We've Got the Power!

Key Words:
- amperage
- current
- direct current (DC)
- irradiance
- kilowatts per hour (kWh)
- photovoltaic array
- power
- voltage
- watts/kilowatts

Student Objective
The student:
- will explain the relationship between irradiance and the amount of power (DC) output of the photovoltaic array
- given a graph of a photovoltaic system's power output can deduce what the weather was for the given day
- given the weather outside and the time, can approximate the power output of the array.

Materials:
- computer or handheld device with internet access
- classroom projection equipment with internet access (alternately, overhead transparencies of the EnergyWhiz graphs can be used)
- web based weather application with current and historical (past month) weather data

Time:
1 class period

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 with higher temperatures slightly decreasing the electrical output. 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.

Irradiance is the measure of the intensity of sunlight, and is expressed as watts per square meter (W/m^2). On a sunny, clear-sky 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.

On a clear cloudless day, irradiance will peak at solar noon; a graph of irradiance over a day 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 correlated 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 (prior to class)

1. Familiarize yourself with the static graphs on the EnergyWhiz website, **http://energywhiz.com/data.php**. These can be accessed by selecting "Sample Data" on the photo toolbar in the center of the page.
2. Familiarize yourself with the data being collected for your school's system, or alternately with another photovoltaic system that has online data. If possible, use a system that is nearby or one that usually has the same general weather patterns as your school. Navigate through the different screens, so you will be able to guide your students in locating irradiance and DC output, and also historical data (irradiance and DC output) for the last month.
3. Locate a weather site that gives current and historical weather data for your school (or the area for the system that you are using).

Procedure (during class)

1. If necessary, divide the students into groups according to how many computers are available to them.
2. **Engage:** Lead the class in a discussion/review of their findings from previous lessons on the different factors that can affect the output of photovoltaics, making sure that weather is mentioned and discussed.
3. Tell the students that they will be investigating how weather conditions affect the amount of electricity that is produced in the array they are studying.
4. Lead a discussion on the nature of sunlight during the day.
   - Ask the class to describe how the "brightness" of sunlight changes throughout the day.
   - Guide the students to talk about how the light from the Sun gets stronger and brighter from dawn to solar noon, and then slowly gets weaker and dimmer until sundown.
5. **Explore and Explain:** Draw the framework of a two axis graph on the board (intensity of sunlight on the y and time on the x. Don't worry about putting any numerical values on the y axis yet). Ask students to draw on a sheet of paper what they think a graph of the intensity of sunlight would look like. (Students may work in groups or individually)
   - After the majority of students have put something on their paper, ask for a volunteer to share their idea on the board.
   - Lead a discussion about this graph; have students modify the graph to show their suggestions. Guide them if necessary.
   - When the students have closely approximated a bell shaped curve, write the EnergyWhiz website address on the board and have the students navigate there

and select the irradiance graph.

- Have the students explain how this graph is similar and different from the graph that they created. Ask the students to describe the weather for that day.

5. Have the students switch to the graph showing irradiance on a day with an afternoon rainstorm. They should be able to explain and point out sunrise, sunset, clouds and afternoon heavy clouds (thunderstorm).
6. Students should complete their Laboratory Manual.

Answer Key

1 - 2. Answers will vary slightly. Students should realize that an increase in irradiance increases the electrical output; they should collect appropriate data, and interpret it correctly in their graphs, equations and conclusions.

3 & 4. Answers will vary, but all times that the irradiance is greater than 1000 Wm^2 will be close to solar noon.

5. Students should have the correct system size in kW.
6. Any significant difference will be a result of a fault of system components. Small differences that follow the same curve most likely are caused by resistance in the wiring or small efficiency losses in the system components.
7. This answer should be 75% of the system size (nameplate rating).

Key Words & Definitions

- **amperage** – measure of the number of electrons flowing through a wire (current)
- **current** – the movement of electrons
- **direct current electricity (DC)** – an electric current flowing in one direction only. This type of electricity is typically used in battery operated devices, RVs, and boats
- **irradiance** – measure of the amount of sunlight at a particular time and place
- **kilowatt** – 1000 watts
- **kilowatts per hour (kWh)** – the standard unit used to describe electricity usage over time
- **photovoltaic array** – complete unit of solar modules
- **power** – common term used to refer to output in watts
- **voltage** – measure of the force of electricity in a circuit. The volt is not a unit of flow, it is analogous to pressure of water in a hose.
- **watts** – the standard unit used to measure electricity, specifically the rate at which electrical energy is dissipated. Watts are calculated by multiplying amperage and voltage.

Further Research

1. Access data from a photovoltaic array in a different state or county and predict the weather at that location, based off the power output. Check the weather service to see if you are correct.
2. If you have an array at your school, shade large areas of the array with sheets of cardboard or blankets to simulate heavy clouds. Observe the output. Then cover areas with screen

or gauze material to simulate hazy conditions. Observe the output.

Internet Sites

http://energywhiz.com/

EnergyWhiz is Florida Solar Energy Center's website for SunSmart Schools data, and student activities. Included are static graphs of an array during various weather conditions that can be used in the classroom for problems and discussions.

http://rredc.nrel.gov/solar/old_data/nsrdb/

National Solar Radiation Database contains 30 years (1961-1990) of solar radiation and supplementary meteorological data from 237 National Weather Service sites, plus a user manual to help in reading the tabular information.

http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/solar-radiation/

National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center is responsible for preserving, monitoring, assessing, and providing public access to the Nation's treasure of climate and historical weather data and information. Here you can find data on solar radiation and climate conditions in the United States.

http://en.openei.org/wiki/Main_Page

Open Energy Information (OpenEI) is a knowledge sharing online community dedicated to connecting people with the latest energy information and data.

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	9	10	11	12	13	14	15	16	17	18	19	20
Nature of Science																					
Standard 1	**SC.912.N.1.**	X																			
Earth and Space																					
Standard 5	**SC.912.E.5.**				X																
Physical Science																					
Standard 10	**SC.912.P.10.**	X														X					
Mathematics Standards		MAFS.912,N-Q.1.1, MAFS.912.S-ID.1.1, MAFS.K12.MP.3.1																			

Science–Standard 1: The Practice of Science
- SC.912.N.1.1- Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science, and do the following: 1) pose questions about the natural world, 6) use tools to gather, analyze, and interpret data, 7) pose answers, explanations, or descriptions of events, 8) generate explanations that explicate or describe natural phenomena, 9) use appropriate evidence and reasoning to justify these explanations to others.

Science–Standard 5: Earth in Space and Time
- SC.912.E.5.4 - Explain the physical properties of the Sun and its dynamic nature and connect them to conditions and events on Earth.

Science–Standard 10: Energy
- SC.912.P.10.1 - Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.
- SC912.P.10.15 - Investigate and explain the relationships among current, voltage, resistance, and power.

Mathematics–Number & Quantity
- MAFS.912.N-Q.1.1 - Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Mathematics–Interpreting Categorical and Quantitative Data
- MAFS.912.S-ID.1.1 - Represent data with plots on the real number line.

Mathematics–Mathematical Practice
- MAFS.K12.MP.3.1 - Construct viable arguments and critique the reasoning of others.

National Next Generation Science Standards
Energy

- HS-PS3-1 - Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component and energy flows in and out of the system are known.

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

We've Got the Power!

1. **Irradiance** is the scientific term for the amount of sunshine that strikes an object. How does the amount of irradiation affect the amount of electricity that your school's photovoltaic system produces? Write a hypothesis below that describes the mathematical relationship between the amount of solar irradiance and the electric output of your system.

2. Gather the data to verify your hypothesis. On the Energy Whiz website, (http://energywhiz.com/data.php), use irradiance and DC output graphs. Additionally, use your own school's data (if available), or the website for another location that your teacher provides. Write your findings and conclusion below, using graphs and/or equations to support your conclusion.

To simplify discussions about the output of photovoltaic cells, modules and arrays, scientists decided on a set of conditions, called Standard Test Condition (STC), that allow mathematical computations and comparisons to be made when input, output and module size are variable. The Standard Test Condition for irradiance is 1000 Wm^2. Irradiance of this value occurs during solar noon on a clear sunny day in most parts of the world; however, here in Florida we often will have sunny days that measure higher.

3. Look at the irradiance data you collected for question 2. Which dates and times had an irradiance level of 1000 Wm^2?

4. Did the irradiance level on any of these days measure greater than 1000 Wm^2? If so, list which date(s) and time(s) went above standard test conditions.

Once you know the irradiance level and the size of a system, you can predict how much electricity the system is producing. You may have noticed a "system size" in kW listed for the array you are studying. This is a shortcut that you can use when making calculations–it is the system's "nameplate" rating provided by the manufacturer. This value was obtained by testing and measuring the panel's output at Standard Test Conditions – 1000 Wm^2. Using this value, you can take the nameplate rating of any array and figure its projected output during all irradiance conditions, since irradiance and DC electrical output are a direct mathematical variation.

5. How much electricity will your system produce when the irradiance level is at STC (1000 Wm^2)? Find the "system size" in the array's description.

   Record it here: _____________

This value is how much electricity your system is expected to produce when the irradiance is 1000 Wm^2. To check your projection of output, check your graphs from question 2 for the times when the irradiance was 1000Wm^2.

6. Is your projection correct? Describe any difference. What might account for this difference?

7. What should your system produce when the irradiance is 750Wm^2?