Good Day Sunshine!

Student Objectives
The student:
- will explain how the intensity of sunlight varies throughout the day
- will explain the relationship between irradiance and the electrical output of a photovoltaic device
- given a graph of irradiance, will deduce what the weather was for the given day
- given the size of a photovoltaic array, the amount of available sunlight and a fixed rate for electricity, will calculate the monetary savings.

Key Words:
intensity
irradiance
photovoltaic array
Sun Hours
watts/kilowatts

Time:
2 class periods

Materials:
- small photovoltaic panel with an amperage output in the range of 300-500 mA (1 per group)
- wires with alligator clips (2 per group)
- milliamp meter (1 per group)
- Science Journal pages

Background Information

Local weather has a dramatic effect on the electrical output from a photovoltaic array. The most obvious factor is cloud cover, but temperature also affects the output from the array (higher temperatures decrease the electrical output slightly). Additionally, in areas without adequate rainfall, the photovoltaic output can be adversely affected by an accumulation of dust and bird droppings, and of course snow cover will block sunlight from reaching the surface of the solar cells. Luckily in Florida, we don’t usually have to worry about either of these two conditions!

Irradiance is the measure of the intensity of sunlight, and is expressed as watts per square meter (W/m^2). On a sunny, cloudless day at solar noon, at sea level, the typical irradiance level is 1,000 W/m^2. This value of irradiance is used as the standard test condition (STC) for photovoltaic testing and design calculations, and is the basis of the manufacturers stated output for cells and panels, which is displayed on the back of full-sized photovoltaic panels.

On a clear cloudless day, irradiance will peak at solar noon; a graph of irradiance over time will produce a bell shaped curve. Large banks of clouds, thunderstorms and weather fronts are all readily apparent on a graph of irradiance, and since photovoltaic output is directly related to irradiance, these weather events can be seen on a graph of the output.

On consistently overcast days, the curve will have the same width but will be much lower, and on partly cloudy days with patches of clouds intermingled with bright sun, the curve will tend to be spiky, showing that the system produces more energy during sunny periods and less energy during cloudy periods.

Procedure (Day 1)

Note: With younger students and/or students who have not been exposed to line graphs, you may want to use only the Day 1 activity, followed up with a discussion on how the Sun's intensity increases in the morning and decreases in the afternoon.

1. If possible, plan this activity for a clear, cloudless day. If that is not possible, try to time the measurement sessions for "between clouds", so that the group's measurements will be taken in full-sun conditions. Plan to take the first measurement early in the morning, and take additional measurements throughout the day, at 1 to 1 ½ hour intervals, with the last measurement as late in the afternoon as possible.
2. Lead a review discussion on the findings from the *Solar Powered System* activity as it related to sun and shade**.**
3. Tell the students that they are going to be doing an experiment to find out if the electricity generated from a solar cell varies depending on the time of day.
4. Pass out the materials to the lab groups and remind the students:
    - to connect the positive wire from their solar cell to the positive lead on the back of the milliamp meter
    - to keep the bare metal on the alligator clips from touching each other (and shorting out the circuit)
    - to angle their solar cells towards the sun
5. Explain to the students that they will be taking measurements throughout the day and recording them in their Science Journal.
6. Lead students out to a sunny area and help as needed. Repeat this several times throughout the day. (*Note: you will be discussing their data the following day*)

Procedure (Day 2)

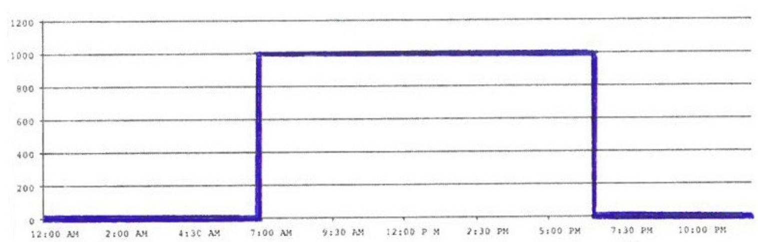
1. If the students did not get a chance to answer the questions and graph their data from the previous day, give them a few minutes to complete their Science Journal.
2. Lead a review discussion on their findings from the previous day. Discuss any discrepancies in data between groups, or any problems encountered drawing their graphs. Make sure that everyone agrees that the amount of electricity (in milliamps) increased as it approached solar noon and decreased again later in the day. *Note: If the class data did not support this (for example, the weather changed unexpectedly) discuss with the students what happened, and if possible, repeat the Day 1 activity before continuing.*
3. Draw graph axes on the board.
    - Label the x-axis "Time of Day" and have the students help you break it into hour

increments from 12:00 am to 11:00 pm.

- Label the y-axis "Irradiance - Amount of Sunlight", and break it into 12 sections labeled 0 Wm^2 through 1200 Wm^2. Tell them this is the measurement of the intensity of the sun from "0" (no sunlight) to 1200 (the brightest natural sunlight at sea-level on Earth).

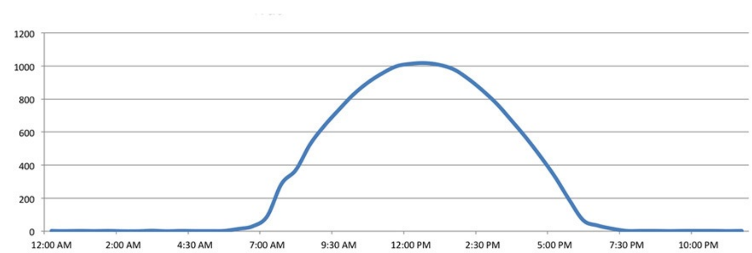
3. Tell the students that as a class they are going to figure out what a graph of the amount of sunlight hitting the ground (and a solar array) on a clear, sunny day would look like. Lead a discussion on sunlight, graphing alternatives for the students to discuss:

- Draw a horizontal line across the graph and state something like: "Since we are graphing a clear day–without clouds–our graph would look something like this, right?" Get the students to disagree with you and state that the sun isn't "out" at night and early morning.
- Get the students to agree on a sunrise and sunset time to use on the graph, erase the horizontal line and then draw a "table' shape on the graph, something like this:



Ask the students if this graph is correct. Lead a discussion about the intensity, brightness and heat of the sun in the morning and the evening. The students should agree that sunlight becomes more intense during the day and then decreases in the afternoon with the "peak" sometime around noon.

- Draw a bell shaped curve on the graph with the peak at noon and 1000 Wm^2. Ask the students if they agree on it.

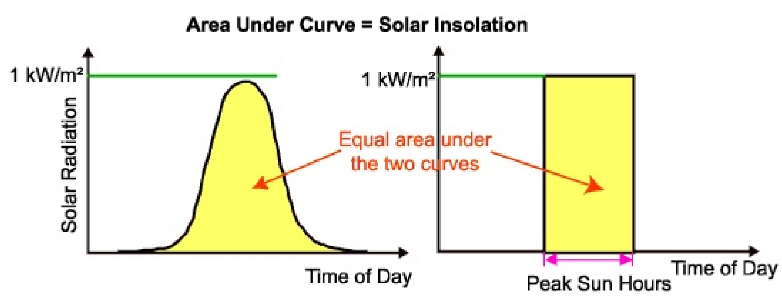


- Ask them what they think will happen to the Sun's intensity if a large thunderstorm occurs around 3:00 pm. Have a student come up and alter the graph and discuss it. *(Note: The students should realize that although there will be a deep dip in the amount of sunlight, it probably won't dip all the way to "0" on the y-axis. Additionally, most of the time when a storm rolls in, the amount of light doesn't drop instantly, so their line should have a bit of a curve to it.)*

4. Students should complete their Science Journal. Assist them as needed.
5. After the students complete their Science Journal pages, lead a discussion on their answers. Points to include are:
   - One measurement (weather) may be inferred by looking at another measurement (in this case the amount of sunlight).
   - The amount of electricity that a photovoltaic solar system produces is directly correlated to the irradiance (intensity) of the sunlight hitting it.
   - Have some students share their graphs of the amount of irradiance they remembered from yesterday. Discuss why there are differences between the graphs (*accuracy of memories, individual interpretation*). Ask the students how they could obtain an accurate graph (*use measuring equipment and graph the results of a current or future day, or alternately see if any scientists were obtaining measurements for the day that has passed.*)

Key Words and Definitions

- **intensity** – extreme degree of strength, force or energy
- **irradiance** – the measure of the power density of sunlight. Irradiance is expressed in watts per square meter.
- **photovoltaic array –** larger size solar system composed of several modules
- **Sun Hours** – (sometimes referred to as Peak Sun Hours) the average daily amount of sunlight in units of kWh/m^2 that an area receives when the total amount of sunlight is converted to the same unit. This enables the quantity to be compared and used mathematically.



- **watts / kilowatts** – the standard unit used to measure electricity, specifically the rate at which electrical energy is dissipated. Kilowatts are one thousand watts.

Further Research

1. Complete the Further Research section on Sun Hours.
2. Help your students complete the Further Research section *$olar $avings*:
   - Divide the students into 12 groups, one for each month of the year.
   - Tell the students that they will be working in groups to predict how much electricity a typical array that is mounted on a house will produce each month, and how much money that array will save.

- Assign each group a month of the year, and tell then they will be calculating the power production for that month and how much money the system will save in electricity costs.
- Have the students complete the problems in the Further Research section. Provide them with insolation charts from the same latitude and climate pattern as your location. If local charts aren't available, the insolation chart for Orlando that was used in the activity may be substituted. Assist the students as necessary.
- Write 'kWh Production and $ Savings' on the board with the months listed below in a column on the left and space to the right for the groups' totals. After all the groups have finished their calculations have the groups write their totals on the board.
- Discuss with the students how local weather has affected the totals each month.
- With the student's input, total the electricity production for the year, and calculate the yearly cost savings. Have the students speculate if this size system would be enough to power their house *(It should be. Some students in the class may have an idea how much their electricity bill is to verify this)*.
- Ask the students if a system this size would be enough to power the school. *(No. The students should realize that their school uses a lot more electricity than one house does)* Ask the students how something as large as a school could be powered by solar *(By having a larger array–maybe covering a large part of the school's roof).*

3. Locate on the internet a school with a photovoltaic system that provides data on the output of their system. (*Note: A good place to start is* ***energywhiz.com***). If possible, use a school that is nearby or one that usually has the same general weather patterns as your school. Print out and compare graphs of irradiance and power output and compare those results to the recorded weather for the given days. Discuss the differences and similarities.

Related Reading

- ***Catch the Wind, Harness the Sun: 22 Super-Charged Projects for Kids*** by Michael Caduto (Storey Publishing, 2011)
  Twenty-two projects plus stories, background information, cartoons and photos covering solar thermal, photovoltaics, solar cooking, climate change, energy production and energy conservations–plus wind energy!
- ***Teaching Electricity: Yes, You Can: Grades 3 - 6*** by Steve Tomecek (Scholastic, 1999)
  Use balloons, paper clips and other easy-to-get stuff for super easy, super-cool activities that light up kids' science learning. Each lesson includes background information along with simple activities.
- ***The Kids' Solar Energy Book*** by Tilly Spetgang (Imagine, 2009)
  With cartoon drawings the author engages the reader in a classroom where students explore solar energy and today's technology: active systems, passive solar, and the conversion of sunlight into electricity. In addition the book covers the cost advantages of energy efficient buildings and changes over time in the production and price of photovoltaics.

Internet Sites

http://www.energywhiz.com/

Florida Solar Energy Center's website for the SunSmart Schools data.

http://www.solarpowersimulator.com/

This Solar Power simulator lets you control the input (amount of sunlight) and load (appliances) and see how much electricity is being generated, how much is being sent to the batteries, and how much electricity is going out to the loads.

http://www.weather.com/

The Weather Channel provides local weather conditions and historical data.

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Florida NGSS Standards & Related Subject Common Core

			.1	.2	.3	.4	.5	.6	.7	.8
Grade 3										
The Practice of Science	**Big Idea 1**	**SC.3.N.1**	X	X	X		X	X	X	
Earth in Space and Time	**Big Idea 5**	**SC.3.E.5**		X						
Forms of Energy	**Big Idea 10**	**SC.3.P.10**	X							
Grade 4										
The Practice of Science	**Big Idea 1**	**SC.4.N.1**	X	X		X	X	X		
Earth in Space and Time	**Big Idea 5**	**SC.4.E.5**			X					
Forms of Energy	**Big Idea 10**	**SC.4.P.10**	X							
Grade 5										
The Practice of Science	**Big Idea 1**	**SC.5.N.1**	X							
Forms of Energy	**Big Idea 10**	**SC.5.P.10**	X							
Mathematics Standards	**Third Grade:** MAFS.3.OA.4.8, MAFS.3.MD.2.3 **Fourth Grade:** MAFS.4.OA.1.3, MAFS.4.MD.1.2, MAFS.4.MD.2.4 **Fifth Grade:** MAFS.5.NBT.2.5, MAFS.5.MD.1.1, MAFS.5.G.1.2									

Third Grade Benchmarks
Science–Big Idea 1: The Practice of Science

- SC.3.N.1.1 - Raise questions about the natural world, investigate them individually and in teams through free exploration and systematic investigations, and generate appropriate explanations based on those explorations.
- SC.3.N.1.2 - Compare the observations made by different groups using the same tools and seek reasons to explain the differences across groups.
- SC.3.N.1.3 - Keep records as appropriate, such as pictorial, written, or simple charts and graphs, of investigations conducted.
- SC.3.N.1.5 - Recognize that scientists question, discuss, and check each others evidence and explanations.
- SC.3.N.1.6 - Infer based on observation.
- SC.3.N.1.7 - Explain that empirical evidence is information, such as observations or measurements, that is used to help validate explanations of natural phenomena.

Science–Big Idea 5: Earth in Space and Time

- SC.3.E.5.2 - Identify the Sun as a star that emits energy; some of it in the form of light.

Science–Big Idea 10: Forms of Energy

- SC.3.P.10.1 - Identify some basic forms of energy such as light, heat, sound, electrical and mechanical.

Mathematics–Operations and Algebraic Thinking

- MAFS.3.OA.4.8 - Solve two-step word problems using the four operations. Represent these problems using equations with a letter standing for the unknown quantity. Assess the reasonableness of answers using mental computation and estimation strategies including rounding.

Mathematics–Measurement and Data

- MAFS.3.MD.2.3 - Draw a scaled bar graph to represent a data set with several categories.

Fourth Grade Benchmarks

Science–Big Idea 1: The Practice of Science

- SC.4.N.1.1 - Raise questions about the natural world, use appropriate reference materials that support understanding to obtain information, conduct both individual and team investigations through free exploration and systematic investigations, and generate appropriate explanations based on those explorations.
- SC.4.N.1.2 - Compare the observations made by different groups using multiple tools and seek reasons to explain the differences across groups.
- SC.4.N.1.4 - Attempt reasonable answers to scientific questions and cite evidence in support.
- SC.4.N.1.5 - Compare the methods and results of investigations done by other classmates.
- SC.4.N.1.6 - Keep records that describe observations made, carefully distinguishing actual observations from ideas and inferences about the observations.

Science–Big Idea 5: Earth in Space and Time

- SC.4.E.5.3 - Recognize that the Earth revolves around the Sun in a year and rotates on its axis in a 24-hour day.

Science–Big Idea 10: Forms of Energy

- SC.4.P.10.1 - Observe and describe some basic forms of energy, including light, heat, sound, electrical, and the energy of motion.

Mathematics–Operations and Algebraic Thinking

- MAFS.4.OA.1.3 - Solve multistep word problems posed with whole numbers and having whole-number answers using the four operations, including problems in which remainders must be interpreted. Represent these problems using equations with a letter standing for the unknown quantity. Assess the reasonableness of answers using mental computation and estimation strategies including rounding.

Mathematics–Measurement and Data

- MAFS.4.MD.1.2 - Use the four operations to solve word problems involving distances, intervals of time, liquid volumes, masses of objects, and money, including problems involving simple fractions or decimals, and problems that require expressing measurements given in a larger unit in terms of a smaller unit.
- MAFS.4.MD.2.4 - Make a line plot to display a data set of measurements in fractions of a unit.

Fifth Grade Benchmarks

Science–Big Idea 1: The Practice of Science

- SC.5.N.1.1 - Define a problem, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigations of various types such as: systematic observations, experiments requiring the identification of variables, collecting and organizing data, interpreting data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

Science–Big Idea 10: Forms of Energy

- SC.5.P.10.1 - Investigate and describe some basic forms of energy including light, heat, sound, electrical, chemical, and mechanical.

Mathematics–Number and Operations in Base Ten

- MAFS.5.NBT.2.5 - Fluently multiply multi-digit whole numbers using the standard algorithm.

Mathematics–Measurement and Data

- MAFS.5.MD.1.1 - Convert among different-sized standard measurement units within a given measurement system and use these conversions in solving multi-step, real world problems.

Mathematics–Geometry

- MAFS.5.G.1.2 - Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

National Next Generation Science Standards

Third Grade Standards

Science–Earth's Systems

- 3-ESS2-1 - Represent data in tables and graphical displays to describe typical weather conditions expected during a particular season.

Fourth Grade Standards

Science–Energy

- 4-PS3-2 - Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

Note: Related Common Core Mathematics Standards are listed in the Florida section above.

Good Day Sunshine!

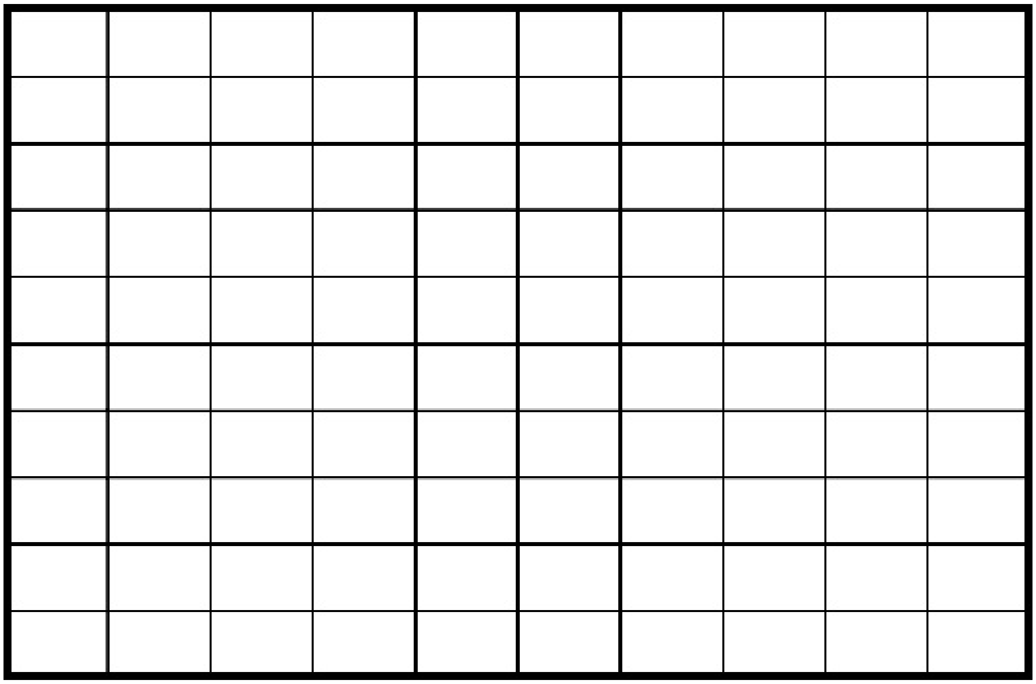
Day 1

1. Record the time and the milliamp reading in the graph below

Time	**Milliamps**

2. Describe your data. Are the recorded measurements the same? How did they change throughout the day?

3. Draw a bar graph from your data below. Label the x axis time (in hours from 9:00 to 3:00), and label the y axis milliamps (0, 50, 100, 150 to 500 mA)



4. Describe in words what your graph tells you about the amount of electricity produced by your panel during the day.

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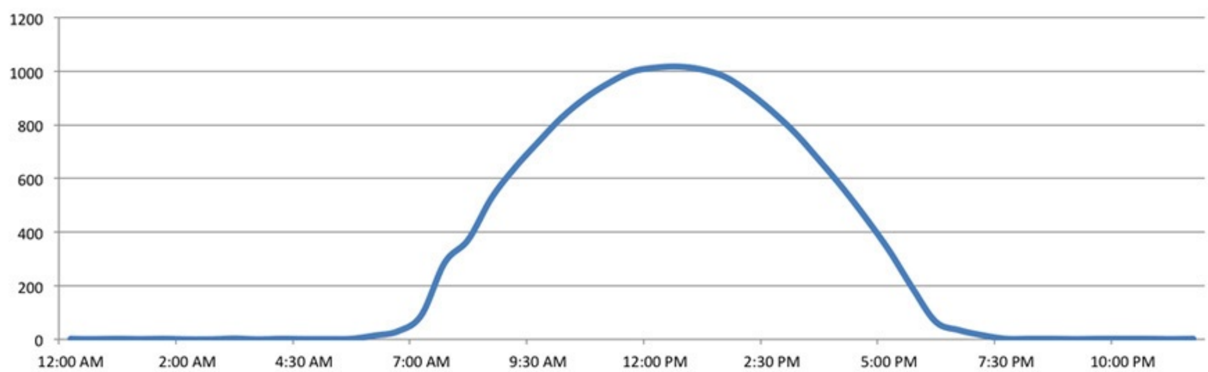
Day 2

Below is a graph of the amount of sunlight hitting a photovoltaic array.



1. About what time was sunrise on this day? ______________________________

2. About what time was sunset on this day? _______________________________

3. From the graph, what do you know about the weather on this day?

____

____

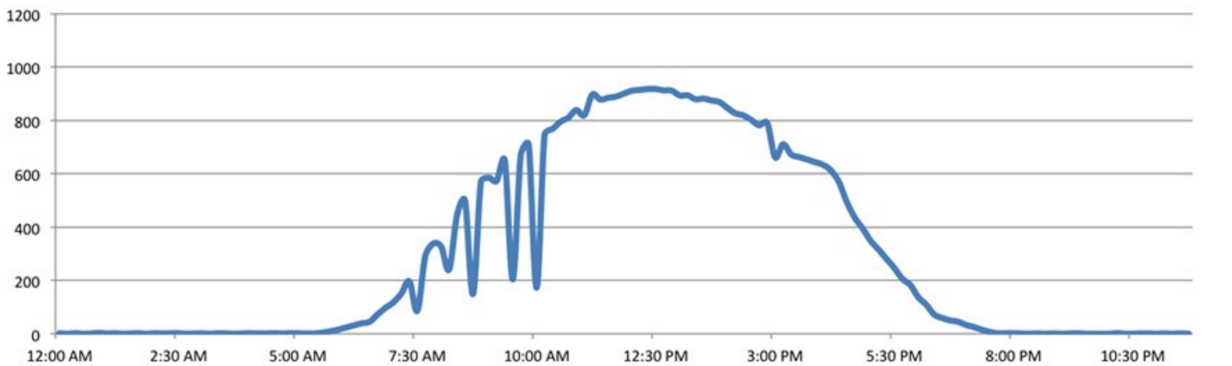
4. During what time of day would the photovoltaic array be producing the most electricity?

____

5. Why? ____

____

Below is a graph of the sunlight hitting the same photovoltaic array on a different day.



6. From the information on the graph, what do you think the weather was like in the morning?

____

____

____

7. What do you think the weather was like in the afternoon?

____

____

8. What was your weather like yesterday? Was it sunny? Cloudy? Rainy? Write a description of yesterday's weather below.

____

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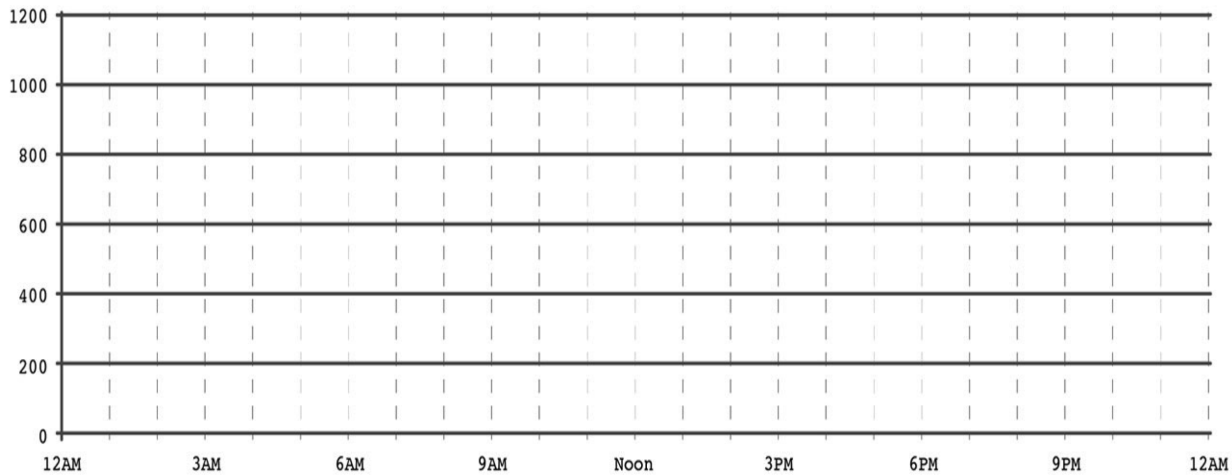
____

9. On the graph below, draw a line representing the Sun's intensity as you described it above (yesterday's weather).



Good Day Sunshine!

How Many Sun Hours Today?

Scientists have measured and recorded the brightness of the Sun (irradiance), all over the world since 1960. This data has been used to calculate the average amount of sunlight at these places during the year. In order to be able to compare sunlight from different places, different seasons, and different weather, the data is changed into "Sun Hours". Sun Hours is the amount of time, on average, that the sun is very, very bright and strong. A very sunny day would have 4 - 6 Sun Hours but a cloudy day may only have 1 Sun Hour.

You learned that the way the panel is tilted towards the Sun changes how much electricity the panel makes. Since not all solar arrays are built with the same tilt, scientists also collected data on solar panels at different tilt angles. Scientists then put this data into charts for everyone to use.

One of these charts is below. It shows the Sun Hours for Orlando, Florida for solar panels that are flat to the ground (0^o tilt), 20^o, 30^o, and 40^o tilt off the ground.

Daily Irradiance (Sun Hours) – for Orlando, FL

Panel Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Yearly
0^o	3.14	3.92	4.99	5.99	6.27	5.78	5.68	5.28	4.72	4.11	3.46	2.92	4.69
20^o	3.92	4.56	5.36	6.01	5.99	5.41	5.37	5.18	4.90	4.63	4.23	3.74	4.94
30^o	4.19	4.75	5.39	5.85	5.67	5.07	5.06	4.99	4.86	4.75	4.49	4.04	4.93
40^o	4.37	4.82	5.31	5.56	5.24	4.63	4.66	4.69	4.71	4.76	4.64	4.24	4.80

Imagine that your school has a photovoltaic array, and that it has been installed at a 28^o angle to the ground. Use the tilt angle in the table above that is closest to this tilt angle to answer the following questions.

1. From the chart, which month has the greatest amount of Sun Hours, March or August? ____________________

2. We think of the summer months as being the most sunny and therefore the best for photovoltaic systems. From the table, do the summer months (June, July and August) have the most Sun Hours?

   ____

3. Which month has greatest amount of Sun Hours? ______________________

4. Which month has the least amount of Sun Hours? ______________________

8. Why do you think April and May have more Sun Hours than July?

____

____

____

____

____

Good Day Sunshine!

$olar $avings

1. How much electricity will a photovoltaic system on a house produce during the month you have been assigned? Here is how to figure this out!

- Month your group has been assigned: ___________________________

- Size of the system you are investigating: ________10__________ kW

  Tilt of the system you are investigating: ________30º__________ tilt

- From the Irradiance (Sun Hours) chart that your teacher gives you, write the number of Peak Sun Hours each day for the month you were assigned:

  ______________________ Peak Sun Hours per day

- Multiply the kW size of the system by the number of Peak Sun Hours per day for this month. That will give you the kilowatt hours per day of electricity the system produces. Label your total **kWh per day in <u>(your month)</u>**.

  ____

- What is the number of days in the month you were assigned? ______

- Multiply the number of days in your month by the number of kWh per day to get the total kWh of electricity your array will produce in the assigned month. Label your result **Total kWh for <u>(your month)</u>**

____

2. How much money does this array save the family in electricity cost during the month you were assigned? Use 12¢ per kilowatt hour for electricity cost.

    - Multiply the total kWh produced for the month by 12¢. Label your answer: **Money saved by the household in <u>(your month)</u>**. Watch your decimal place! Remember you are working with money!

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