratory - the nation's oldest freshwater biological research station - installed both solar thermal and photovoltaic solar panel systems throughout its facility to reduce energy consumption. These solar technologies are generating over 30,000 kWh annually and offset Stone Laboratory's carbon footprint by more than 96,000 lbs in their first three years of installment.

The Solar Technology Curriculum offers teachers a blended approach to instruction; Nearpod presentions (***www.nearpod.com*** or the free app) utilize a highly engaging content delivery application, allowing students to interact directly with background knowledge and lessons while providing real-time formative assessment. Teachers can create a free account and generate session codes used to administer Nearpod lessons to students. Ohio Sea Grant's Solar Technology Curriculum is available in the Nearpod store by searching "Ohio Sea Grant Solar Technology."

The four lessons are built around Bybee's (1978) 5 E Learning Cycle (engage, explore, explain, elaborate, evaluate) and incorporate multiple science and engineering practices outlined in the Next Generation Science Standards (2013). Students have the opportunity to design investigations, analyze and interpret data, and communicate understanding through the use of models. The lessons are written using a structured or guided inquiry approach which can easily be adapted to meet the needs of higher- or lower-level learners. The teacher materials incorporate a variety of instructional strategies, contain suggestions for formative and summative assessment, and are accompanied by student-friendly, ready-to-print handouts.

Understanding the Mechanics of Solar Technology

Teacher Activity

BACKGROUND

Though the term "technology" often has the connotation of being sophisticated and complex, solar technology can actually be quite simple. Light energy can be converted through a series of transformations into mechanical energy. So how does this process work?

OBJECTIVES

In this activity, students will investigate the factors that influence the speed and pattern of movement in simple solar toys. After hypothesizing the internal mechanism that moves the toy, students will dissect the toy to further examine its inner workings and determine the types of energy transformations that occur.

After completing this investigation, students will be able to:

- Explain the effects of various factors on the functioning of a solar toy.
- Describe the mechanism of how a solar toy works.
- Identify the types of energy transformations that occur in a solar toy.

GRADE LEVELS – 7-12 Science

TIME REQUIRED – 2 class periods (one part each day)

MATERIALS PER STUDENT OR GROUP

- simple solar toy – flower, animal, plane, etc. (often found at a dollar store)
- small LED flashlight
- forceps
- other materials that may be involved in student-designed investigations: timer, calculator, ruler, colored gel sheets (found at craft stores or available online)

* *It is suggested that students use a pencil to make drawings and add labels. One additional color (or even a pen) may be helpful to color-code labels.*

* *The quality of the solar toys dictates how long they can be reused. Field testing results suggest that basic solar toys can be reassembled and reused 3-5 times before needing to be replaced; however, that range will vary depending on the grade level of the student and their care of the toy.*

ALIGNMENT

Next Generation Science Standards

DCI:	Conservation of Energy and Energy Transfer (PS3.B)
DCI:	Relationship between Energy and Forces (PS3.C)
SEP:	Planning and Carrying Out Investigations
CC:	Energy and Matter

Energy Literacy Principles

#1.1, 1.3, 1.4, 1.5	Energy is a physical quantity that follows precise natural laws.
#4.1	Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

This solar technology curriculum was funded by an OSU CARES grant in partnership with the following Ohio State University departments: Ohio Sea Grant and Stone Laboratory; Extension and Energize Ohio Signature Program; Facilities, Operations, and Development; and the Office of Energy and Environment.

ALIGNMENT (*cont'd*)

Ohio's Model Science Curriculum

Grade 7 Physical Science:	Energy can be transformed or transferred but is never lost.
High School Physics:	Conservation of Energy
High School Environmental Science:	Earth's Resources

PRIOR TO THE LESSON

1. Print and cut apart enough investigative questions for each group to have one. Some groups may have the same question if there are more than 9 groups. These can be reused for multiple classes or multiple years.
2. Print enough Solar Mechanics Terminology Lists for each group to have one. These can be reused for multiple classes or multiple years.
3. Compile sets of materials. Each group should have a solar toy, flashlight, and forceps. Other materials can be placed in a central location for students to use as needed.

Lesson

ENGAGE

Show the following video (***go.osu.edu/solartoys***) of dancing solar toys as students enter the room and get ready for class.

EXPLORE & EXPLAIN

Students should have prior understanding of types of energy and transformations. A quick poll or quiz using Nearpod can easily elicit students' background knowledge.

PART 1: TO WHAT EXTENT DO VARIOUS FACTORS AFFECT THE MOVEMENT OF A SOLAR TOY?

1. Have each group draw an investigative question out of a bowl.
2. Students will design an experiment and collect data to answer their assigned question.
3. Use the instructions on the student page to guide students through the process of designing and carrying out their own investigation.
4. Have student groups share their findings with the class before moving on to Part 2.

PART 2: HOW DO THE COMPONENTS OF A SOLAR TOY MAKE IT MOVE?

1. Now that students have investigated what factors affect the movement of a solar toy, discuss the types of energy transformations that might be occurring within it.
2. Students then hypothesize how the internal components of the toy might be arranged. They are asked to label the parts they draw to the best of their ability. At this point, the emphasis is on the function of the part rather than the technical name. Example: "This piece must hold the electricity from the solar panel."

Teacher's Note:
This activity is designed as a minimally guided or open inquiry investigation. It can be modified to be a structured inquiry lesson. Teachers can provide a set procedure for students to follow or a data table for students to use if scaffolding or additional structure is needed.

✓ This is a checkpoint for formative assessment; teachers should look at students' drawings and initial the paper before students proceed.

3. Next students confirm or revise their hypotheses by carefully opening the solar toy to see the components and their arrangement. There is space for the student to draw what they actually see. This time, however, students are asked to assign labels to the components even if they are not positive of the terms or what they mean. Encourage students to write labels in pencil.

   * *The teacher can perform the solar toy "dissection" as a demonstration using a document camera projecting the process so all students can see. Note, however, that this strategy will limit the exploration and conceptual understanding by students.*

✓ This is a checkpoint for formative assessment; teachers should look at students' drawings and labels and initial the paper before providing students with the Solar Mechanics Terminology List.

4. Once students have the terminology list they can correct labels as needed. Using a different color writing utensil, they can also identify the energy transformations that are happening inside the toy.

ELABORATE
Successful completion of this activity prepares students to apply the acquired knowledge and skills in future activities where they must design technological/engineering solutions using science concepts (highest level of cognitive demand in Ohio's Model Science Curriculum). Many activities exist online that have students construct a car or creature that uses solar energy to produce movement.

Solar Kit Lessons: A compendium of solar energy resources for middle school students. ***www.nrel.gov/education/pdfs/nesea_solar_kit_lessons.pdf***

Solar Car Project: How to build a mini solar car with simple materials ***www.xof1.com/buildMiniSolarCar.php***

EVALUATE
Assessment tasks are built into the student page. Question 4 in Part 1 and questions 7 and 8 in Part 2 require students to demonstrate science knowledge (second highest level of cognitive demand in Ohio's Model Science Curriculum).

Selected Answers to Student Worksheet

PART 1
Answers will vary for all questions.

PART 2
1-6. Answers will vary.
7. light ➔ electric energy in photovoltaic cell, electric energy ➔ magnetic energy in voice coil, magnetic energy ➔ mechanical energy in magnet/pendulum
8. The solar toy moves when the photovoltaic cell is activated. The light energy is converted to electricity which is stored in the capacitor. The electrical board brings the wire from the photovoltaic cell in contact with the wire from the voice coil. Pulses of electric current then move down the voice coil (made of copper) creating a magnetic field. The pulses in the magnetic field pull the magnet toward the coil. The magnet is attached to a pendulum which moves the lever arms making the solar toy "dance."

FINAL QUESTIONS
1. Answers will vary, but the dependent variable will likely be the movement or speed of the solar toy.
2. F, E, D, A, C, B
3. Answers will vary.
4. No energy transformation is 100% efficient. Some energy will always be converted into heat.

SOURCE
Solar Energy Curriculum Consortium
Lead: Lyndsey Manzo, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Susan Bixler, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Kristen Fussell, Research Development and Grants Manager, Ohio Sea Grant and Stone Laboratory
Angela Greene, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Erin Monaco, Program Assistant, Ohio Sea Grant and Stone Laboratory
Eric Romich, OSU Extension Field Specialist, Energy Development
Kristin Stanford, Education & Outreach Coordinator, Ohio Sea Grant and Stone Laboratory

Solar Mechanics Terminology List

Component	Function
Capacitor	a two-terminal electrical component used to temporarily store electrical energy
Electrical board	backboard for holding wires close to each other
Magnet	attracted to a magnetic field thus moving the level arm to which it is attached
Pendulum	weight suspended from a pivot so that it can swing freely
Photovoltaic (PV) cell	device that converts energy from light directly into electricity
Voice coil	provides a conduit for electrical energy; a magnetic field is generated along its axis

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Investigative Question 1:
How does distance of light affect the movement of the toy?

Investigative Question 2:
How does light intensity affect the movement of the toy?

Investigative Question 3:
How does the angle of light affect the movement of the toy?

Investigative Question 4:
How does the color of light affect the movement of the toy?

Investigative Question 5:
What color of light results in the fastest movement of the toy?

Investigative Question 6:
What angle of light results in the fastest movement of the toy?

Investigative Question 7:
What distance of light results in the fastest movement of the toy?

Investigative Question 8:
What intensity of light results in the fastest movement of the toy?

Investigative Question 9:
Does natural light or artificial light have a greater effect
on the movement of the toy?

Understanding the Mechanics of Solar Technology

Student Activity

Name ____

BACKGROUND

Though the term “technology” often has the connotation of being sophisticated and complex, solar technology can actually be quite simple. Light energy can be converted through a series of transformations into mechanical energy. So how does this process work?

In this activity, you will investigate the factors that influence the speed and pattern of movement in simple solar toys. After hypothesizing the internal mechanism that moves the toy, you will dissect the toy further examine its inner workings and determine the types of energy transformations that occur.

PROCEDURE

PART 1: TO WHAT EXTENT DO VARIOUS FACTORS AFFECT THE MOVEMENT OF A SOLAR TOY?

1. Choose an investigative question from your teacher. Write your question in the space below.

2. Use the space below to write the procedure you will use to collect data to answer the question.

   What variable is being tested in your experiment? ______________________________

3. What data will you collect? Use the space below to construct a data table.

   What variable is being measured in your experiment? ___________________________

4. Write a conclusion that answers the investigative question. Be sure to use evidence to justify your statement.

PART 2: HOW DO THE COMPONENTS OF A SOLAR TOY MAKE IT MOVE?

You've explored WHAT external factors affect solar toy movement, now hypothesize HOW it moves. What's the pathway from light to movement? Keep in mind that movement happens without plugging anything into an electrical outlet or flipping a switch.

1. Make a list of the possible energy transformations that are likely happening to make the toy move.

2. Draw what you envision the inside of the solar toy looks like. Label the components you draw by describing what they must do; don't feel like you have to know the proper names of the parts. Show your drawing to your teacher before proceeding.

   __________ teacher initials

3. Carefully begin to dissect the solar toy. Delicately remove the outer shell without disassembling the internal components. The forceps may help you move the tiny components.

4. Use this space to create a drawing of the pathway of components that ultimately make the toy move.

5. USING A PENCIL, label the drawing above with the following terms. Use your background knowledge and consider what the terms might mean to do your best job at labeling the drawing. Show your drawing and labels to your teacher before proceeding.

   capacitor **photovoltaic cell** **voice coil** **magnet** **electrical board** **pendulum**

   __________ teacher initials

6. Now that you know about the function of each component fix any labels that were originally incorrect.

7. Look back at the first question in this section. Now make a complete and accurate list of all the energy transformations that must happen to make the toy move.

8. Demonstrate your understanding by answering the original question:
   How do the components of a solar toy make it move?

   Write your answer as a complete paragraph that lists all of the components, discusses the components' functions, and identifies where energy transformations are occurring. Use your answers from questions 5-7 to help frame your paragraph.

Use good writing conventions as this is the most important part of the activity.

FINAL QUESTIONS

What makes a solar toy move?

1. Identify the variables in your investigation:

   Independent: ________________________________ Dependent: ________________________________

2. Match the components of a solar toy with its function

   ______ electrical board — a. transmits an electric current that creates a magnetic field

   ______ capacitor — b. moves a pendulum as it is attracted to a magnetic field

   ______ pendulum — c. converts light energy to electricity

   ______ voice coil — d. moves the "dancing" parts of a solar toy

   ______ photovoltaic cell — e. stores electrical energy

   ______ magnet — f. holds wires close together

3. Use this space to draw a diagram or flow chart of all the energy transformations that occurred to make the toy move. Be sure to label each type of energy in your drawing.

4. Are the energy transformations 100% efficient? Explain your answer.

Using Models to Investigate Solar Thermal Technology

Teacher Activity

BACKGROUND

Sunlight is an external, unlimited source of energy for Earth. Humans transfer and transform energy from the sun into forms useful for human endeavors that can be used in many ways. Energy from the sun traveling millions of miles through space transfers heat without direct contact. This is called radiant energy.

Figure 1: Solar thermal technology on the roof of Ohio State University's Stone Laboratory.

Solar thermal technology is one example of how the sun's energy might be collected, transformed, and used by humans. Solar thermal technology is based on a standard design: Energy from the sun is used to heat a fluid in tubes that is either pumped (active system) or driven by natural convection (passive system). The heat energy in the liquid can then be transferred to other systems through contact points.

Solar thermal technology is primarily used to heat water or spaces in homes and businesses. Solar thermal technology was added in 2014 to the roof of the Stone Laboratory dining hall to heat all water used for the cafeteria (Figure 1). What key features are necessary for efficient heating of water in solar thermal tubes?

The dining hall not only uses the most hot water on Gibraltar Island, especially when classes are in session, but is the location with the best light for a solar thermal project. Stone Laboratory has installed an Active Evacuation Tube System to heat water used in the dining hall. The sun heats a glycol filled tube, which exchanges heat to the hot water system (see step 1 below and diagram in Figure 2). There is no mixing of fluids. Heat exchange is through a metal-to-metal contact point located on the system. The solar collectors are made of parallel rows of transparent glass tubes. Inside each tube, a parabolic trough shaped metal reflector (Figure 3) absorbs solar energy and inhibits radiated heat loss. This design allows the sunlight to pass through the glass, but allows very little heat to escape. Air is removed and a vacuum is created in each of the tubes at the factory, which helps eliminate heat loss.

How does this system work?

Step 1 - Heat from the sun is collected by glycol filled tubes and transferred to the main tap water line. Glycol and water are in separate lines and never mix. The heat transfers through metal-to-metal contact points on the roof along the entire panel.

Step 2 - The heated water circulates through a storage tank in the dining hall where it warms several hundred gallons of water for use throughout the day.

Step 3 - Control sensors monitor the heat in the tank and will circulate the water until the desired temperature is reached. On warm sunny days, the water in the storage tank can be too hot to safely use. The temperature is lowered by stopping the flow of the water to the roof and adding cooler tap water into the storage tank.

Step 4 - On colder days or at night, electricity may be used to heat the water with a standard hot water tank.

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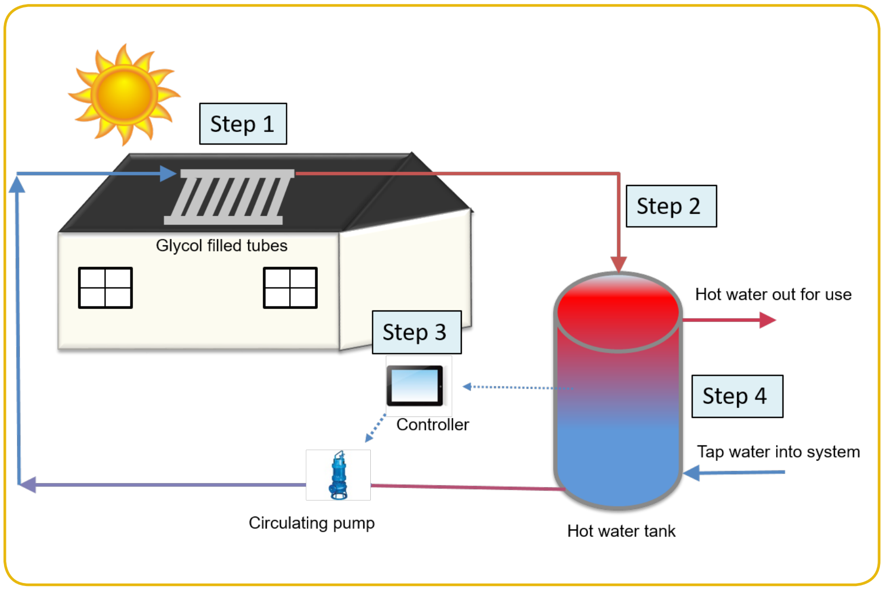


Figure 2: Diagram of the solar thermal technology used at Ohio State University's Stone Laboratory.

Figure 3: Images of the solar collection tubes on the roof of the dining hall. Each tube contains a glass outer tube and a parabolic trough shaped metal absorber tube attached to a fin. The fin is covered with a black coating that absorbs solar energy well and inhibits radiated heat loss.

OBJECTIVES

In this activity, students will learn about and build models of solar thermal tubes to determine the optimal design for the greatest heat transfer.

After completing this investigation, students will be able to:

- Identify and describe the function of key features in a solar thermal system.
- Explain the variables that increase the efficiency of solar thermal systems.

GRADE LEVELS – 7-12 Physical Science
TIME REQUIRED – Approximately 2 to 3 class periods
MATERIALS PER STUDENT OR GROUP

- 2 – 1oz clear glass bottles with lid
- 2 – 5/32" X 2" pieces of black windshield washer tubing
- wooden blocks or books
- room temperature tap water
- cold tap water
- reflective tape
- ruler
- safety goggles
- 2 – 8oz plastic water bottles with lids
- 1 or 2 - thermometers
- isopropyl alcohol
- hot tap water
- clear tape
- scissors
- heat resistant gloves or oven mitt
- student worksheet
- heat lamps with 120 Watt full spectrum plant bulb (number dependent on arrangement of bottles; can be eliminated if the investigation is conducted outside on a sunny day or in a classroom window with sun exposure). It is imperative that the bulb be a 120 Watt full spectrum plant bulb. This experiment does not work with a bulb that is not full spectrum, such as a reptile heat light.

ALIGNMENT

Next Generation Science Standards

DCI: Definition of Energy (PS3.A)
DCI: Conservation of Energy and Energy Transfer (PS3.B)
SEP: Developing and Using Models
SEP: Planning and Carrying Out Investigations
CC: Systems and Systems Models

Energy Literacy Principles

#1.1, 1.2, 1.3 Energy is a physical quantity that follows precise natural laws.
#2.2 Physical process on Earth are the result of energy flow through the Earth systems.
#4.1, 4.7 Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.
#5.3, 5.4 Energy decisions are influenced by economic, political, environmental, and social factors.

Ohio's Model Science Curriculum

Grade 7 Physical Science: Energy can be transformed through a variety of ways.
High School Environmental Science: Alternate Energy Sources and Efficiency

PRIOR TO THE LESSON

1. Print a copy of the Guide for Constructing a Solar Thermal Model for each group. These can be printed on cardstock or laminated to be used for multiple classes.
2. Print and cut apart the eight model designs (four for Part 1 and four for Part 2; place the slips of cardstock in a bowl). We suggest Parts 1 and 2 are done on separate days.
3. Determine an area where students will place models. Set up lamps so that all models will receive equal light.
4. Review the terms in the provided vocabulary list located in the reference documents to this curriculum.

Lesson

ENGAGE

1. Display the following questions that will promote thinking about the convenience of hot water. Some examples may include:
    a. Do you prefer to take hot or cold showers?
    b. How did people in the 1800s get hot water?
    c. How is water heated in your home?
    d. Do you ever run out of hot water in your home?

EXPLORE & EXPLAIN

1. Take students through the Nearpod Presentation *Exploring Solar Thermal Technology*. This interactive presentation will give students an overview of solar thermal heating systems and provide an example of how it's currently being used.
2. Student groups will then construct models of solar thermal systems and - as a class - investigate variables that maximize heat absorption.
    a) On Day 1 students will investigate variations in the liquid in the models.
    b) On Day 2 students will investigate variations in the structures of the models; the liquid will remain constant.
    c) Students should refer to the *Guide to Constructing a Solar Thermal Model* for the basic process of assembling all models.

Figure 4: Image of model set-up with two bottles. Feel free to place up to 4 bottles under each light set-up.

PART 1: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE LIQUID

3. Divide students into four groups. All groups will construct the same basic model in their two bottles (replicates), but the liquid of the glass bottle will differ for each group. Have one member from each group draw a piece of cardstock out of a bowl to determine the variable each group will investigate. Students will only be testing the liquids within the bottle and are not building a complete solar thermal model for Part 1. Students should average the results of the two replicates. Variables will include: isopropyl alcohol, room temperature tap water, hot tap water, and cold tap water.
4. Student groups then construct their assigned models. Remind students to work efficiently; they will need to take the temperature of the liquid inside the glass bottle prior to heating and again after the predetermined time under the full spectrum bulb. **They should work quickly to minimize heat loss or gain.**
5. When ready, have students place models under the lights. Use blocks of wood or books to prop models at a 35°-45° angle approximately 20-25 cm from the bulb (Figure 4).
6. Students should note the time they place the model under the light as each group may have a different starting time.
7. It is suggested to leave models under the light for 10 minutes. Models can be left longer, but keep in mind that the temperatures of the liquids can get very hot if left under the light for more than 20 minutes.
8. At the end of a predetermined interval, students should note the ending time. Using heat resistant gloves or an oven mitt, students will carefully remove the glass bottle, remove the cap, and determine the final temperature of the liquid inside the glass bottle and record their temperatures in the data table.
9. Students should then average the results of the temperatures of their liquid from their replicate bottles and record their temperatures on the data table.
10. Compile group data for the entire class. Students should then use the collective data to determine the most effective liquid for heat transfer.

CAUTION

This procedure heats water very quickly causing the water to become extremely hot when using the plant bulb model. Several hours of exposure to a 120-Watt plant bulb can raise the water temperatures to more than 100°C.

PART 2: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE MODEL DESIGN

1. Review the findings from Part 1 with students.
2. Ask the question, "During the first experiment, we found that the liquid that was most efficient at heating up quickly was ________________. Today we are going to try to improve upon our results to gain the most efficient solar thermal model possible."
3. All groups will use the same liquid in the bottles (as determined previously). One member from each group will draw a slip of cardstock out of a bowl to determine the structural variable each group will investigate. Structural model variables include adding:
   a) liquid-filled glass bottles enclosed in plastic water bottles
   b) two strips of black tubing inside the liquid-filled glass bottles enclosed in plastic water bottles
   c) liquid-filled glass bottles enclosed in plastic water bottles containing reflective tape
   d) two strips of black tubing inside the liquid-filled glass bottles enclosed in plastic water bottles containing reflective tape
4. Students should place their bottles under the full spectrum light and note the time, as each group may have a different starting time.
5. It is suggested to leave models under the light for 10 to 15 minutes. Models can be left longer, but keep in mind that the temperatures of the liquid can get very hot if left under the light for more than 20 minutes.
6. At the end of a predetermined interval, students should note the ending time. Using heat resistant gloves or an oven mitt, students carefully remove the glass bottle from the plastic encasement, remove the cap, and determine the final temperature of the liquid inside the glass bottle.

CAUTION

This procedure heats water very quickly causing the water to become extremely hot when using the plant bulb model. Several hours of exposure to a 120-Watt plant bulb can raise the water temperatures to more than 100°C.

7. Students should average the results of the temperatures of their liquid from the replicate bottles.
8. Compile group data for the entire class. Students should then use the collective data to determine the most effective structural model for heat transfer.
9. Students can work individually or with their groups to answer analysis and conclusion questions.

ANALYSIS, INTERPRETATION AND APPLICATION

Sample Answers to Student Worksheet Questions *Please note that answers may differ based on experimental findings.*

PART 1: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE LIQUID

1. Answers may vary based on experimental results, but the warm/hot water should have demonstrated the least change in temperature; cold water should have demonstrated the most change in temperature. This is because the hot water is already beginning at a higher temperature than the room temperature or cold water. The rate of heating of a liquid depends on the magnitude of the temperature difference between the liquid and its surroundings. As a result, cold water will be absorbing heat faster while it is still cold; once it gets up to the temperature of hot water, the heating rate slows down and becomes the same as the hot water.
2. Answers may vary based on experimental results, but the alcohol should have demonstrated the greatest change in temperature. This is because isopropyl alcohol has a lower heat capacity than water; that is, it takes less energy to raise the temperature of isopropyl alcohol (2.68 J/gK) than it does water (4.18 J/gK).
3. The room temperature water could be considered the control trial. The different temperatures of the water and the use of the alcohol (a different liquid) are considered to be variations of the room temperature water.
4. The alcohol represented glycol or another form of antifreeze. Because water can't be used in climates with freezing temperatures, alcohol – with a lower freezing point than water – was used to replicate glycol. This enabled an investigation of a non-water liquid.
5. The alcohol should have demonstrated the greatest change in temperature. This is because isopropyl alcohol has a lower heat capacity than water; that is, it takes less energy to raise the temperature of isopropyl alcohol (2.68 J/gK) than it does water (4.18 J/gK). Ensure students have cited evidence in support of their answer.
6. Answers will vary based on student hypotheses.

PART 2: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE MODEL DESIGN

1. Glass bottle with rubber tubing, an outer plastic bottle enclosure, and a parabolic reflective tape strip
2. Glass bottle with an outer plastic bottle enclosure
3. Glass bottle with an outer plastic bottle enclosure - This variable was held constant. The other three models were variations and extensions of this design.
4. The glass bottles with rubber tubing enclosed in an outer plastic bottle with reflective tape should have demonstrated the greatest temperature change. The rationale for these three factors is explained in the answers to questions 5,6, and 7.
5. Some light will pass through the glass bottle and its contents; the silver tape reflects light that has passed through the bottle, thus increasing the amount of solar energy absorbed inside the glass bottle. (Mimics the parabolic trough in the solar thermal tubes).
6. The black tubing behaves similarly to the black coating in the solar thermal tube that absorbs solar energy.
7. Not only did the plastic bottle protect the glass bottle, but the space between the two bottles created an insulating layer to reduce heat loss from the glass bottle.
8. Answers will vary.
9. Answers may vary, but the glass bottle with rubber tubing , an outer plastic bottle enclosure, and a reflective tape parabolic strip should have been the most effective model. This design most closely resembles the system components at Stone Lab.
10. Answers will vary.

ELABORATE

This exercise provides an excellent opportunity to discuss sample size, steps in an investigative process, as well as the reliability and accuracy of data.

Conceptual knowledge gained from this investigation can be transferred to other disciplines. Sample math problems are provided here:

11. Stone Lab's Solar Thermal Tubes heated 722 gallons of water on a summer day in July. If 1 US gallon of water = 8.35 pounds of water in pound weight, how many pounds of water were heated?
12. The temperature of ground water in Ohio below approximately ten feet is 50°F year-round and the final temperature of the water coming out of the solar thermal system is 110°F. A BTU is the amount of work needed to raise the temperature of one pound of water by one degree Fahrenheit. How many BTU's were produced on that July summer day by the solar thermal instillation? (Hint: amount of water heated x change in temperature = BTU's produced)
13. Electricity is measured in kilowatt-hours (kWh). One kWh of energy is equal to 1000 watt hours and will power a 100 watt light bulb for 10 hours. If 1 BTU = 0.000293071 Kilowatt Hours (kWh), how many kilowatt hours of energy was produced at Stone Lab on that particular July day by our solar thermal instillation?

Answers

11\. 722 gallons of water X 8.35 lbs. = 6028.7 lbs. of water (6,029 lbs.)

12\. 6,029 lbs. x a change in 60°F = 361,740 BTU

13\. 361,740 BTU x 0.000293071 kWh = 106.02 kWh

EVALUATE

The following are sample questions that teachers may choose to incorporate into formative or summative assessments:

1. Can solar thermal technology be used in locations at higher latitudes? How would use of a solar thermal system differ as the location latitude increases (as you move closer to the poles)?
2. An engineer designs solar thermal systems for one client in Phoenix, Arizona and one client in Big Sky, Montana. Would a single design work for both clients? What design and construction factors would the engineer need to consider for each client?
3. How could you design a simple home solar water heater?

SOURCE

Solar Energy Curriculum Consortium

Lead: Susan Bixler, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Kristen Fussell, Research Development and Grants Manager, Ohio Sea Grant and Stone Laboratory
Angela Greene, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Lyndsey Manzo, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Erin Monaco, Program Assistant, Ohio Sea Grant and Stone Laboratory
Eric Romich, OSU Extension Field Specialist, Energy Development
Kristin Stanford, Education & Outreach Coordinator, Ohio Sea Grant and Stone Laboratory

cold tap water

outer plastic bottle

room temperature water

outer plastic bottle with black tubing

hot tap water

outer plastic bottle with reflective tape

isopropyl alcohol

outer plastic bottle with black tubing and reflective tape

Using Models to Investigate Solar Thermal Technology
Guide for Constructing a Solar Thermal Model

Each group should collect the necessary materials:

- 2 – 1oz clear glass bottles with lid
- thermometer
- heat lamps with 120 Watt full spectrum plant bulb
- wooden blocks or books
- heat resistant gloves or oven mitt
- student worksheet
- 2 – 8oz plastic water bottles with lids
- clear tape
- scissors
- ruler
- safety goggles

Supplies below depend on your assigned treatment:

- isopropyl alcohol
- hot tap water
- 2 – 5/32" X 2" pieces of black windshield washer tubing
- room temperature tap water
- cold tap water
- reflective tape

PART 1: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE LIQUID

1. All groups will construct the same model with both glass bottles, but the liquid of the glass bottle will differ for each group. Liquids will include isopropyl alcohol, room temperature water, hot tap water, and cold tap water.

> **WORK EFFICIENTLY!**
>
> **Read steps 2-5 before setting up the investigation. It's important to work quickly to accurately determine temperature changes and minimize heat loss.**

2. Fill both bottles with the assigned liquid to where the neck of the bottle begins.
3. Determine the starting temperature of the contents inside the glass bottles and then cap the bottle. Record the starting temperature on the data sheet.
4. Place both models under the lights. Use blocks of wood or books to prop box of models at a 35°- 45° angle approximately 20-25 cm from the bulb for a predetermined time set by your teacher.
5. Take the temperature of the liquid inside the glass bottle prior to heating and again after the predetermined time under the full spectrum bulb. Work quickly to minimize heat loss or gain. At the end of the time interval determined by your teacher, use heat resistant gloves or an oven mitt to carefully remove the glass bottle, remove the cap, and determine the final temperature of the contents inside the glass bottle. Note the time the model was removed from under the light.
6. Record and average the two ending temperatures of both bottles on the data sheet provided.

PART 2: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE MODEL DESIGN

1. Regroup into the four groups from your Part 1 Lab.
2. You will fill both bottles with the liquid that the class determined to be most efficient from your Part 1 Lab. Do not fill your bottle until instructed to do so.
3. Have one member from your group draw a slip of paper out of a bowl to determine the structure of the solar thermal model that your group will be build.
   The structural models will include:
   - Glass bottle with an outer plastic bottle enclosure
   - Glass bottle with an outer plastic bottle enclosure with a reflective tape strip
   - Glass bottle with rubber tubing and an outer plastic bottle enclosure
   - Glass bottle with rubber tubing, an outer plastic bottle enclosure, and a reflective tape strip

4. Measure up 2.5 cm from the bottom of an 8 oz plastic water bottle. Carefully puncture the bottle with the tip of the scissors and make a circular cut. You will be using both parts of the bottle.
5. If you have been instructed to add parabolic reflective tape, measure and cut 10.2 cm of silver reflective tape; place it onto one half of the inside of the top piece of the plastic bottle. (Figure 1)
6. If your model requires rubber tubing, place 2 strips of 5/32" X 2" black windshield washer tubing lengthwise and next to each other into an empty glass bottle.

Figure 1

WORK EFFICIENTLY!

Read steps 7-10 before setting up the investigation. It's important to work quickly to accurately determine temperature changes and minimize heat loss. You may want to practice assembling the glass bottle inside of the water bottle before actually running the trials.

Figure 2

7. Fill the bottles with the pre-determined liquid to where the neck of the bottle begins (Figure 2). Determine the starting temperatures of the liquid in the bottles and cap the bottles.
8. Attach a loop of silver tape to the top of the bottle's cap to help stabilize the glass bottle. Place the bottle, cap side down, into the neck of the plastic bottle. Stabilize the bottle in an upright position making sure the reflective tape and black windshield washer tubing (if applicable) are facing up (Figure 3).
9. Slightly squeeze the bottom piece of the plastic bottles so that it can be put inside the top portion of the plastic bottle. Press it down until it is touching the glass bottles. Use clear tape to seal completely around the seam where the two plastic bottle pieces are now joined (Figure 4).
10. Place both models under the lights. Use blocks of wood or books to prop the box of models at a 35°- 45° angle approximately 20-25 cm from the bulb for a predetermined time.
11. At the end of the time interval determined by your teacher, use heat resistant gloves or an oven mitt to carefully remove the glass bottle from the plastic encasement, remove the cap, and determine the final temperature of the contents inside each glass bottle. Note the time the model was removed from under the light.
12. Record and average the ending temperatures of both bottles on the data sheet provided.

Figure 3

Figure 4

Using Models to Investigate Solar Thermal Technology

Name ______________________________

Student Activity

BACKGROUND

Sunlight is an external, unlimited source of energy for Earth. Humans transfer and transform energy from the sun into forms useful for human endeavors that can be used in many ways. Energy from the sun traveling millions of miles through space transfers heat without direct contact. This is called radiant energy.

Solar thermal technology is one example of how the sun's energy might be collected, transformed, and used by humans. Solar thermal technology is based on a standard design: Energy from the sun is used to heat a fluid in tubes that is either pumped (active system) or driven by natural convection (passive system). The heat energy in the liquid can then be transferred to other systems through contact points.

Solar thermal technology is primarily used to heat water or spaces in homes and businesses. Solar thermal technology was added in 2014 to the roof of the Stone Laboratory dining hall to heat all water used for the cafeteria (Figure 1). What key features are necessary for efficient heating of water in solar thermal tubes?

The dining hall not only uses the most hot water on Gibraltar Island, especially when classes are in session, but is the location with the best light for a solar thermal project. Stone Laboratory has installed an Active Evacuation Tube System to heat water used in the dining hall. The sun heats a glycol filled tube, which exchanges heat to the hot water system (see step 1 below and diagram in Figure 2). There is no mixing of fluids. Heat exchange is through a metal-to-metal point located on the system. The collectors are usually made of parallel rows of transparent glass tubes. Inside each tube, a parabolic trough shaped metal reflector (Figure 3) absorbs solar energy and inhibits radiated heat loss. This design allows the sunlight to pass through the glass, but allows very little heat to escape. Air is removed, or evacuated, from the space between the glass tubes and the metal tubes to form a vacuum, which helps eliminate heat loss.

Figure 1: Solar thermal technology on the roof of Ohio State University's Stone Laboratory.

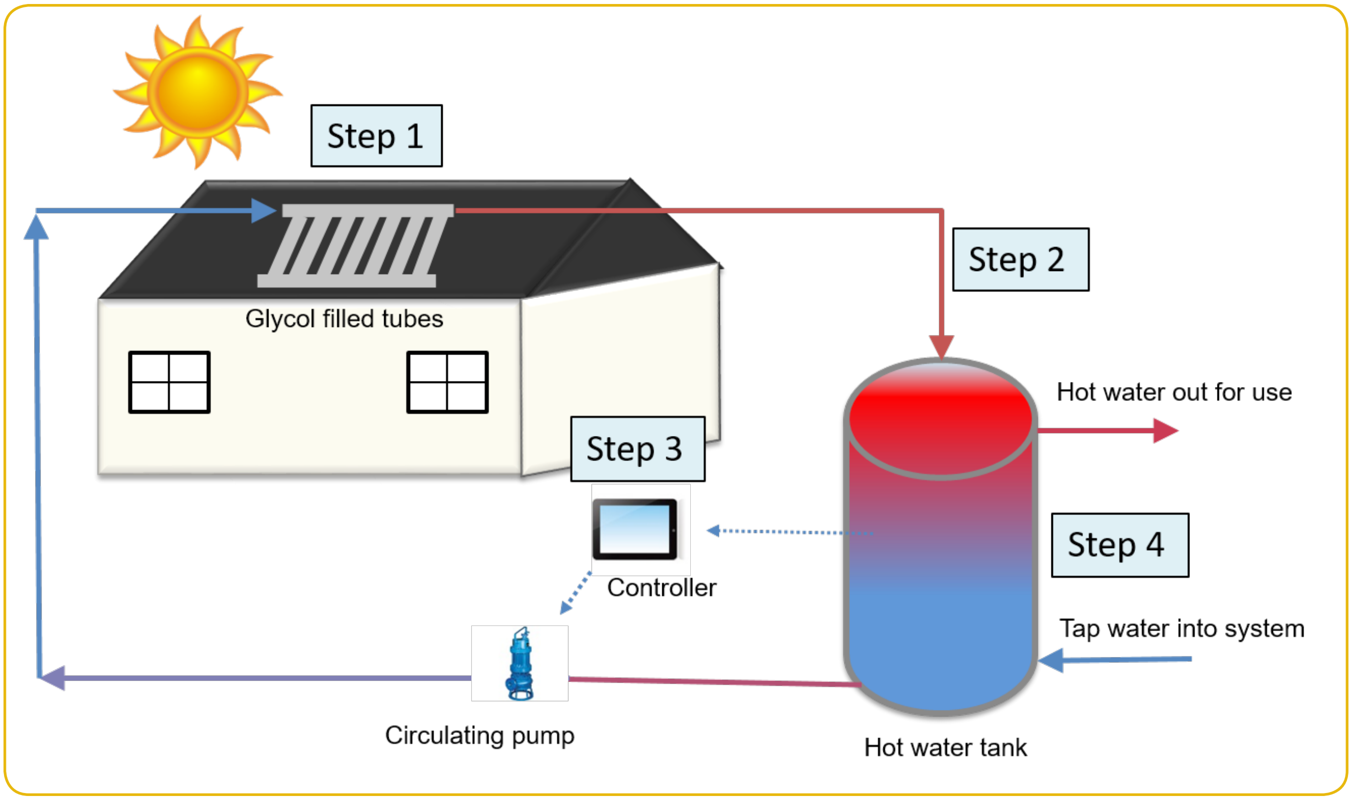


Figure 2: Diagram of the solar thermal technology used at Ohio State University's Stone Laboratory.

PROCEDURE

How does this system work?

Step 1 - Heat from the sun is collected by glycol filled tubes and transferred to the main tap water line. Glycol and water are in separate lines and never mix. The heat transfers through metal-to-metal contact points on the roof along the entire panel.

Step 2 - The heated water circulates through a storage tank in the dining hall where it warms several hundred gallons of water for use throughout the day.

Step 3 - Control sensors monitor the heat in the tank and will circulate the water until the desired temperature is reached. On warm sunny days, the water in the storage tank can be too hot to safely use. The temperature is lowered by stopping the flow of the water to the roof and adding cooler tap water into the storage tank.

Step 4 - On colder days or at night, electricity may be used to heat the water with a standard hot water tank.

In this activity, you will learn about and build models of solar thermal tubes to determine the optimal design for the greatest heat transfer.

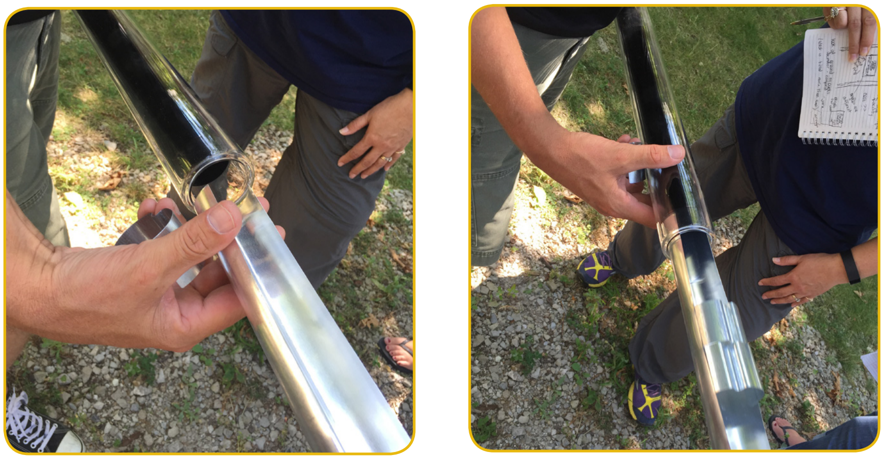


Figure 3: Images of the solar collection tubes on the roof of the dining hall. Each tube contains a glass outer tube and a parabolic trough shaped metal absorber tube attached to a fin. The fin is covered with a black coating that absorbs solar energy well and inhibits radiated heat loss.

PART 1: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE LIQUID

Group Members ____

Contents of Glass Bottle Part 1 ____

1. Construct two replicates of the model assigned to your group. Follow the Direction in the Guide for Constructing a Solar Thermal Model.

2. Remember to take the temperature inside the glass bottle prior to completing assembly. **Work efficiently to minimize heat loss or gain from inside the glass bottle.**

3. Place the sealed model under the lights as instructed by your teacher. Use blocks of wood or books to prop models at a 35°- 45° angle approximately 20-25 cm from the bulb. Note the time the model was placed under the light. See Figure 4.

Figure 4: Image of model set-up with two bottles. Feel free to place up to 4 bottles under each light set-up.

4. Make the following predictions while the models are under the lights.
   a) The liquid expected to show the greatest change in temperature is

   ______________________________ because ...

   b) The liquid expected to show the least change in temperature is

   ______________________________ because ...

   c) Compared to the temperature change expected with water, the temperature in the bottle with isopropyl alcohol will ...

CAUTION
This procedure heats water very quickly causing the water to become extremely hot when using the plant bulb model. Several hours of exposure to a 120-Watt plant bulb can raise the water temperatures to more than 100^{o}C.

5. At the end of the time interval determined by your teacher, use heat resistant gloves or an oven mitt to carefully remove the glass bottle, remove the cap, and determine the final temperature of the contents inside the glass bottle. Note the time the model was removed from under the light.

6. Record your group's data for replicate 1 and 2 in the table below.

7. Once all data have been collected, fill in the average change in temperature for all four treatments in the class data table.

PART 1: DATA COLLECTION

Liquid Tested ________________________________

Replicate	Starting Time	Starting Temperature (°C)	Ending Time	Ending Temperature (°C)
1				
2				

Average Elapsed Time: _________________ minutes   Average Temperature Change: _________________ °C

Class Data

Liquid Tested	room temperature water	cold water	hot water	isopropyl alcohol
Average Temperature Change (°C)				

ANALYSIS, INTERPRETATION AND APPLICATION

1. Describe how heat absorption varied between the three temperatures of water (hot, room temperature, cold).

2. How did heat absorption in the bottle with isopropyl alcohol compare to the bottles with water?

3. Which bottle served as the control trial? Explain why.

4. When isopropyl alcohol was used instead of water as the liquid in the glass bottle, what did the alcohol represent? What is the benefit of using alcohol at a location with cold winters?

5. Which liquid was most efficient at heat absorption? Cite specific evidence from the data that supports your claim about the best liquid for a solar thermal model.

6. Look back at your initial hypotheses. Do your findings support your hypotheses? Explain.

PART 2: INVESTIGATING FACTORS TO MAXIMIZE HEAT TRANSFER: VARIATIONS IN THE MODEL DESIGN

Group Members ____

Structure of Glass Bottle Model - Part 2 ____

Liquid used in glass bottle (From Part 1) ____

1. Construct two replicates of the model assigned to your group. Follow the Direction in the *Guide for Constructing a Solar Thermal Model*.

2. Remember to take the temperature inside the glass bottle prior to completing assembly. Work efficiently to minimize heat loss or gain from inside the glass bottle.

3. Place the sealed model under the lights as instructed by your teacher. Use blocks of wood or books to prop models at a 35°- 45° angle approximately 20-25 cm from the bulb. Note the time the model was placed under the light.

Figure 5: Diagram of Part 2 set-up.

CAUTION

This procedure heats water very quickly causing the water to become extremely hot when using the plant bulb model. Several hours of exposure to a 120-Watt plant bulb can raise the water temperatures to more than 100^{o}C.

4. Make the following predictions for the models under the lights.
   a) The model expected to show the greatest change in temperature is

      ________________________ because ...

   b) The model expected to show the least change in temperature is

      ________________________ because ...

5. At the end of the time interval determined by your teacher, use heat resistant gloves or an oven mitt to carefully remove the glass bottle from the plastic encasement, remove the cap, and determine the final temperature of the contents inside the glass bottle. Note the time the model was removed from under the light.

6. Record your group's data for replicate 1 and 2 in the table below.

7. Once all data have been collected, fill in the average change in temperature for all four treatments in the class data table.

PART 2: DATA COLLECTION

Description of Model Tested ___________________________________

Replicate	Starting Time	Starting Temperature (°C)	Ending Time	Ending Temperature (°C)
1				
2				

Average Elapsed Time: ______________ minutes Average Temperature Change: ______________ °C

Class Data – Liquid used in all Bottles ______________________

Model Description	Outer Plastic Bottle	Outer Plastic Bottle and Rubber Tubing	Outer Plastic Bottle with Parabolic Reflective Tape	Outer Plastic Bottle with Parabolic Reflective Tape and Rubber Tubing
Average Temperature Change (°C)				

ANALYSIS, INTERPRETATION AND APPLICATION

1. According to the class data, which model had the greatest change in temperature?

2. According to the class data, which model had the least change in temperature?

3. Which model served as the control trial? Why?

4. Which model was the most effective as heat absorption? Cite specific evidence from the data that supports your claim about the best liquid for a solar thermal model.

5. Describe the function of the silver tape in the models used in Part 2. Use the description of the solar thermal technology at Stone Laboratory to guide your answer.

6. Describe the function of the black tubing in the models.

7. What was/were the purpose(s) of the plastic bottle surrounding the glass bottle? How did using the plastic bottle improve the overall design of the model?

8. Models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. What are some potential shortcomings to the model your group constructed? What would you change if you could redesign your model?

9. Did the model that was most efficient most closely parallel the construction of the solar thermal tubes at Stone Lab? Justify your answer.

10. As part of an overall commitment to a healthier environment and reducing the energy use, Ohio Sea Grant and Ohio State University's Stone Lab are implementing a variety of measures to reduce energy and water use. Efforts include solar thermal heating for generating hot water and photovoltaic solar arrays for generating electricity, as well as low-flow toilets, showerheads and faucets. What measures are being taken at your school or by your family to reduce energy or water use?

Building a Solar Photovoltaic Array by Exploring Series and Parallel Circuits

Teacher Activity

BACKGROUND

Photovoltaic (PV) solar cells can be arranged in many different ways. They could be in a long line on the top of a parking pavilion or in a grid layout on the top of a square roof. It's important for solar array developers to understand the characteristics of various types of circuits so they can design arrays to best meet the needs of their clients within given parameters.

Chris Campbell @flickr

OBJECTIVES

In this activity, students will build and investigate different arrangements of series and parallel circuits to determine the optimal design for the greatest energy production.

After completing this investigation, students will be able to:

- Differentiate between voltage, current, and power.
- Differentiate between series and parallel circuits and complete or incomplete circuits.
- Accurately use a multimeter to measure amps and volt outputs.
- Convert current and voltage readings from series, parallel and combination circuits to power in watts.
- Use a variety of series and parallel circuits to build a PV solar array with specific parameters.

GRADE LEVELS – 7-12 Physical Science

TIME REQUIRED – 2 class periods (one each for Parts 1 and 2)
Teacher discretion to complete Practice and Application questions during or outside of class time

MATERIALS PER STUDENT OR GROUP

- 4 solar cells with red and black leads and clips
- 2 additional alligator clips
- multimeter
- 1 24-inch piece of red wire
- Mini light bulb and/or mini fan (such as those at *pitsco.com/Lamp_Socket_Light_Bulbs or robotshop.com/en/12v-6000rpm-fan-157x157x04.html*)

This solar energy curriculum was funded by an OSU CARES grant in partnership with the following Ohio State University departments: Ohio Sea Grant and Stone Laboratory; Extension and Energize Ohio Signature Program; Facilities, Operations, and Development; and the Office of Energy and Environment.

ALIGNMENT

Next Generation Science Standards

DCI: Conservation of Energy and Energy Transfer (PS3.B)
DCI: Definition of Energy (PS3.A)
DCI: Designing Solutions to Engineering Problems (ETS1.B)
SEP: Developing and Using Models
SEP: Planning and Carrying Out Investigations
SEP: Using Mathematics and Computational Thinking
SEP: Constructing Explanation and Designing Solutions
CC: Energy and Matter: Flows, Cycles and Conservation
CC: Systems and Systems Models
CC: Interdependence of Science, Engineering, and Technology

Energy Literacy Principles

#1.1, 1.3, 1.7, 1.8 Energy is a physical quantity that follows precise natural laws.

Ohio's Model Science Curriculum

Grade 7 Physical Science: Energy can be transformed through a variety of ways.
High School Physics: Electricity and Magnetism

PRIOR TO THE LESSON

1. Assemble one set of circuit cards for each group. These can be printed on cardstock and placed into an envelope for use for multiple classes or years.
2. Compile investigation materials for groups. Having each group's equipment collected in a plastic shoebox and ready for them will expedite the start of investigations.
3. Review the terms in the provided vocabulary list located in the reference documents to this curriculum.

Teacher's Note:
You may choose how to print the student pages. Pages 3.12 - 3.15 contain the investigation instructions and questions. Page 3.16 contains the data tables; those could be stapled to pages 1-4 or handed out separately. Pages 3.17 and 3.18 are the Practice and Application questions; it's suggested to provide those to students only after they have completed all other parts of the investigation.

Lesson

ENGAGE

1. Begin by providing students or groups with a set of circuit cards. Instruct them to create two piles based on characteristics they observe. DO NOT use the terms series or parallel with students at this point.
2. Ask students or groups to compare their classification schema with others near them. Discuss the similarities and differences between the groups as a class and then present students with the terms series and parallel.
3. Have them consider the meanings of the words and then assign a series or parallel label to each group of cards. At this point, make sure all students or groups have the 24 images in correctly labeled categories.

Answer: Images A, C, F, H, I, L, M, O, P, Q, S, U, and X are series circuits; images B, D, E, G, J, K, N, R, T, U, V and W are parallel circuits.

EXPLORE & EXPLAIN

PART 1: HOW DO VOLTAGE, CURRENT, AND POWER DIFFER IN SERIES AND PARALLEL CIRCUITS?

1. Choose a sunny day and outdoor area free of trees, buildings and shadows as much as possible.
2. Divide students into teams, and provide each team with four mini solar cells.
3. Connect the multimeter to one mini solar cell and record the data readout (volts and amps) on the data sheet. Refer to Figure A. This will allow readings to be converted to watts and the series, parallel, and combination should produce similar power in watts.

4. Instruct each team to build a parallel circuit connected to a load source (i.e. fan, light, etc.). Connect all black wires together and attach to the black end of the multimeter. Connect all red wires together and attach to the red end of the multimeter. Refer to Figure B.
5. Unhook 1 black alligator clip. Observe what happens to the fan, then reconnect the black alligator clip to complete the circuit.
6. Remove the fan from the circuit and connect the multimeter to record the data readout from the multimeter (volts and amps) on their data sheet. While still connected to the multimeter, remove a black alligator clip and record the data readout from the multimeter (volts and amps).

Teacher's Note: Instructions for using a multimeter are located in the reference documents of this curriculum.

Figure A. Baseline reading from one mini cell

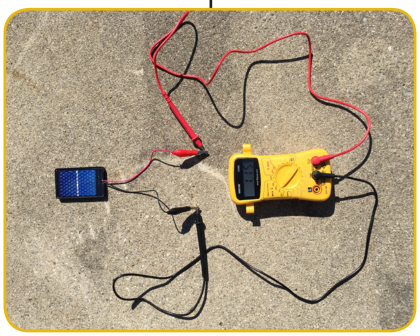


Figure A: A multimeter attached to a PV solar panel with red wires connected to the red probe and black wires connected to the black probe. This is a baseline reading for one solar panel.

Figure B. Parallel circuit connection

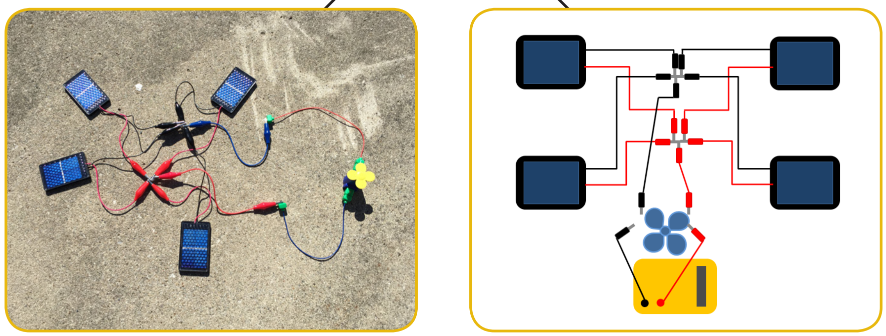


Figure B: Red wires connected to red wires and black wires connected to black wires in a parallel circuit to operate a fan. The fan can be replaced by a multimeter to collect quantitative data.

7. Instruct each team to build a series circuit connected to a load source (i.e. mini fan, mini light, etc.). Connect each mini solar cell wire to the wire of an adjacent panel of opposing color (i.e. connect red wires to black wires). Refer to Figure C.
8. Unhook one black alligator clip. Observe what happens to the fan, then reconnect the black alligator clip to complete the circuit.
9. Remove the fan from the circuit and connect the multimeter to record the data readout from the multimeter (volts and amps) on their data sheet. While still connected to the multimeter, remove a black alligator clip and record the data readout from the multimeter (volts and amps).

Figure C. Series circuit connection

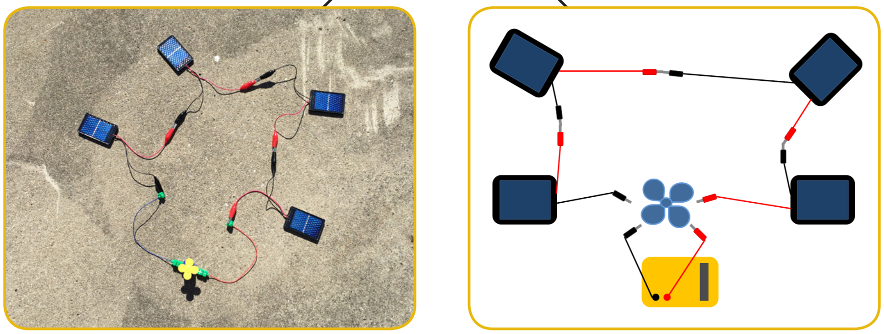


Figure C: Red wires connected to black wires in a series circuit to operate a fan. The fan can be replaced by a multimeter to collect quantitative data.

A formative assessment checkpoint occurs as students complete their data collection and communicate their findings.

10. Have students complete the reflective questions.

Answers to Reflective Questions in Part 1

1. a. parallel b. parallel c. series d. parallel e. both – equal power
2. sample answers could include: the amount of light, the angle of light, the load source
3. In general, the arrangement of PV solar panels is the independent variable; current and voltage (and ultimately power) are dependent variables.
4. There is no relationship between the number of PV solar cells and voltage in a parallel circuit.
5. Power would:
   a. increase because the maximum energy potential would increase.
   b. not change because while voltage increases, current decreases.
   c. decrease to zero because the circuit is broken.
6. Unhooking an alligator clip from a parallel circuit is not as detrimental as it is in a series circuit. Electricity can still flow through an alternative path in a parallel circuit; there is no alternative path in a series circuit.

PART 2: CAN YOU CONSTRUCT A COMBINATION CIRCUIT USING SERIES AND PARALLEL CONNECTIONS?

12. Instruct each team to use both series and parallel connections to construct a combination circuit. Have the students connect the PV solar array to a fan or light that will act as a load source (a device that will consume the energy just produced). Refer to Figure D.
13. Remove the fan from the circuit and connect the multimeter to record the data readout from the multimeter (volts and amps) on their data sheet.
14. Students should communicate their findings on a piece of paper. Have students write the investigative question at the top. Let students choose the format they use to explain their findings, such as Venn diagrams, tables, or drawings. Encourage students to color code their explanations or graphics.

Figure D. Combination circuit connection

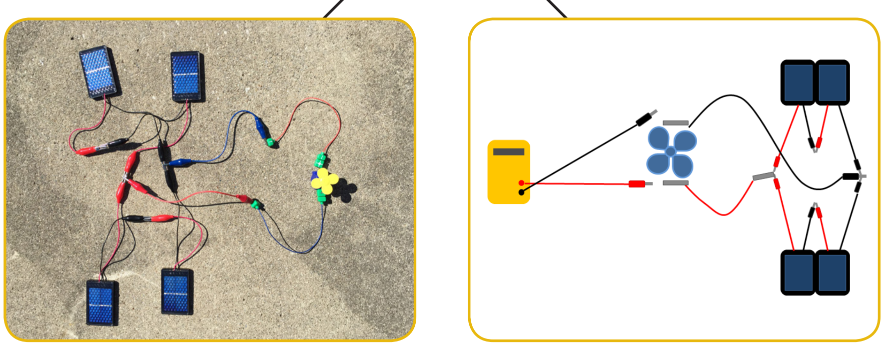


Figure D: Combination circuit (series and parallel): Two sets of two mini solar cells wired together in a series (red to black). Next, make a parallel connection by connecting the remaining wires together (red to red and black to black). Using the alligator clips, connect the multimeter to the parallel connections in the circuit.

Answers to Reflective Questions in Part 2

1. Assuming the sun remains consistent, there would be no change in power. Remember, power is the rate at which energy is transferred and is usually measured in watts. Power in watts is calculated as (Watts = Volts x Amps). As demonstrated and observed in the activity with the mini solar cells, in a series circuit the voltage increases by the number of voltage sources in the circuit (i.e. number of mini cells) while the current remains the same. Conversely, in a parallel circuit the voltage remains the same, while the current increases by the amps of each cell wired in the parallel circuit. Therefore, regardless if the 10 solar panels were arranged as a series circuit, parallel circuit, or a combination circuit, the max power would be the same.
2. a. series b. parallel c. series d. series e. parallel
3. A parallel circuit is arranged with multiple paths through which electricity can flow. Parallel circuits allow other lights on the string to stay on if one bulb burns out. In a series circuit, there is a single path in which electrons flow. If one bulb burns out and the electricity cannot flow, the whole string of lights goes out.

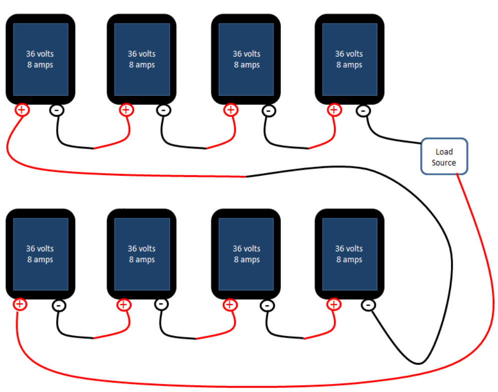
ELABORATE

15. Have students review the concepts of series, parallel, and combination circuits by completing the **Practice and Application** questions. It's at the teacher's discretion whether student complete these during or outside of class.

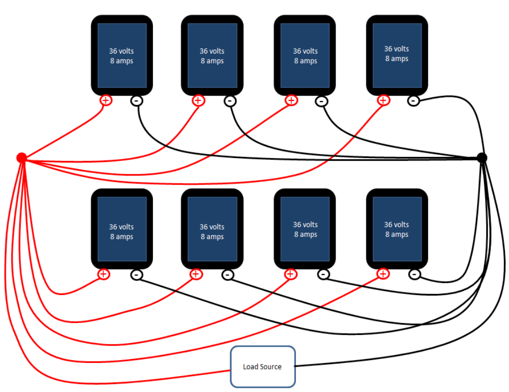
Answers to Practice and Application Questions

1. Voltage = 288 volts Current = 8 amps Power = 2304 watts
2. Voltage = 36 volts Current = 64 amps Power = 2304 watts
3. Wiring 2 strings of 4 PV solar panels as a parallel connection will meet the needs of the inverter. Each
   Series 1: voltage: 36 volts X 4 = 144 volts current = 8 amps
   Series 2: voltage: 36 volts X 4 = 144 volts current = 8 amps
   Total: voltage = 144 volts, current = 16 amps

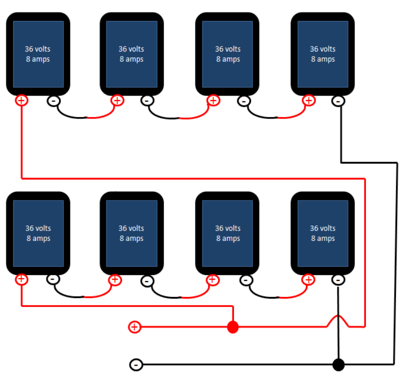
Question 1 Drawing



Question 2 Drawing



Question 3 Drawing



EVALUATE

Parts 1 and 2 of the activity provide opportunities for formative assessment.

Part 2 – though students may not realize it – is really a performance based assessment.

Teachers can use students' answers to the Reflective Questions in Part 1 and/or the Practice and Application questions.

Finally, the Practice and Application questions can easily be used as a stand-alone summative assessment or integrated into a larger unit assessment.

SOURCE

Solar Energy Curriculum Consortium

Lead: Eric Romich, OSU Extension Field Specialist, Energy Development
Susan Bixler, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Kristen Fussell, Research Development and Grants Manager, Ohio Sea Grant and Stone Laboratory
Angela Greene, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
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Kristin Stanford, Education & Outreach Coordinator, Ohio Sea Grant and Stone Laboratory

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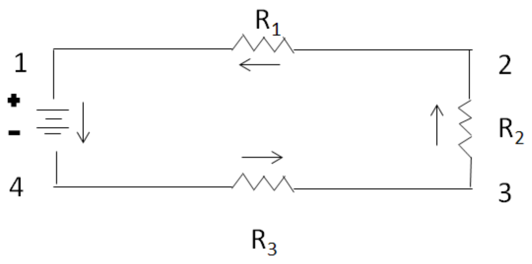

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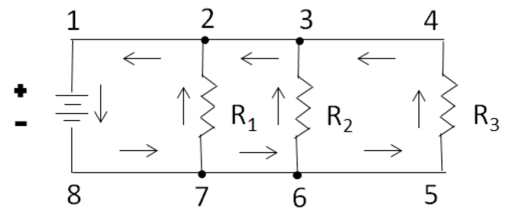

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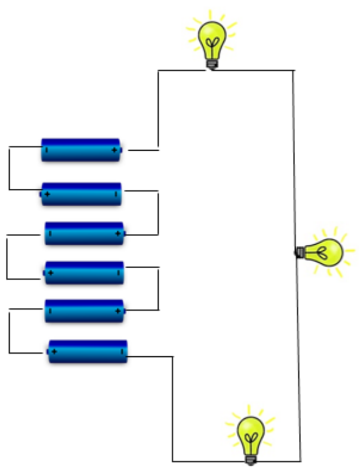

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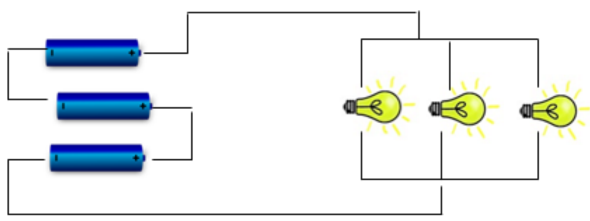

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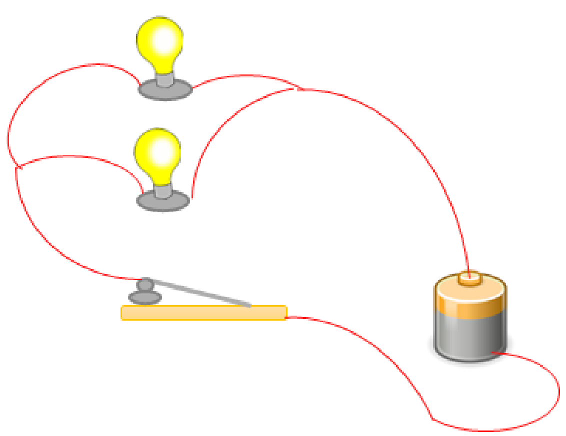

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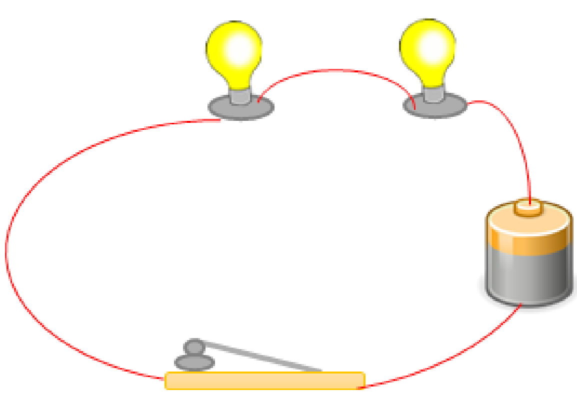

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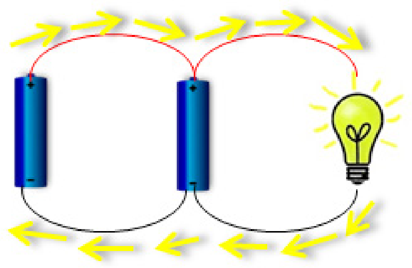

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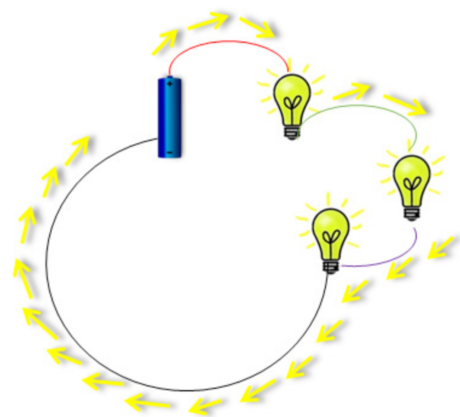

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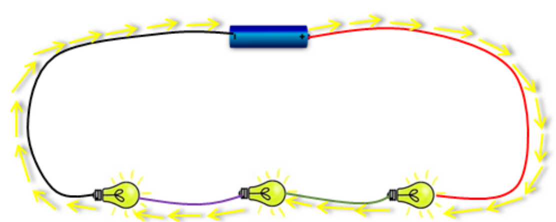

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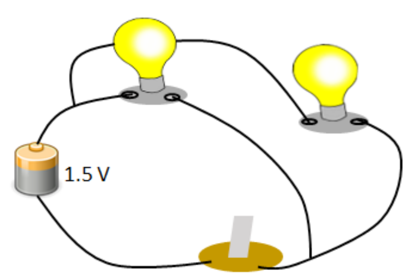

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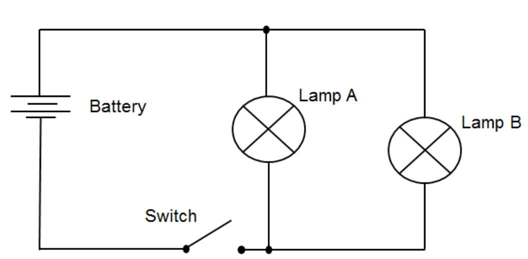

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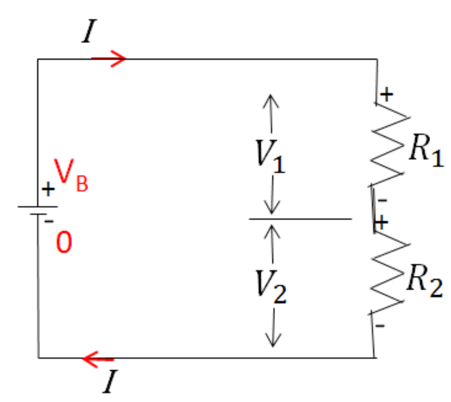

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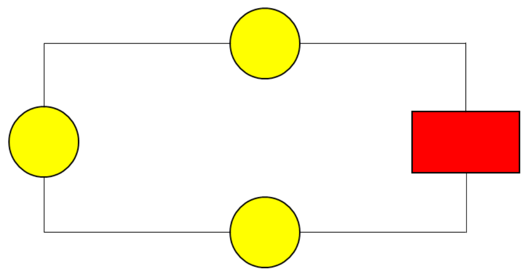

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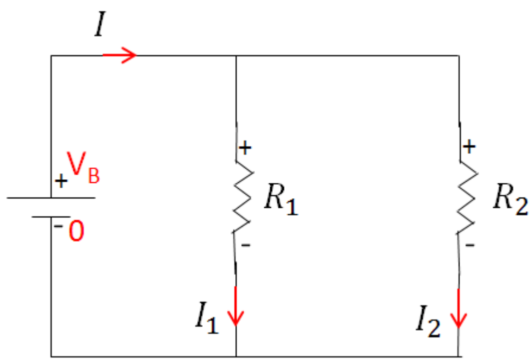

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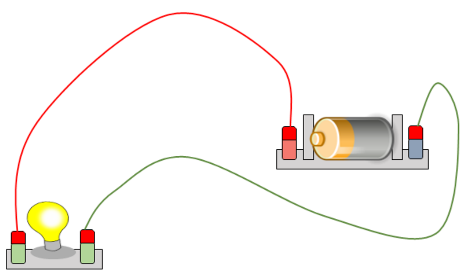

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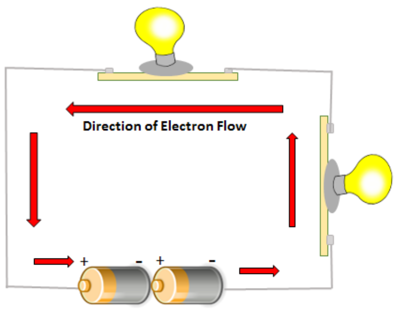

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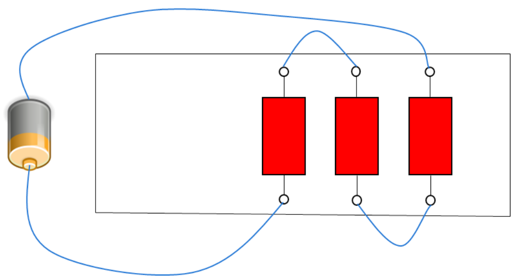

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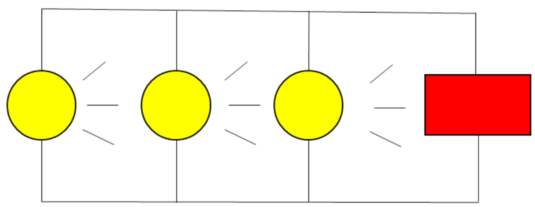

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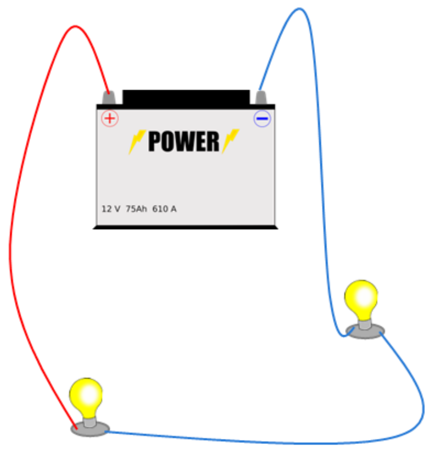

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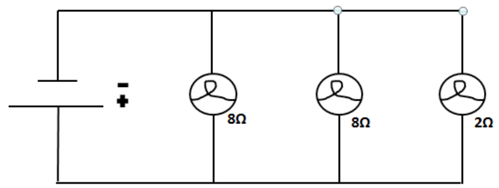

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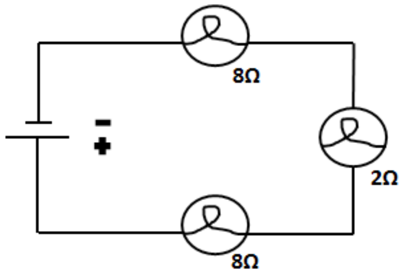

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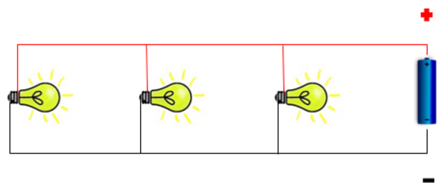

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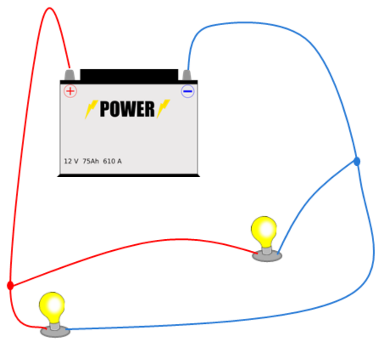

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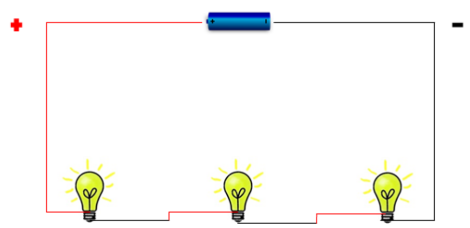


SERIES CIRCUITS

PARALLEL CIRCUITS

Building a Solar Photovoltaic Array by Exploring Series vs. Parallel Circuits

Student Activity

Name ____

BACKGROUND

Photovoltaic (PV) solar cells can be arranged in many different ways. They could be in a long line on the top of a parking pavilion or in a grid layout on the top of a square roof. It's important for solar array developers to understand the characteristics of various types of circuits so they can design arrays to best meet the needs of their clients within given parameters.

In this activity, you will build and investigate different arrangements of series and parallel circuits to determine the optimal design for the greatest energy production.

Chris Campbell @flickr

PROCEDURE

Describe the characteristics of a:

Series Circuit	Parallel Circuit

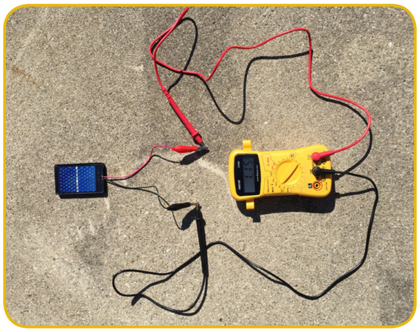
What do these terms mean?

Voltage	Current	Power
Unit:	Unit:	Unit:
How is voltage determined?	How is current determined?	How is power determined?

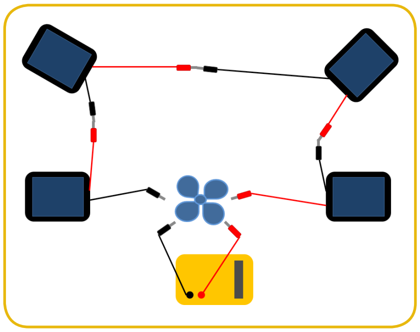
PART 1: HOW DO VOLTAGE, CURRENT, AND POWER DIFFER IN SERIES AND PARALLEL CIRCUITS?

1. Gather the following materials
    - 4 solar cells with red and black leads and clips
    - 2 additional alligator clips
    - multimeter
    - 1 24-inch piece of red wire
    - Mini light bulb and/or mini fan

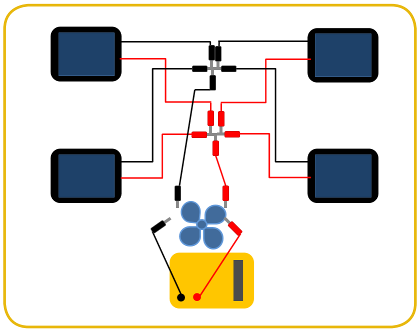
Keep in mind the basic connection patterns for series and parallel circuits:
series = red wires connected to black wires
parallel = red wires connected red wires and black wires connected to black wires



Baseline reading from one mini cell



SERIES CIRCUIT



PARALLEL CIRCUIT

2. Connect the multimeter to one mini solar cell and record the data readout (volts and amps) on the data sheet as your baseline reading.
3. Now build a parallel circuit consisting of four solar panels and connect your PV solar array to a fan or light that will act as your load source (a device that will consume the energy just produced).
4. Unhook one black alligator clip, observe what happens to the fan or light, and then reconnect the black alligator clip. Record the data readout.
5. Remove the fan from the circuit and connect the multimeter to record the data readout from the multimeter (volts and amps) on your data sheet. While still connected to the multimeter, remove a black alligator clip and record the data readout from the multimeter (volts and amps).
6. Repeat steps 3-5, but this time build a series circuit. Record your data on the data table provided.

Reflective Questions:

1. Assuming all circuits involve four panels, indicate the type of circuit or circuits . . .
    a. where current is increased by the number of PV solar panels. ____________________
    b. where voltage remains constant throughout the circuit. ____________________
    c. that produces the greatest voltage. ____________________
    d. that produces the greatest current. ____________________
    e. that produces the greatest power. ____________________

2. What factors were kept constant during all of your trials?

3. Identify the overall independent and dependent variables being investigated.

4. Describe the relationship between the number of PV solar cells and voltage in a parallel circuit.

5. Predict how power would change if . . .

    a. the number of PV solar panels increased from four to six in a series circuit.

    b. the arrangement of four solar cells in parallel circuit was changed to a four solar cells in a series circuit.

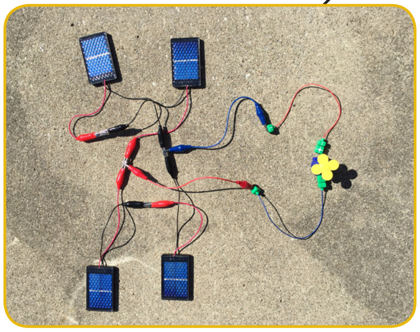
    c. a PV solar panel was removed from a series circuit and wires were left unconnected.

6. Think about the effect of unhooking an alligator clip from a series circuit with 4 PV solar panels. Compare this to the result you would expect to see if you unhook an alligator clip from a parallel circuit with 4 PV solar panel.

PART 2: CAN YOU CONSTRUCT A COMBINATION CIRCUIT USING SERIES AND PARALLEL CONNECTIONS?

7. Using both series and parallel connections, construct a combination circuit and connect your PV solar array to a fan or light that will act as your load source (a device that will consume the energy just produced). Refer to Figure D.

Figure D. Combination circuit connection



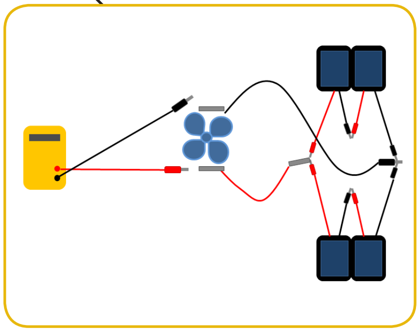


Figure D: Combination circuit (series and parallel): Two sets of two mini solar cells wired together in a series (red to black). Next, make a parallel connection by connecting the remaining wires together (red to red and black to black). Using the alligator clips, connect the multimeter to the parallel connections in the circuit.

8. Remove the fan from the circuit and connect the multimeter to record the data readout from the multimeter (volts and amps) on your data sheet.

9. When you feel confident you have enough data to answer the investigative question (How do voltage, current, and power differ in series, parallel, and combination circuits?), display your findings on a piece of paper. Be sure to put the investigative question at the top. The group may decide the best format in which to convey findings, but make sure all parts of the investigative question are answered on your display.

Reflective Questions:

1. A student designs a series circuit with 10 PV solar panels each rated at 36 volts and 8 amps and a max power rating of 288 watts. Predict what would happen to the power of the system if the 10 PV solar panels were rearranged into a parallel circuit. Justify your answer with an explanation or a drawing.

2. Think about the practical application of series and parallel circuits. For each item, predict (circle) whether it runs on series or parallel circuits.

a. holiday lights	series circuit	OR	parallel circuit
b. street lights	series circuit	OR	parallel circuit
c. flashlight	series circuit	OR	parallel circuit
d. TV remote control	series circuit	OR	parallel circuit
e. chandelier	series circuit	OR	parallel circuit

3. You've purchased a decorative tree and plan to place white lights on its branches. There are many choices of light sets at the store. Would you choose lights wired in a series circuit or in a parallel circuit? Use circuit science to help explain your answer.

Building a Solar Photovoltaic Array by Exploring Series and Parallel Circuits

DATA TABLE

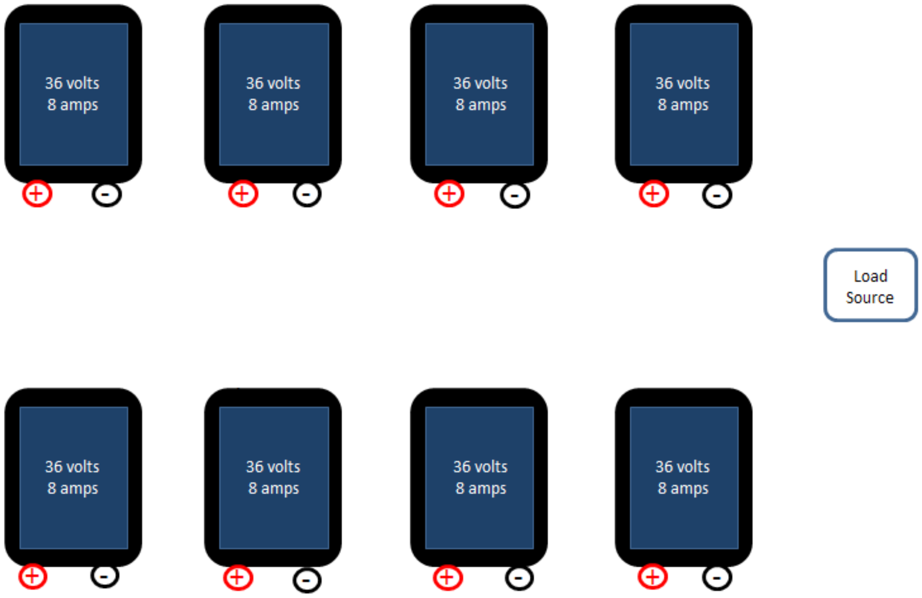
VOLTAGE X CURRENT = POWER

Circuit Type	# of Panels	Volts (V)	Amps (A)	Power (W)
Baseline				
Parallel				
Parallel with clip removed				
Series				
Series with clip removed				
Combination				

Building a Solar Photovoltaic Array by Exploring Series and Parallel Circuits

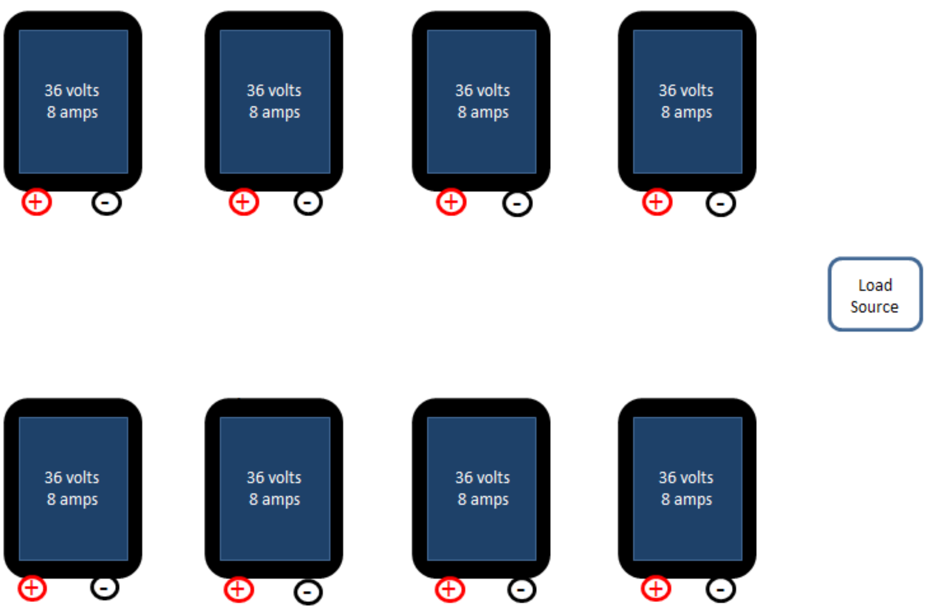
PRACTICE AND APPLICATION

1. Use the image below, as well as red and black writing utensils, to illustrate how you can connect the eight PV solar panels in a series circuit. Calculate the voltage, current and power produced by this array.



Voltage = ___________ Current = _____________ Power = _______________

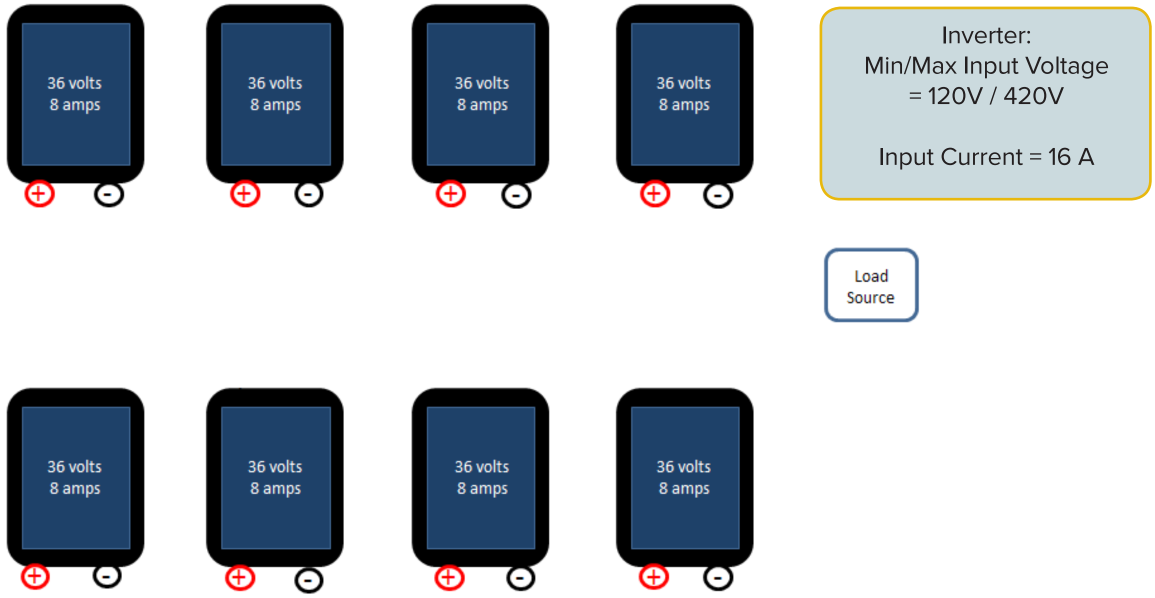
2. Use the image below, as well as red and black writing utensils, to illustrate how you can connect the eight PV solar panels in a parallel circuit. Calculate the voltage, current and power produced by this array.



Voltage = ___________ Current = _____________ Power = _______________

3. You have a remote cabin deep in the woods that you use for weekend camping and hiking trips. The cabin does not have electricity which means you cannot charge your cell phone or computer. In addition, you cannot power your television or video game console. While you enjoy being out in nature, you want to have the ability to charge your devices and play video games in the event of rainy weather.

   Your cabin has eight PV solar panels and an inverter (a device that converts direct current from a solar panel to alternating current). Use the image below to illustrate how you can use a combination of series and parallel connections to match the input voltage and current required by the inverter. Show your math work to confirm your arrangement meets the electrical requirements of the inverter.



Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

Teacher Activity

BACKGROUND

The Ohio State University's Stone Laboratory sits on the 6.5-acre Gibraltar Island in the harbor at Put-in-Bay, Ohio in Lake Erie. Established in 1895, it is the oldest freshwater biological field station in the country. As facilities were renovated in 2013, photovoltaic (PV) solar panels and solar thermal installations were placed on the island to reduce energy consumption. The installations were designed to maximize usage for education, research, and outreach opportunities (Figure 1).

On the left side (west) of Figure 1, the solar pavilion is visible with 44 240-watt panels. Half of the panels (22) are monocrystalline silicon (15% efficiency, a little more expensive, and normally a little more efficient on cloudy days) and half are polycrystalline silicon (14% efficiency and a little less expensive). The panels on top of the solar pavilion are tilted at a 10° angle from the ground. Two 3-panel monocrystalline ground mounts are in front of the pavilion. The panels on the western ground mount are fixed at approximately a 36° angle to Earth's surface so they are perpendicular to the sun's rays in late spring and early summer. The eastern ground mount is set at approximately 26° so that it is perpendicular to the sun's rays at the summer solstice (21 June). This arrangement allows Stone Laboratory to research how the angular placement of panels affects energy produced. Typically, panels should be placed at latitude tilt to maximize energy output over the course of an entire year; for Stone Laboratory, this would be 42° given its location (41.6° N, 82.8° W).

Figure 1: Solar Panel Installations at Stone Laboratory. Circles highlight the Ground West mount and Solar Pavilion panels used in this lesson.

This solar technology curriculum was funded by an OSU CARES grant in partnership with the following Ohio State University departments: Ohio Sea Grant and Stone Laboratory; Extension and Energize Ohio Signature Program; Facilities, Operations, and Development; and the Office of Energy and Environment.

OBJECTIVES

In this activity, students will measure and use the angles at which the sun's rays strike Earth's surface to design a PV solar arrangement that maximizes electrical energy production. Using the results of the investigation and a thorough analysis of real-time data from various PV solar panels at Stone Laboratory, students will present plans for arrangement and use of PV solar technology systems to maximize energy production in various location throughout a year.

After completing this investigation, students will be able to:

- Describe how the angle of the sun's rays influences energy production in a PV solar cell.
- Demonstrate how to use a protractor and calculate the internal angle of a triangle.
- Create and interpret graphical representations of PV solar panel data.
- Design an optimal PV solar arrangement given a set location and season.

GRADE LEVELS – 7-12 Earth and/or Environmental Science
TIME REQUIRED – 2 class periods (one part each day)
MATERIALS PER STUDENT OR GROUP

Part 1: Each student should have access to the internet and a student handout (if not using Nearpod).

Part 2: Each group of students should have:

- pizza box
- sharpened pencil
- large paperclip
- protractor
- ruler
- markers
- tape
- alligator clips
- solar mini panels
- digital voltmeter or multimeter
- student handout

Part 3: Each student should have access to the internet and an online graphing program (e.g., Microsoft Excel), as well as the student handout. A handout for creating a data table and graph are provided if students have limited computer access.

Teacher's Note:
Instructions for using a multimeter are located in the reference documents of this curriculum.

ALIGNMENT

Next Generation Science Standards

DCI: Human Impacts on Earth Systems (ESS3.C)
DCI: Conservation of Energy and Energy Transfer (PS3.B)
DCI: Developing Possible Solutions (ETS1.B)
SEP: Developing and Using Models
SEP: Planning and Carrying Out Investigations
SEP: Analyzing and Interpreting Data
SEP: Constructing Explanation and Designing Solutions
CC: Energy and Matter
CC: Interdependence of Science, Engineering, and Technology
CC: Influence of Engineering, Technology, and Science on the Society and the Natural World

Energy Literacy Principles

#1.4, 1.5, 1.7, 1.8 Energy is a physical quantity that follows precise natural laws.
#2.2 Physical processes on Earth are the result of energy flow through the Earth system.
#4.4 Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

Ohio's Model Science Curriculum

Grade 7 Physical Science: Energy can be transformed through a variety of ways.
High School Environmental Science: Earth's Resources
Global Environmental Problems and Issues

PRIOR TO THE LESSON

1. Review how to use a protractor to calculate the internal angle of a triangle.
2. Ensure students can effectively use a chosen online graphing program.

Lesson

ENGAGE

PART 1: PREPARING FOR THE INVESTIGATION

1. Display the following questions that will promote thinking about the convenience of hot water. Some examples may include:
    1. Have students read the introductory information about solar technology at Stone Laboratory. They should also visit ***ohioseagrant.osu.edu*** and follow the instructions on their paper to learn how the island's technology is converting solar energy into electrical energy.
    2. Elicit information about students' comprehension of the reading and animation by using the paper-based questions.

Teacher's Note:
It is suggested that students complete this part for homework prior to main lesson.

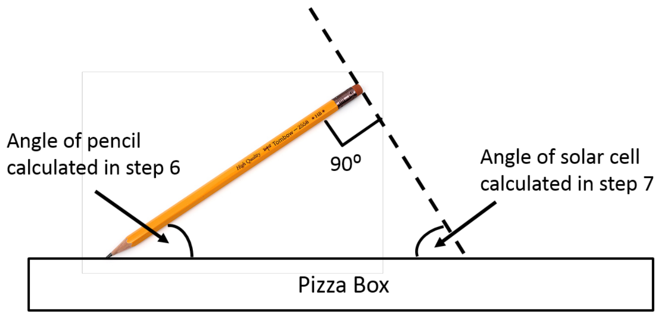
This is a checkpoint for formative assessment; Answers to Questions on Pre-Investigation Checkpoint
1. D 2. E 3. A 4. C 5. B

EXPLORE & EXPLAIN

PART 2: HOW DOES THE ANGLE OF THE SUN'S RAYS INFLUENCE ENERGY PRODUCTION IN A PHOTOVOLTAIC SOLAR CELL?

1. Students will follow instructions on the handout to use a pencil, pizza box, and protractor to determine the angle at which the sun's rays are hitting Earth.

The sum of the inside angles of a triangle is 180°.
180° - 90° - angle of the pencil = angle of the PV solar cell



Teacher's Note:
If students are having difficulty calculating the angle, encourage them to hold a ruler (or piece of paper) perpendicular to the end of the pencil. From there students can calculate the angle by visualizing a triangle. Three angles total 180°; thus, 180° – 90° – angle of the pencil = angle to place PV solar cell.

2. Though basic instructions are provided on the student handout, guide students through the process of designing their own investigation to determine how electrical energy output varies as they change the angle of the pizza box lid (which now holds a PV solar cell).

Placing the pizza box at the angle observed in the first procedure should result in the greatest voltage generated.

Answers to Questions on Student Handout

1. The sun is higher in the sky during the summer months, resulting in a smaller angle of the PV solar cell placement to allow the sun's rays to hit the panel at a 90° angle. During the winter months, students should expect to find the PV solar cell needs to be placed at a larger angle to Earth's surface in order to achieve the most direct sunlight.

2. Answers will vary, but the angle of the sun's rays reaching Earth's surface varies throughout the year. This is because Earth is tilted slightly (23.5°) from its axis. During the summer months in the northern hemisphere, solar radiation reaches Earth at an angle closer to 90° than during the winter months.

PART 3: HOW DOES THE ANGLE OF A PV SOLAR PANEL AFFECT ENERGY PRODUCTION THROUGHOUT THE YEAR?

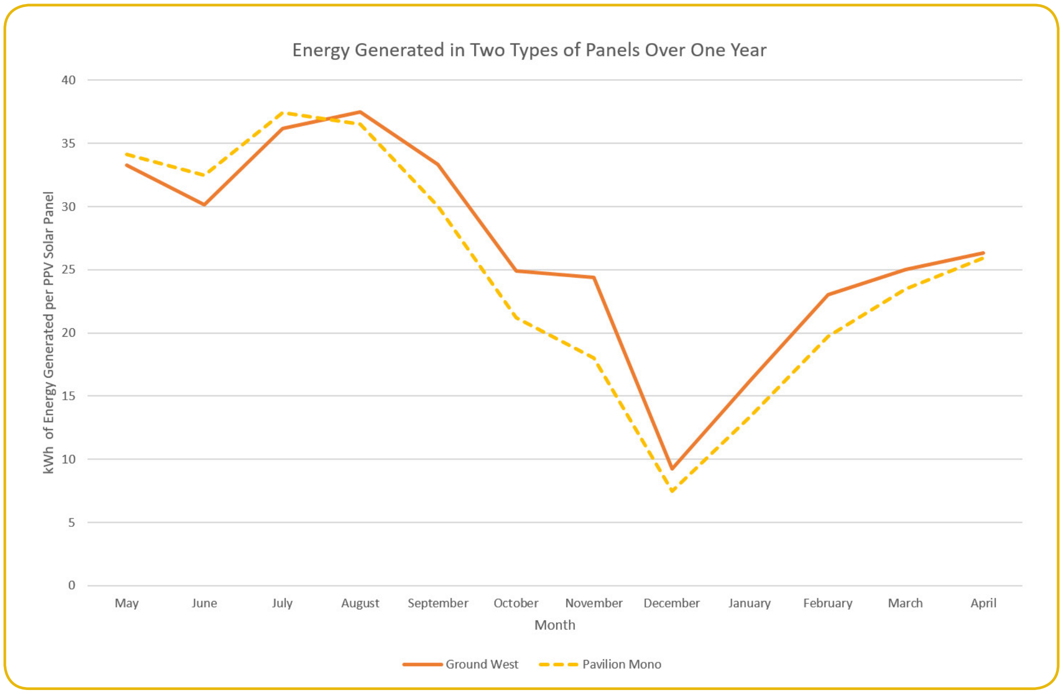
1. Have students access real-time PV solar panel data at ***ohioseagrant.osu.edu*** and use an online graphing program to analyze the energy output by season in two different panel arrangements at Stone Laboratory. Students should scroll halfway down the page to find the Solar Panel Data on the right hand side of the page. Click the *Solar Dashboard* button to access more detailed information.
   a. Clicking on *Live Data* will display the nine types of solar technology across the top of the screen; clicking on the tabs displays the total kilowatt hours (kWh) of energy produced by that type of panel.
   b. The tabs to change the time interval of the graphs (days, weeks, months, years, lifetime) are on the right side of the screen.
   c. Clicking on a bar graph will display the exact amount of energy produced.

Teacher's Note:
Remind students that the table and graph will not be by calendar year; the last bar will be the current month and may not show a full month of generation.

2. Students will work with data from the last 12 months for the three panels on the western ground mount (Ground West) and the 22 monocrystalline silicon panels on the solar pavilion (Pavilion Mono). Using an online graphing program, they will create a spreadsheet listing the PER PANEL output in kWh by month for the current YEAR of data for the Ground West and Pavilion Mono solar panels . A sample data table is shown here.
   a. Months are shown with the current month as the last bar on the graph (not necessarily January).
   b. Data in the columns "Ground West Total" and "Pavilion Mono Total" are directly from the website.
   c. Energy production per panel is calculated by dividing the total by 3 (for the Ground West panels) or 22 (for the Pavilion Mono panels).

	Energy Output (kWh)			
Month	Ground West Total (3 panels)	Ground West Per Panel	Pavilion Mono Total (22 panels)	Pavilion Mono Per Panel
May	99.75	33.25	750.41	34.11
June	90.48	30.16	714.72	32.49
July	198.56	36.19	823.51	37.43
August	112.48	37.49	804.12	36.55
September	100.04	33.35	660.88	30.04
October	74.75	24.92	467.09	21.23
November	73.20	24.40	396.45	18.02
December	27.79	9.26	164.88	7.49
January	48.59	16.20	292.24	13.37
February	69.12	23.04	434.14	19.73
March	75.00	25.00	516.34	23.47
April	78.94	26.31	536.01	25.95

3. Students should then create a line graph showing the per panel output in kWh by month for the past year of data for the Ground West and Pavilion Mono solar panels. The graph should have two lines, one for the Ground West and one for the Pavilion Mono panels. The shown below is an example that uses the above data.



Teacher's Note:
If students do not have access to a spreadsheet and graphing program, please use the blank table and graph provided with this lesson.

4. Questions on the handout then guide students through analyzing and interpreting the data, applying their knowledge to additional scenarios, and presenting a plan for arrangement and use of PV solar technology systems to maximize energy production at various locations throughout a year.

Answers to Questions on Student Handout

1. The Ground West array produced the most energy from August through April. Conversely, the Pavilion Mono array produced more energy in May through July.
2. The table should be completed as follows:

Season	Spring	Summer	Fall	Winter
Array Producing the Most Energy Per Panel (kWh)	Ground West	Pavilion Mono	Ground West	Ground West

3. a. One would expect the Pavilion Mono to produce more energy in the summer because it has a smaller angle of incline (10°), which allows the sun's rays to hit more directly (closer to a 90° angle) when the sun is higher in the sky during the summer. One would expect the Ground West array to produce more energy in the winter because of its larger angle of incline (36°) when the sun is lower in the sky.

   b. Answers will vary. If Stone Laboratory's data do not support the hypotheses above, this could be a result of equipment malfunction on one set of panels. It could also be due to the fact that the angle difference between the two panels is not drastic. Therefore, even small issues with equipment, tree shading, weather, etc. can affect the data output.

4. This will vary depending on the location and calendar year of the school. Many Ohio schools are in session August through May, and have a greater energy demand in those months than in the summer. Assuming the array cannot be moved, an angle close to latitude tilt (~42°) is preferred since school is not in session in the summer when a smaller angle is more beneficial. Schools at higher latitudes would place their PV solar arrays at an even greater angle, whereas schools at lower latitudes would place their PV solar arrays at a smaller angle.

5. Miami, Florida sits at approximately 26° north latitude; the city receives more direct sunlight in the summer months than winter months. The PV solar panels should be installed at an angle lower than 26° (potentially near 10°) as there will be a greater energy demand in the summer than winter months.
6. Duluth, Minnesota sits at approximately 46.7°.
   a. The PV solar panels should be installed at the same angle as the city's latitude to maximize energy production throughout the course of the year.
   b. Duluth receives more direct sunlight in the summer than winter months. Thus, the PV solar panels should initially be installed at an angle less than 46.7° (potentially almost near 30°). As fall approaches the angle should be increased and ultimately be slightly greater than 46.7° in the winter months. The angle needs to be greater as Duluth is tilted further from the sun in winter months. As spring arrives, the angle should be reduced back towards 46.7° and even less as Duluth receives more direct sunlight during summer months.

ELABORATE

Integrate engineering skills into the activity. Provide students with a small PV solar panel and a variety of recycled building materials (cardboard, foam, wood scraps, dowel rods, tape, glue, etc.). Assign each group of students a city and provide them with this prompt:

You work for a solar technology installation firm. You have clients that are unhappy with their PV solar panels not generating maximum energy due to the angle of the sun and its movement throughout the year. Using only recycled or reused materials found at home or school, design a model of a system that would maximize the energy generated from the PV solar panels year-round that you could offer your clients. Additionally, develop a short presentation that explains and justifies the rationale of your design.

A number of websites are available for students to research installation angles, PV solar panel movement, and structural designs. A few examples include:

pvsolar.com
energy.gov/science-innovation/energy-sources/renewable-energy/solar
nrel.gov

EVALUATE

The following questions can be used on formative assessments to evaluate students' understanding and application of concepts in this activity.

You are designing a PV solar panel array for a new home in Phoenix, Arizona; the owners plan to live there year-round.

a. Scenario A: The owners are asking for stationary panels where the angle cannot be changed. To maximize energy production, at what angle should they set the PV solar panels? Justify your reasoning.

b. Scenario B: The owners are willing to pay the extra costs associated with installing the PV solar panels on a mobile frame that allows for the angle of the panels to change. The panels will be installed in November. To maximize energy production, at what angle should they initially place the PV solar panels? Develop a monthly plan for how the owners should shift the PV solar panels each month.

SOURCE

Solar Energy Curriculum Consortium

Lead: Kristen Fussell, Research Development and Grants Manager, Ohio Sea Grant and Stone Laboratory
Susan Bixler, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Angela Greene, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Lyndsey Manzo, Education & Outreach Assistant, Ohio Sea Grant and Stone Laboratory
Erin Monaco, Program Assistant, Ohio Sea Grant and Stone Laboratory
Eric Romich, OSU Extension Field Specialist, Energy Development
Kristin Stanford, Education & Outreach Coordinator, Ohio Sea Grant and Stone Laboratory

Name ____

Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

PRE-INVESTIGATION CHECKPOINT

Match each term with the phrase that best describes it:

1. ______ otherwise known as photovoltaic cells
2. ______ generated by movement of a loop of wire or a disk of copper between the poles of a magnet
3. ______ converts direct current to alternating current
4. ______ measures the amount of electricity supplied or produced
5. ______ an energy source that has the potential to provide for all of Earth's energy needs

A. inverter B. sun C. meter D. solar panels E. electricity

Using the five terms above, write a short description of the process of how solar energy can be transformed to electricity.

____

____

____

____

Name ____

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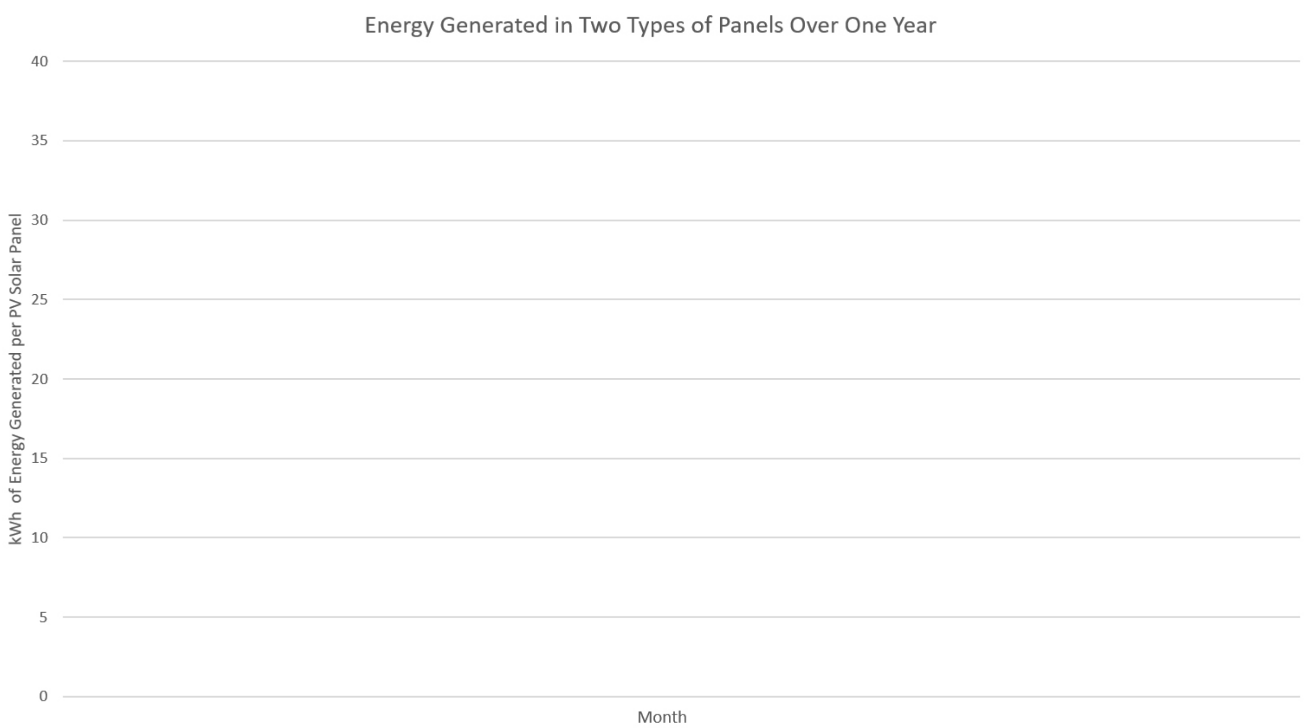
Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

HOW DOES THE ANGLE OF A SOLAR PANEL AFFECT ENERGY PRODUCTION THROUGH TIME?

	Energy Output (kWh)			
Month	Ground West Total (3 panels)	Ground West Per Panel	Pavilion Mono Total (22 panels)	Pavilion Mono Per Panel



Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

Student Activity

Name ______________________________

BACKGROUND

The Ohio State University's Stone Laboratory sits on the 6.5-acre Gibraltar Island in the harbor at Put-in-Bay, Ohio in Lake Erie. Established in 1895, it is the oldest freshwater biological field station in the country. As facilities were renovated in 2013, **photovoltaic (PV) solar panels** and solar thermal installations were placed on the island to reduce energy consumption. The installations were designed to maximize usage for education, research, and outreach opportunities (Figure 1).

On the left side (west) of Figure 1, the solar pavilion is visible with 44 240-watt panels. Half of the panels (22) are monocrystalline silicon (15% efficiency, a little more expensive, and normally a little more efficient on cloudy days) and half are polycrystalline silicon (14% efficiency and a little less expensive). Two 3-panel monocrystalline ground mounts are in front of the pavilion.

In this activity you will measure and use the angles at which the sun's rays strike Earth's surface to design a PV solar arrangement that maximizes electrical energy production. Then using the results of the investigation and a thorough analysis of real-time data from various PV solar panels at Stone Laboratory, you will present plans for arrangement and use of PV solar technology systems to maximize energy production in various locations throughout a year.

Figure 1: Solar Panel Installations at Stone Laboratory. Circles highlight the Ground West mount and Solar Pavilion panels used in this lesson.

PROCEDURE

PART 1: PREPARING FOR THE INVESTIGATION

1. Visit ***ohioseagrant.osu.edu*** and scroll to the middle of the page to access the Solar Panel Data (right side).
2. Click on *Solar Dashboard* and then *How It Works*. Click through the five tabs under How It Works to learn how solar energy is converted into electrical energy. Be prepared for your teacher to check your understanding of the basic process of how solar technology works.

PART 2: HOW DOES THE ANGLE OF THE SUN'S RAYS INFLUENCE ENERGY PRODUCTION IN A PHOTOVOLTAIC SOLAR CELL?

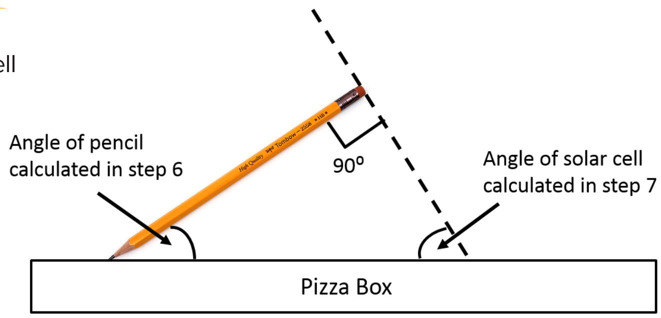
Photons may be reflected away from, pass through, or be absorbed by PV solar cells. Only the absorbed photons provide energy to generate electricity. Identifying the angle at which the sun's photons strike Earth's surface and understanding how sunlight interacts with the PV solar panel allows for the optimal performance of a solar energy system.

Follow the directions below to determine the angle at which the sun's rays are currently striking Earth's surface.

1. Note the time of day and location of your investigation.
2. Place a pizza box on a flat sunny surface.
3. Carefully straighten the paperclip and insert it into the pencil eraser creating a handle.
4. Place the sharpened end of the pencil on the center of the box surface and hold the paperclip handle.
5. Use the pencil shadow to identify the angle the sun's rays are striking Earth's surface. (Hint: Face the pencil eraser toward the sun and adjust it until there is no shadow.)
6. Use a protractor to measure the angle between the pizza box and pencil; this is the angle the sun's rays are hitting Earth. Record the angle of the pencil.
7. Calculate the proper angle for the placement of a solar panel so the sun's rays hit the solar panel at a 90^0 angle.

The sum of the inside angles of a triangle is 180°.
180° - 90° - angle of the pencil = angle of the PV solar cell

Your teacher may provide you with a ruler to hold perpendicular to the eraser end of the pencil so that you can confirm the calculated angle.



Location	Time of Day	Angle of the Sun's Rays	Angle of the Solar Cell

Now determine the angle at which the solar panel produces the most electricity.

8. Use tape to fasten the mini solar cell to the top of the pizza box.
9. Connect the voltmeter or multimeter to the alligator clips.
10. Experiment by positioning the pizza box top at different angles (measured by the protractor) and note the voltage output on the voltmeter or multimeter. Record the results of at least five angles different from the one previously calculated.

Angle of Solar Panel								
Electricity Produced (volts)								

QUESTIONS

1. At what angle did the solar panel produce the most volts? What does this indicate about the current location of the sun?

2. Pick a season different from the current one. Would you hypothesize that your angle of greatest productivity would increase or decrease during that season and why?

PART 3: HOW DOES THE ANGLE OF A SOLAR PANEL AFFECT ENERGY PRODUCTION THROUGH TIME?

Follow the directions below and use an online graphing program to analyze the energy output by season in two different panel arrangements at Stone Laboratory.

1. Go to ***ohioseagrant.osu.edu*** and scroll halfway down the page to find the *Solar Panel Data* on the right hand side of the page. Click on *Solar Dashboard* to access more detailed information.
   a. Clicking on *Live Data* will display the nine types of solar technology across the top of the screen; clicking on the tabs displays the total kilowatt hours (kWh) of energy produced by that type of panel.
   b. The tabs to change the time interval of the graphs (days, weeks, months, years, lifetime) are on the right side of the screen.
   c. Clicking on a bar graph will display the exact amount of energy produced.
2. You will work with data from the last 12 months for the three panels on the western ground mount (Ground West) and the 22 monocrystalline silicon panels on the solar pavilion (Pavilion Mono). Months are shown with the current month as the last bar on the graph (not necessarily January).
   a. Create a spreadsheet with five columns: Month, Ground West Total, Ground West Per Panel, Pavilion Mono Total, Pavilion Mono Per Panel
      i. Data in the columns “Ground West Total” and “Pavilion Mono Total” come directly from the website.
      ii. Calculate energy production per panel by dividing the total value by 3 (for the Ground West panels) or 22 (for the Pavilion Mono panels).
   b. Create a line graph showing the per panel output in kWh by month for the past year of data for the Ground West and Pavilion Mono solar panels. The graph should have two lines, one for the Ground West and one for the Pavilion Mono panels. Be sure to include a title, key, and axis labels on your graph.

QUESTIONS

1. Which solar array (Ground West or Pavilion Mono) produced the most kWh of energy per panel for each month of the year?

2. Complete the chart. Which solar array (Ground West or Pavilion Mono) produced the most kWh of energy per panel for each season?

Season	Spring	Summer	Fall	Winter
Array Producing the Most Energy Per Panel (kWh)				

3. Consider the different angles of the panels (Ground West = 36° and Pavilion Mono = 10°) in each type of array.
   a. Explain which array you would expect to produce more energy per panel in the summer. Explain which array type you would expect to produce more energy per panel in the winter.

   b. Do the real-time data collected by Stone Laboratory support the above hypotheses? If not, provide reasons why this may be.

4. You are designing a stationary PV solar panel array for your school. Based on the geographic location and calendar of your school, at what angle should the PV solar panels be installed? Justify your reasoning.

5. You are designing a stationary PV solar panel array for a new home in Miami, Florida; the owners plan to live there only from May through August. To maximize energy production, at what angle should the PV solar panels be installed? Justify your reasoning.

6. You are designing a PV solar panel array for a new home in Duluth, Minnesota; the owners plan to live there year-round.
   a. Scenario A: The owners are asking for stationary panels where the angle cannot be changed. To maximize energy production, at what angle should the PV solar panels be installed? Justify your reasoning.

   b. Scenario B: The owners are willing to pay the extra costs associated with installing the PV solar panels on a mobile frame that allows for the angle of the panels to change. The panels will be installed in June. To maximize energy production, at what angle should they initially place the PV solar panels? Develop a seasonal plan for how the owners should shift the PV solar panels throughout the year.
   Justify your reasoning.

Instructions for using a Multimeter

WHAT IS A MULTIMETER?
A multimeter is a tool that combines the functions of an ammeter, voltmeter, and ohmmeter, which allows you to measure current, voltage, and resistance with one device. Because the multimeter can be used for various electrical measurements, it is essential that you plug the probe test leads into the proper terminal for the measurement (current, voltage, or resistance) you are recording.

This is a guide to help you properly use a multimeter to measure the voltage and current when using the Solar Technology Curriculum. Some of these activities use photovoltaic solar cells that produce a DC voltage to construct various circuits. While multimeters can measure both DC and AC voltage, AC voltage is not included in the scope of this guide.

MEASURING VOLTAGE

1. Plug the black probe into the common ‘COM’ terminal of the multimeter.

2. Plug the red probe into the VΩmA terminal.

3. Set the multimeter Function/Range selector to the appropriate DC voltage mode (indicated by a V with a solid bar over it, not a sine wave ~).

   Note: Each setting on the dial lists the maximum voltage that can be measured in that range setting. If you are unsure what range to select, start with the highest range setting and work your way down to achieve the desired setting.

4. Place the red probe on the positive terminal, and the black probe on the negative terminal.

   Note: If you reverse the probes you will still get an accurate voltage measurement, however it will give you a negative reading.

5. Record the results on the digital display screen.

MEASURING CURRENT

1. Plug the black probe into the common 'COM' terminal of the multimeter.

2. Plug the red probe into the DC10A terminal.

3. Set the multimeter Function/Range selector to the appropriate Amps range position.

> **Note:** There are numerous types of multimeters with various ranges, however many have range settings allowing you to measure a current range from 0 to 200mA (milliamps) to 10A (Amps). To avoid blowing a fuse in the multimeter, start with the 10A jack until you are sure that the current is less than 200mA.

4. Disconnect the power source to the circuit.

5. To measure current, the multimeter must be included as part of the circuit. Place the red probe on wire that was disconnected and the black probe on the wire or location where the circuit was disconnected in the step above.

> **Note:** If you reverse the probes you will still get an accurate current measurement, however it will give you a negative reading.

6. Reconnect the power source to the circuit.

7. Record the results on the digital display screen.

SAFETY WARNINGS

To avoid electrical shock and/or damage to the multimeter, always read the owner's manual including the safety and warning precautions, general use procedures, and service requirements.

Always consider electrical sources, circuits, and electronic equipment to be energized. Always keep your fingers behind the probe finger guards when taking measurements and do not use a multimeter or test leads that appear to be damaged.

Solar Technology Curriculum Vocabulary

Absorption - The passing of a substance or force into the body of another substance.

Active Solar Heater - A solar water heater or space-heating system that uses pumps or fans to circulate the fluid (water or heat-transfer fluid like diluted antifreeze) from the solar collectors to a storage tank system.

Ampere - A unit of measure for an electrical current; the amount of current that flows in a circuit at an electromotive force of one Volt and at a resistance of one Ohm. Abbreviated as amp.

British Thermal Unit (BTU) - The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit; equal to 252 calories.

Circuit(s) - A conductor or a system of conductors through which electric current flows.

Current (Electrical) - The flow of electrical energy (electricity) in a conductor, measured in amperes.

Conductor - The material through which electricity is transmitted, such as an electrical wire, or transmission or distribution line.

Convection - The transfer of heat by means of air currents.

Electrical Energy - The energy associated with electric charges and their movements.

Energy - The ability to do work or the ability to move an object. Electrical energy is usually measured in kilowatt hours (kWh), while heat energy is usually measured in British Thermal Units (BTU).

Heat Exchanger - Any devise that transfers heat from one fluid (liquid or gas) to another or to the environment.

Heat Transfer Fluid - A gas or liquid used to move heat energy from one place to another; a refrigerant.

Induction - The process of producing an electrical or magnetic effect through the influence of a nearby magnet, electric current, or electrically charged body.

Insulation - Materials that prevent or slow down the movement of heat.

Insulator - A device or material with a high resistance to electricity flow.

Kinetic Energy - Energy available as a result of motion that varies directly in proportion to an object's mass and the square of its velocity.

Load - The power and energy requirements of users on the electric power system in a certain area or the amount of power delivered to a certain point.

Mechanical Energy - The energy of motion used to perform work.

Nonrenewable Fuels - Fuels that cannot be easily made or "renewed", such as oil, natural gas, and coal.

Ohm - The unit of resistance to the flow of an electric current.

Ohm's Law - In a given electrical circuit, the amount of current in amperes (i) is equal to the pressure in volts (V) divided by the resistance, in ohms (R).

Parabolic Trough - A solar energy conversion device that uses a trough covered with a highly reflective surface to focus sunlight onto a linear absorber containing a working fluid.

Parallel Connection - A way of joining photovoltaic cells or modules by connecting positive leads together and negative leads together; such a configuration increases the current, but not the voltage.

Passive Solar Heater - A solar water or space-heating system in which solar energy in collected, and/or moved by natural convection without using pumps or fans.

Photovoltaic Conversion - The process by which radiant (light) energy is changed into electrical energy.

Photovoltaic Cells - A device, usually made from silicon, which converts some of the energy from light (radiant energy) into electrical energy. Another name for a solar cell.

Potential Energy - Energy available due to position.

Power - The rate at which energy is transferred. Electrical energy is usually measured in watts (Watts = Volts x Amps). Also used for a measurement of capacity.

Radiant Energy - Any form of energy radiating from a source in waves.

Radiation - Any high-speed transmission of energy in the form of particles or electromagnetic waves.

Renewable Energy - Energy derived from resources that are regenerative or for all practical purposes cannot be depleted. Types of renewable energy resources include moving water, (hydro, tidal and wave power), thermal gradients in ocean water, biomass, geothermal energy, solar energy, and wind energy.

Resistance - The inherent characteristic of a material to inhibit the transfer of energy. In electrical conductors, electrical resistance results in the generation of heat. Electrical resistance is measured in Ohms. The heat transfer resistance properties of insulation products are quantified as the R-value.

Resistor - An electrical device that resists electric current flow.

Semiconductor - Any material that has a limited capacity for conducting an electric current. Certain semiconductors, including silicon, gallium arsenide, copper indium diselenide, and cadmium telluride, are uniquely suited to the photovoltaic conversion process.

Series Connection - A way of joining photovoltaic cells by connecting positive leads to negative leads; such a configuration increases the voltage.

Volt (V) - The volt is the International System of Units (SI) measure of electric potential or electromotive force. A potential of one volt appears across a resistance of one ohm when a current of one ampere flows through that resistance.

Voltage - The difference in electrical potential between any two conductors or between a conductor and ground. It is a measure of the electric energy per electron that electrons can acquire and/or give up as they move between the two conductors.

Watt - A metric unit of power, usually used in electric measurements, which gives the rate at which work is done or energy used.

All terms and definitions were retrieved from the following sources:

U.S. Department of Energy. (2016, June). *Glossary of Energy-Related Terms*. Retrieved from Office of Energy Efficiency and Renewable Energy: ***http://energy.gov/eere/energybasics/articles/glossary-energy-related-terms#C***

U.S. Department of Energy Energy Information Administration (USDOE/EIA). (2016, June). *Glossary*. Retrieved from Energy Kids U.S. Energy Information Administration: ***http://www.eia.gov/kids/energy.cfm?page=kids_glossary#top-container***