SunSmart Schools

Note: This lesson is included for students in SunSmart Schools (and other schools that have a photovoltaic system), to learn about their system's operation. This lesson may be modified and used with any system (home, school, office, etc) that has online data that can be accessed by the students. In these cases, the other information that you will need to gather about the system to be used is: 1) the total "rated" output of the system (i.e. 10kW, 20.6 kW, etc), 2) the tilt angle of the array, and 3) a photo that is detailed enough for the students to count the number of modules in the array.

Student Objective
The student:
- can name the component parts and describe the function of each in a photovoltaic system
- can explain the system's data output and explain its function.

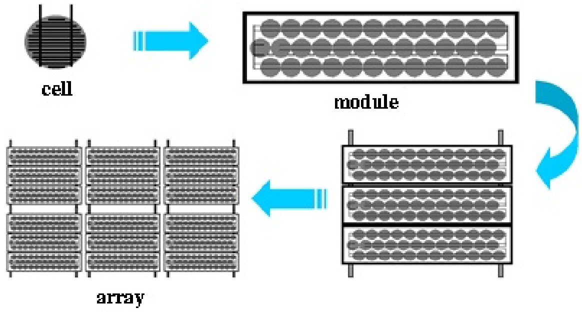
Materials:
- viewing access to a photovoltaic system (optimal) or photo of a system with available online data
- computer with internet access

Key Words:
alternating current (AC)
data acquisition system
direct current (DC)
distribution panel
inverter
kilowatt hours
photovoltaic array
photovoltaic cell
photovoltaic module
semiconductor material
silicon
voltage

Time:
1 class period

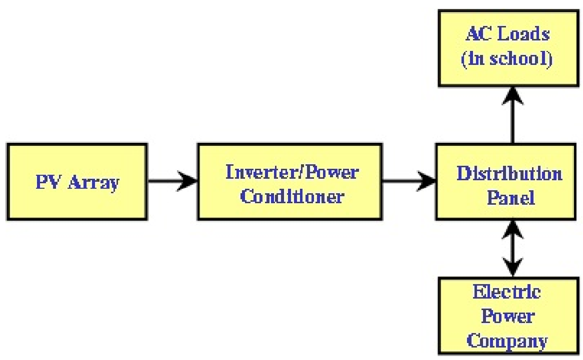
Background Information

Crystalline solar cells are made of the element silicon. When light shines on a solar cell, the energy of the light penetrates into the cell and "knocks" negatively charged electrons loose from their silicon atoms. The freed electron has potential energy (voltage). These freed electrons flow through the internal electro-static field and out of the cell. Silicon based solar cells produce only about ½ volt, so cells are connected together to give more useful voltages. Usually 30 - 36 solar cells are connected in a circuit to give a final voltage of about 15-17 volts in a module. To increase the power output further, modules are connected together to form an array.



After leaving the modules, the current is conditioned to match the voltage and current type in the electric lines coming from the power company. The energy output from the system can then be used in the building for lighting, computers, air conditioning, or any application powered by electricity. Depending on the size of the system, it may not produce enough energy to power all of the building's needs, but in that case it does reduce the amount of electricity that needs to be purchased from the electric company.

Parts of the Photovoltaic System



Photovoltaic array - The array which is made up of several photovoltaic modules, converts sunlight directly into electric current. Like batteries, the current produced is direct current (DC).

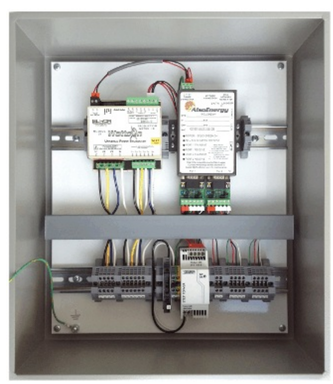
Inverter - The inverter changes the DC electricity produced by the modules into alternating current (AC) which is the type of electricity used in the electric grid. Below are photos of three types of inverters–Trace (Xantrex), SMA (Sunny Island) and OutBack.

Many inverters have a display panel on the front that will show the amount of electricity being produced instantaneously, as well as the amount that has been produced that day. These read-outs can be interesting for the students once they understand the units referenced. They can also be useful when doing shading or cooling experiments on the actual array.

Distribution panel - The distribution panel is the point where the photovoltaic system output is wired to load circuits in the building and to the incoming power lines from the electric utility. This allows the AC power produced by the system to either supply part of the electrical demands of the building or to feed into the general electric power lines if the school does not need the power at that time. This box is usually located in the school's electrical room next to the breaker box.

Electric meter - The electric meter keeps track of the amount of electrical energy produced by the photovoltaic system. Electrical energy is measured in **kilowatt-hours**.

Data acquisition system - The data acquisition system collects data from several different sensors and sends them to a server that posts the data on the internet where it can be monitored by students anywhere. Two examples are below–Greenhouse (left) and Also Energy (right).



Batteries - Your system may also include batteries to store the electricity for use during power outages. Solar batteries look similar to large car batteries, but are specifically designed to be charged and discharged thousands of times. The charging and discharging of the batteries is controlled by the **Charge Controller**

Procedure

1. Group students together for this Data Acquisition activity according to how many computers are available.
2. **Engage:** Discuss (or review) background photovoltaic information with the class. Points to cover include:
   - Photovoltaic cells are made up of silicon, the main component of sand. Silicon is also commonly used in semiconductors.
   - Photovoltaic cells are wired together into panels called modules. The modules in a system are wired together into a photovoltaic array.
   - Photovoltaic cells generate direct current (DC) electricity. DC is the type of electricity used by battery operated devices. The circuits in typical homes, schools and businesses carry alternating current (AC) electricity. The DC electricity produced by photovoltaic cells has to be transformed into AC electricity before it can be used by the typical building.
   - Electric meters measure how much electricity flows through them. The units used to measure electricity over time is kilowatt hours.
3. Escort students outside to observe the school system. If possible, let them look at the system components that are housed in the electrical room also. Note: If you do not have a photovoltaic system at your school, show the students photos of the system they will be using in their data activities. Write the website address on the board for your school's system or the system you are using.
4. **Explore:** Students should analyze, compare and contrast information as they complete their Laboratory Manual.

Answer Key - Laboratory Manual

1-2. Answers will vary depending on the system.

3. Answers should match the information given for the system's data page.
4. Answers will vary, but students should show an understanding of the need to tilt the array to be perpendicular to the rays of the sun. Advanced students should show their understanding of solar noon, and the correlation of the tilt angle to the school's latitude.
5. Roof mount arrays are sometimes positioned to match the pitch of the roof. However, ground mounted arrays should be positioned at the optimal angle. Also in Florida, arrays are sometimes positioned at latitude plus 15°. This increased angle, lowers the face of the panel, compensating for the decreased intensity of sunlight during the winter and providing more equal amounts of electricity throughout the seasons.
6. Students should show an understanding that since the DC is converted to AC, the shape of the graph will be the same.
7. The AC graph will show slightly less power on all points than the DC graph because of energy losses during the conversion to AC from DC at the inverter.
8. Differences in the AC power graph not shown in the DC power graph would tell an operator that something was malfunctioning between the photovoltaic panel and the output of the inverter–possibly the inverter.

Answer Key - Problems

1-3. Answers will vary depending on the output of your system. Check student math.

4. Answers will vary from student to student, however, the average home could be powered by a 7 - 10 kW system. Check to see if students are using units correctly–comparing one week's power output of the school's system to one week's household power output.

Key Words & Definitions

- **alternating current (AC)** – a flow of electric charge that reverses its direction at regular intervals. In the United States, this type of electric flows through electrical transmission lines, and is typically used in homes, offices and schools.
- **data acquisition system** – a system that collects data from several different sensors and sends them to a server that posts the data on the internet where it can be monitored by students all over the world
- **direct current (DC)** – a flow of electric charge moving in one direction only. This type of electric flow is typically used in battery operated devices, automobiles and boats.
- **inverter** – changes a DC electric charge produced by the modules into alternating current (AC)
- **kilowatt hours** – the basic unit of electric energy used in one hour
- **photovoltaic array** – the term for the complete unit of solar modules
- **photovoltaic cell** – the individual units in a photovoltaic module. Each cell is manufactured separately. These may then be wired together to make larger modules and produce more power.
- **photovoltaic module** – the term for a photovoltaic panel made up of a number of cells wired together
- **semiconductor material** – a material such as silicon that will conduct electric energy under certain conditions; its electron flow is between conductors and insulators. Silicon, arranged in a crystalline structure, is used in microchips and PV cells to facilitate the flow of electricity.
- **silicon** – a metalloid element with four valence electrons that is the main component of photovoltaic cells. Silicone is most commonly found in the earth's sand.
- **voltage** – a measure of the force or "push" given the electrons in an electrical circuit; a measure of the electric potential difference

Further Research

1. Research "single crystal", "polycrystalline" and "thin film" photovoltaics. Which type of PV cell is used in the system from this activity? What are the advantages and disadvantages of this type of cell?
2. If you have a PV system at your school, what percentage of your school's electrical usage does the PV array produce? Obtain a copy of your school's monthly electric statement or cost of its monthly electric usage and calculate what percentage is being supplied by the PV system. How could you increase this percentage? Include ways that would mean an investment of money as well as those that could be done without costing the school any additional money.

Internet Sites:

http://www.energywhiz.com/

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

https://www.fsec.ucf.edu/go/solar_basics/

Florida Solar Energy Center, "Photovoltaic Fundamentals".

http://vimeo.com/album/1863654/video/38120404

Part of the SunSmart Facility Manager webinar produced by the Florida Solar Energy Center describing the SunSmart system components and how they operate.

http://www.engineeringtoolbox.com/electrical-formulas-d_455.html

Common electrical formulas and conversions.

https://www.youtube.com/watch?v=TCq0K3DlFdc

Monocrystalline vs. Polycrystalline Solar Panels - What's the Difference?, video explains the difference in the manufacturing process and differences in efficiency between the two types of crystalline panels.

http://www.solar4rschools.org/

Solar 4R School program.

http://www.solarschools.net/

Australia's solar school program.

SunSmart Schools

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 4	**SC.912.N.4**		X																		
Earth and Space																					
Standard 5	**SC.912.E.5.**				X																
Standard 6	**SC.912.E.6.**						X														
Physical Science																					
Standard 10	**SC.912.P.10.**	X													X	X					
Life Science																					
Standard 17	**SC.912.L.17.**											X						X			
Mathematics Standards		MAFS.912.S-ID.1.3, MAFS.912.S-ID.3.9, MAFS.K12.MP.3.1																			

Science–Standard 4: Science and Society
- SC.912.N.4.2 - Weigh the merits of alternative strategies for solving a specific societal problem by comparing a number of different costs and benefits, such as human, economic, and environmental.

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 6: Earth Structures
- SC.912.E 6.6 - Analyze past, present, and potential future consequences to the environment resulting from various energy production technologies.

Science–Standard 10: Energy
- SC912.P.10.1 - Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.
- SC912.P.10.14 - Differentiate among conductors, semiconductors, and insulators.
- SC912.P.10.15 - Investigate and explain the relationships among current, voltage, resistance and power.

Science–Standard 17: Interdependence
- SC.912.L.17.11 - Evaluate the costs and benefits of renewable and nonrenewable

resources, such as water, energy, fossil fuels, wildlife, and forests.
- SC.912.L.17.17 - Assess the effectiveness of innovative methods of protecting the environment.

Mathematics–Statistics and Probability
- MAFS.912.S-ID.1.3 - Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points.
- MAFS.912.S-ID.3.9 - Distinguish between correlation and causation.

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

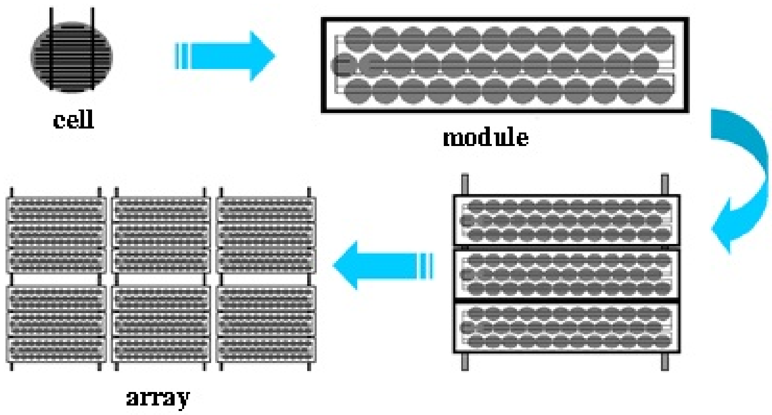
National Next Generation Science Standards
Energy
- HS-PS3-1 - Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component and energy flows in and out of the system are known.

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

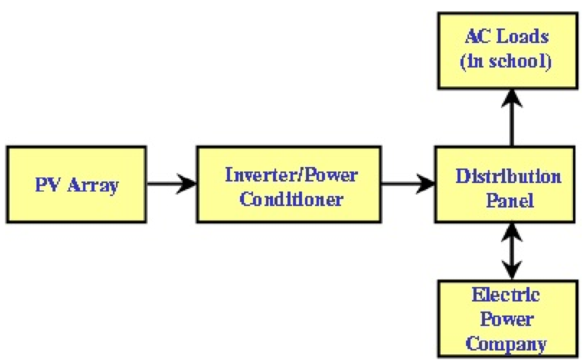
SunSmart Schools

In a PV system, groups of solar cells are connected together in “modules” (or “panels”), and the modules are connected together to form a solar “array”. At the inverter, the current is conditioned to match the voltage and current type present in the electric grid (DC is converted to AC and the frequency of the utility’s power grid is matched).

Parts of a Photovoltaic System



Photovoltaic array - The array which is made up of several photovoltaic modules, converts or transforms sunlight directly into electric current. Like batteries, the current produced is direct current (DC).



Inverter - The inverter changes the DC electricity produced by the modules into alternating current (AC) which is the type of electricity used in your school and homes.

Distribution panel - The point where the photovoltaic system output is wired to load circuits and to the incoming power lines from the electric utility. This allows the AC power produced by the system to either supply part of the electrical demands of the building or to feed into the general electric power lines if the building does not need the power at that time.

Electric meter - The electric meter keeps track of the amount of electrical energy produced by the photovoltaic system. Electrical energy is measured in **kilowatt-hours**.

Data acquisition system - The data acquisition system collects data from several different sensors and sends them to a server that posts the data on the internet where it can be monitored.

Observations

With your class, observe the photovoltaic system you will be monitoring.

1. How many photovoltaic modules make up the array?

2. The stated capacity of a system is how many watts of electricity your system is designed to produce. From the total capacity (in watts) of the photovoltaic system, calculate the electric output of a single module in the system.

3. What is the tilt angle listed for the system?

4. From what you discovered in the previous photovoltaic investigations, why do you think the array is positioned at that angle?

5. If the array is not positioned at the "optimal" angle for its location, why do you think it was installed at a different angle?

6. Look at the AC power and the DC current graphs on the data site. Why do you think they are similar?

7. How are the AC power and the DC current graphs different? What caused the difference?

8. Why would having both channels of data be useful to someone monitoring the system?

SunSmart Schools

Given: $\text{Efficiency} = \dfrac{\text{useful energy output}}{\text{total energy input}} \times 100$

1. Calculate the system's efficiency in converting the Sun's energy to DC electricity. *Note: The amount of the Sun's energy hitting the array is labeled irradiance on the data site.*

2. Calculate the system's efficiency in converting DC to AC electricity.

3. Calculate the dollar amount of electricity offset (savings on the electric bill) for yesterday, last week, last February, and last July.
Note: if you do not know the cost for electricity, use 12 cents per kWh.

   a. Yesterday's savings -

   b. Last week's savings -

   c. February's savings -

   d. July's savings -

4. Using one of your family's monthly electric bills, and assuming the output from the system for the last week is typical of its output over a course of time, determine if a system of this size would be sufficient for your family's power needs. If the system is either too large or too small, calculate the percentage increase or decrease in size your home system should be to be a more perfect match to your family's energy needs.