Lesson Title: **MEASURING SUNLIGHT: THE PYRANOMETER**

Grade level: High School

Lesson length: 1-3 hours, depending on coverage and emphasis

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Instructor's Guide

Learning Goals:

Students will understand how to use a pyranometer--a tool commonly used in the solar industry.

Students will use a pyranometer to measure solar irradiance in a solar relevant setting.

Students will collect and objectively analyze relevant data to draw valid conclusions.

Students will understand basic characteristics governing the placement of a solar PV array.

Students will learn solar characteristics that must be maximized to install solar panels for best performance.

Students will learn and use relevant earth science and solar photovoltaic vocabulary.

Students will understand basic differences between fixed and tracking solar PV arrays.

Materials, Resources, and Technology Required:

- Presentation unit and screen may be desired
- Several pyranometers
- Clipboards
- Computers with internet connection for student research purposes

Introduction to the activity:

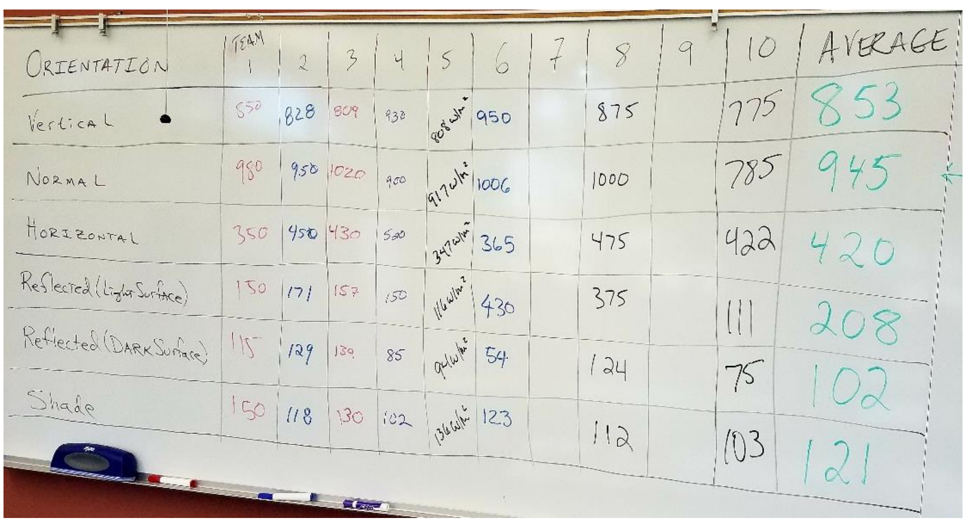
Beginning an activity where students will measure the sun's irradiance could be as simple as asking the question: How should a fixed solar PV array be placed in order to receive the fastest payback? A question like this requires some consideration. "The fastest payback" from a PV array will eventually lead students to "the most sun." Knowing how to measure that sunlight--the sun's irradiance--before a fixed PV array is bolted down becomes vital. And a simple device to measure sunlight? The pyranometer--which you'll introduce to your students and have them use for this activity.

Activity, Part 1

Introduce students to the pyranometer and how it's used. Arrange student groups. Review the various orientations and situations in which your student groups will measure irradiance using their pyranometer. Also, review use of the data table for the lesson. If you plan to develop class averages, review how and where that will be done. Then it's time to head outside with your students to a safe location you've previewed that will work with this lesson.

Be available to guide them in the proper use of the pyranometer for the various orientations and situations in the activity as students acquire data.

Back inside, review student data and answer questions that naturally come up in discussion. Develop class averages, if that was your plan.



Activity, Part 2

Set students to work completing the **Show What You Know** concluding assessment questions from the lesson. Provide assistance as needed.

In advance of the activity you should carefully review all of the **Show What You Know** questions in the Student Activity Guide for this lesson. Decide how far you wish to take the lesson. Edit and remove questions from the Student Guide to fit your coverage and emphasis before duplicating the lesson for your students to use. You may wish to remove some of the questions from the Student Guide for later use on a student exam.

You will also have to decide whether to have students complete these concluding assessments individually or in their groups. Some of the questions recommend or suggest additional research, so you may have to arrange internet access for your students.

Show What You Know [Answer Guide]

1. Rank the six Orientations and their Situations in order from highest irradiance to lowest irradiance using the best data available.

Consult data collected by the class for this activity. In general the highest irradiance measurements will be found in the Orientations and their Situations where the sun's rays hit the collecting surface of the pyranometer the most directly (collecting surface perpendicular to the sun's rays).

2. How did reflected irradiance differ depending on the color of the reflecting surface?

Consult data collected by the class for this activity. In general higher irradiance measurements will be found reflected from lighter colored surfaces.

3a. About what percent of available solar radiation is reflected from the ground from a *dark* surface? Completely show how you calculated your answer in the space available.

Percent of available solar radiation reflected from dark surface:

* Answer

Math work: **(reflected measurement <u>dark surface</u> X 100 highest measurement)**

3b. About what percent of available solar radiation is reflected from the ground from a *light* surface? Completely show how you calculated your answer in the space available.

Percent of available solar radiation reflected from light surface:

*

Math work: **(reflected measurement light surface X 100 highest measurement)**

4. About what percent of available solar radiation is available in the shade? Completely show how you calculated your answer in the space available.

Percent of available solar radiation available in the shade:

*

Math work:

(shade measurement X 100 highest measurement)

5. You've decided to install a solar PV panel array--congratulations! It will be a fixed array, secured in position on your roof.

Doing some research, you decide to install them facing 180°, which of course is due south. In this orientation, or "azimuth," your solar panels will face "solar noon." This is the time of the day when the sun is highest in the sky and at its greatest intensity. It's also the time of day that splits the day in half. There is the same amount of daylight after solar noon as there is before solar noon.

Now do some more research. What should be the tilt angle of your solar panels--at what angle should they be "tilted up" in order to receive the most energy from the sun? Discuss what you learned in this activity in answering the question.

Solar panels should be installed to maximize their direct exposure to the sun's rays, giving them the highest available irradiance values. This means that fixed tilt solar panels should be "tilted up" at roughly the latitude of their location. The sun's position is "at latitude" each year on the first day of spring and fall. Then the sun "moves" about as far above that latitude in the summer as it "moves" below that latitude in the winter. Therefore an "at latitude" tilt will usually yield about the best average sunlight--and irradiance available--for the year.

In practice, solar panels are often tilted down from latitude to reduce wind load. They may also be tilted up or down from latitude for aesthetic purposes.

6. What is the biggest advantage to installing a solar panel system that moves with the sun (a "tracking" system)? Discuss what you learned in this activity in answering the question.

The biggest advantage to a tracking solar PV system is that it keeps the array directly facing the sun throughout the day. In this way it maximizes the array's direct exposure to the sun. This provides higher irradiance values than a system of the same size that isn't always directly facing the sun because it's fixed in place. Since sunlight--irradiance--is key to performance, a tracking system generates more electricity than its same size fixed counterpart.

7. Bifacial solar modules are relatively new to the solar PV market. Bifacial modules produce solar electric power from both the front and back of the panel. As you can see in **Illustration 1.0** below, the back side of bifacial modules has a clear covering applied to it. When installed over a highly reflective surface, an additional 25% solar production from the back of the module can be achieved.

Illustration 1.0

Use data you collected and what you have learned in this activity to describe what kind of surface would be ideal to have a few feet behind a fixed, ground mounted array of bifacial solar PV modules.

The ideal surface to have behind bifacial modules should be one that reflects light well. From the data collected, students should conclude that this would be a light colored surface.

Though the idea of bifacial modules may be new to students, this should be an easy question to answer. You may wish to extend the question by asking students to do some light research on reflective surfaces that have been tested to work effectively behind bifacial modules.

8. The majority of solar systems that are installed are fixed in position. List and explain at least three disadvantages of tracking solar systems that help to explain why they are installed less often than fixed solar systems.

Each of the following tracking system disadvantages is given in contrast to a same size, fixed system counterpart:

- **Tracking arrays are more expensive to install.**
- **Tracking systems require more maintenance.**
- **Tracking PV arrays are more complex, requiring more variables to be considered and addressed when locating and installing the system.**
- **Solar tracking systems generally do not handle harsh conditions as well.**
- **Some of the extra energy gained with tracking system is "lost" because the array requires energy to move.**
- **For all of the reasons above, a tracking system may be seen by bankers as a higher financial risk; it may be harder to get a loan to finance the project.**

9. Let's say at solar noon on a clear day, a one square meter fixed-in-place solar panel is receiving 1000 W/m^2 of sunlight. With an efficiency rating of 20%, the solar panel will produce 200 W/m^2 of usable electricity at that time. If the panel were able to produce at this "full capacity" all day it could produce 4,800 Watt-hours of usable electricity:

$$200\ Watts\ x\ 24\ hours = 4800\ Wh$$

This quantity is the same as 4.8 kWh of electricity:

$$200\ \cancel{Watts}\ X\ 24\ hours\ X\ \frac{1\ kiloWatt}{1000\ \cancel{Watts}} = 4.8\ kWh$$

However, the amount of electricity produced by this one square meter solar panel will never be equal to its full capacity. In fact, on a typical day, the panel might only produce 1.0 to 1.2 kWh of usable electricity - less than 25% of its full capacity. [A solar array that produces electricity at 20% of its full capacity would be said to have a Capacity Factor of 20%.]

List and briefly explain at least five circumstances that keep any solar panel from producing at its full capacity, even on a good day. You must discuss what you learned in this activity in developing your answers.

Student answers should be more complete than these. In short, solar panel production will be lower than full capacity whenever any of these conditions exist--conditions when available sunlight and irradiance values are below maximum.

- **Night.**
- **Cloudy and / or dark during the day.**
- **Solar panels are soiled.**
- **Solar panels have snow on them.**
- **Solar panels are shaded.**
- **Early morning and late afternoon.**
- **Deepest summer and winter.**

10. The world map in **Illustration 2.0** is also available in color on the internet. It shows average solar radiation received on land across the earth. Note the greatest irradiance values (dark) are found through "the middle" of the earth--from about 30° south of the equator to about 30° north of it. Why are average irradiance values so much greater there, and less (sometimes a lot less) in other world regions? You must discuss what you learned in this activity in developing your answer.

The region described above and on the map, being on or close to the equator receives, on average, more direct sunlight during the year than areas outside of it. For this reason, the measured irradiance values in this region will be higher than elsewhere. Great region in which to install solar!

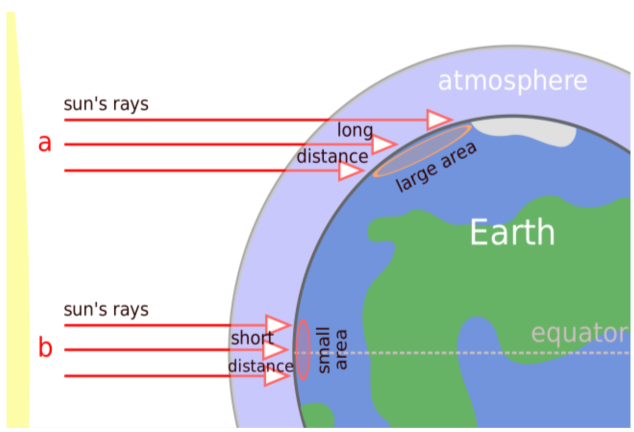


Illustration 2: