LESSON PLAN

Cost-Effective Solar Cells

Lesson #1: Solar Energy Equity and Sustainability

AUTHOR

Tom Wolverton

CONTACT

Teacher Contact: *tom.wolverton@vansd.org 360-992-6021*

CE Editor Contact: CEbrightfutures@b-e-f.org, 503-553-3950

DESCRIPTION

This lesson is designed to span 2 days with 40-minute sections. On the introduction day, three solar power articles will be read to set up a Socratic Seminar dialogue on Day 2. A teacher will need to read the articles. The articles investigate the pros and cons of solar energy, the sustainability of solar energy technology, and newer solar energy technology advances. As this is an introductory lesson, teachers do not yet need to feel confident about solar cell basics. Students should become familiar with some of the basic principles of solar power generation through article reading, as well as some social, cultural, and economic impacts of solar power generation.

GRADE LEVEL(S)

9, 10, 11, or 12

SUBJECT AREA(S)

Chemistry, Physics, Solar Panels, Solar Cells, Power, Current, Voltage, Electricity Generation

ACTIVITY LENGTH

2 days X 40 minutes

LEARNING GOAL(S)

1. Students will read at least three articles discussing solar power generation, and the social, cultural, and economic implications of sustainable solar energy
2. Students will discuss social, cultural, and economic implications of sustainable solar energy in a Socratic Seminar format.

CONTENT BACKGROUND

STUDENT BACKGROUND

- Students participating in this lesson should be familiar with the following scientific practices and concepts:
    - Reading non-fiction text for supporting evidence and main ideas
    - Discussing texts with peers in a Socratic Seminar format

EDUCATOR BACKGROUND

Solar power generation is an exciting technology that has the potential to provide clean electrical power without reliance on fossil fuel combustion. Solar power is also limited by social, cultural, and economic factors. Factors that should be discussed by students include access to natural resources, costs of solar cell component mining and manufacturing, efficiency, energy storage, incident angle of sunlight, aesthetics, developed nation access, and durability among others. Educators could also address the grid-level impacts of variable resources like solar, as well as scale of solar generation (from utility-scale to building-scale); these impacts could include variability of energy production, equitable access to energy, and shifting role of utilities in response to solar development. As this field is rapidly changing, the social, cultural, and economic factors may evolve from year-to-year. Newer technologies may need further student and educator research beyond the background of the following basic concepts. Further information and definitions can be found at: https://cebrightfutures.org/learn

Solar Energy:

Solar energy is the radiant electromagnetic energy - or light - received from the Sun by the Earth. While the solar radiation received by the Earth's atmosphere is relatively constant, the amount of sunlight hitting the Earth's surface varies widely due to many factors including:

- atmospheric effects, including absorption and scattering
- local variations in the atmosphere, such as water vapor, clouds, and pollution;
- latitude of the location
- the season of the year and the time of day

The above effects have several impacts on the amount and quality of the solar energy that we actually receive, including variation in the amount of power, the specific wavelengths of light and the angle at which sunlight strikes the Earth's surface (incident angle of sunlight). In addition, the variability of the solar radiation at a particular location will be affected by the above considerations. For instance, desert regions tend to have lower variations due to local atmospheric phenomena such as clouds. Equatorial regions have low variability between seasons.

Incident Angle of Sunlight:

When the Sun's rays are perpendicular to an absorbing surface, the irradiance incident on that surface has the highest possible power density. As the angle between the sun and the absorbing surface changes, the intensity of light on the surface is reduced. When the surface is parallel to the sun's rays (making the angle from perpendicular to the surface 90°) the intensity of light falls to zero because the light does not strike the surface. For intermediate angles, the relative power density is cos(θ) where θ is the angle between the Sun's rays and direct normal (or perpendicular) to the surface.

The irradiance absorbed by the surface can be found by multiplying the total irradiance by cos(θ).

$I_i = I_t \cos(\vartheta)$

Where

I_i: Irradiance absorbed by the surface

I_t: Total irradiance

ϑ: Incident angle

Therefore under peak sun conditions (1,000 Watts/meter^2) if the angle of the sun's rays strike a surface 15° off from perpendicular, the irradiance absorbed the surface would be:

I_i= 1,000 W/m^2 x cos(15°) = (1,000)(~.966) ≈ 966 W/m^2

Ultimately, this makes sense because the incident angle is 0° if the sunlight is directly normal to the absorbing surface and cos(0°) = 1, meaning that 100% of the available irradiance is absorbed by the surface. Similarly, when the surface is parallel to the Sun's rays, the incident angle is 90°, and because cos(90°) = 0, the surface absorbs no irradiance. In the above example, cos(15°) = .966, and so the surface is absorbing 96.6% of the available solar power.

In designing photovoltaic (PV) systems, this question of how much available irradiance is absorbed by the photovoltaic modules is very important, since the amount of energy the system is able to produce is directly proportional to the amount of energy it absorbs from the Sun. Some systems are therefore designed with trackers on them, which cause the photovoltaic modules to follow the Sun's movement across the sky, maximizing the amount of time that the PV modules are directly normal to the sunlight. For fixed tilt systems, however, this is not possible, and so the system must be designed using the tilt angle and orientation that will best fits the needs of the system's owner. Most often, this means installing the system at the angle that will absorb the most irradiance over the course of the year, but in some cases there may be times when there is a critical need for energy and so the system can be designed to produce more electricity when it's most needed.

Photovoltaic Effect:

The photovoltaic effect is the creation of a voltage - or of a corresponding electric current - in a material upon exposure to light. Electromagnetic radiation creates an electrical potential differences (or voltage) in the material, which then induces a continuous flow of electrons in a single direction if the circuit connecting the two terminals of the photovoltaic material is closed. The amount of current that flows is directly proportional to the amount of light that strikes the photovoltaic surface.

Photovoltaic Materials:

The most fundamental component of a photovoltaic module is its individual photovoltaic cells. They are made up of a semiconductor material that exhibits the photovoltaic effect. The material most commonly used in PV technology is silicon because of its abundance and affordability, but other semiconductors are sometimes used for particular applications. By doping the silicon with other elements, two oppositely charged layers are created in the cell, a positive (p) layer and a negative (n) layer, which meet at a p-n junction. The p-n junction is essentially a diode, meaning that current can only flow in one direction through the junction. Therefore, a voltage exists between the two layers of the PV cell.

When photons strike the cell, this will give electrons the energy they need to move from the valence band to the conduction band, making them available to move through the circuit. The voltage across the cell will then cause these electrons to flow if there is a closed circuit connecting the negative layer at the top cell to the positive layer at the bottom. This is the electric current, which corresponds directly to the amount of solar energy available to elevate electrons into the conduction band. Once these electrons have traveled through the circuit to the bottom p-layer, they will then travel back through the p-n junction and return to the n-layer. This cycle will continue as long as the circuit is closed and the cell is exposed to light.

MATERIALS NEEDED

HANDOUTS/PAPER MATERIALS

- 3 Solar Power Current Events Articles (see Day 1 below for links)
- Current Events Summary Sheets: https://drive.google.com/file/d/0B32cgN2goxwfUWlybnBFQTBWcmc/view

CLASSROOM SUPPLIES

- *Highlighters*

ACTIVITY SUPPLIES (PER GROUP OF 3-4 STUDENTS)

DAY 1: N/A

DAY 2: N/A

LESSON PROGRESSION

PLANNING AND PREP

This lesson is designed to span 2 days. On Day 1, students will read at least 3 current events articles revolving around solar power generation as well as the social, cultural, and economic impacts of solar power generation. On Day 2, students will engage in dialogue in a Socratic Seminar format.

Educators should prepare handouts of the Current Events Article Summary for each student. Before Day 2, educators should familiarize themselves with the format and techniques in a Socratic Seminar (see https://www.facinghistory.org/resource-library/teaching-strategies/socratic-seminar).

LESSON SEQUENCE

Day 1: Reading articles and summarizing

1. **(5 minutes).** Introduce the Current Events Article Summary sheets to students: Let the students know that they can use these summary sheets during their Socratic Seminar next time
2. **(5 minutes).** Distribute the solar power articles to students. The articles below may be used, but teachers are encouraged to select current articles as the field is rapidly changing. If NEWSELA is available for teachers and students, articles may be chosen from that source as well.
    - **Solar Power basics:**
        i. https://cleantechnica.com/2018/05/28/how-solar-power-works-how-much-solar-panels-cost/
        ii. https://www.zmescience.com/ecology/renewable-energy-ecology/how-solar-panels-work-0423/
        iii. NEWSELA Article (available with subscription at https://newsela.com/): "How Things Work: Solar Cells"
    - **Sustainability & Energy:**
        i. https://www.forbes.com/sites/jamesellsmoor/2018/12/30/6-renewable-energy-trends-to-watch-in-2019/#be784a64a1f7
        ii. https://www.forbes.com/sites/uhenergy/2019/01/04/policies-or-technology-the-key-to-a-sustainable-energy-future/#7299b6235c7c
        iii. NEWSELA Article (available with subscription at https://newsela.com/): "What is Sustainabilty?"
    - **Solar Energy Issues:**
        i. https://www.solarreviews.com/blog/pros-and-cons-of-solar-energy
        ii. https://www.washingtontimes.com/news/2019/jan/3/solar-panels-present-big-issues-in-farming-communi/
        iii. NEWSELA Article (available with subscription at https://newsela.com/): "Issue Overview: Solar Energy"

3. **(30 minutes).** Have students read and summarize at least 3 articles in preparation for the Socratic Seminar on Day 2. It's recommended that the students all share at least 2 common articles assigned by the teacher. A 3rd article can be the teacher's or student's choice.

Day 2: Socratic Seminar

1. **(5 minutes).** Arrange the student desks/chairs in one of the 3 following configurations, depending on your (and your student's) familiarity with Socratic Seminars and class size/setup.
    - Full Circle: One large circle with all students participating in the dialogue
    - Fishbowl: One large circle surrounding a slightly smaller circle—half of the students will engage in dialogue at a time & will switch circles at a later point.
    - Smaller circles: Two or more dialogues will be occurring at the same time
2. **(10 minutes).** Review Socratic Seminar guidelines and the standards you will be assessing students on. Rules for a Seminar are found below and this teaching strategy is described at https://www.facinghistory.org/resource-library/teaching-strategies/socratic-seminar .
    - Students don't need to raise their hands, just wait for their turn patiently. The teacher or student leader can help facilitate quieter students having space to speak.
    - Speak one person at a time and avoid side conversations.
    - Listen and speak to each other, not just the teacher. Build on each other's discussion points and use each other's first names.
    - Thoughtfully and respectfully respond to others when there is a disagreement. A Socratic dialogue is not a debate. Ask your classmates to clarify their points when you disagree.
    - Use evidence from the text and real-life examples give greater understanding to the content of the dialogue.
3. **(40 minutes).** Begin the seminar dialogue by posing one of the following questions:
    - *Why should the United States invest in solar power?*
    - *Is solar energy the best choice for sustainable energy?*
    - *What are some drawbacks to solar power?*

    Follow-up or additional questions:

    - *How do solar cells work?*
    - *How do solar panels work?*
    - *How is solar power sustainable?*
    - *What does it mean to be sustainable?*
    - *Is solar power the best solution?*

A good seminar will continue on its own from a single question with experienced students. If Socratic Seminars are new to you and/or your students, here are some tips:

1. *Leave extra wait time after posing a question.*
2. *Let the students manage the conversation and its direction. Intervene and re-focus with a new question if the conversation becomes off-topic or you need to ensure that a particular topic is discussed.*
3. *Pay attention to who is talking and who is not. Either track the students directly on a clipboard or have the students tally the number of times they have spoken using tokens or flipping over a playing card each time they speak.*

ASSESSMENT AND EXTENSIONS

FORMATIVE ASSESSMENT

As students are preparing for the Socratic Seminar on Day 1, several formative assessments can be performed by the teacher. The Current Events Article Summary sheet(s) can be used as a check on student reading progress. Check to see if the students have captured the main ideas of the articles correctly and if they have generated quality questions from the text. The generated questions are valuable for the Socratic Seminar and could be collected likewise as exit cards from the students at the end of Day 1.

Another option for formative assessment is available on the NEWSELA website (https://newsela.com/). When choosing articles, the teacher can assign the articles to their students. Students can adjust the reading level on their articles and teachers can track reading statistics such as average reading time, number of articles read, post-reading quiz scores, writing scores, annotation count, and assign a general reading skills score.

SUMMATIVE ASSESSMENT

During the Seminar, the following standards can be assessed by the teacher or peer-assessed in the fishbowl configuration. The teacher can use a clipboard to track evidence of the standards or use a student feedback form like the one found here. The first Common Core Speaking & Listening standard is broader in scope, while the three listed sub-standards add specificity to the grading. Alternatively, a broader NGSS Science & Engineering Practice can be used.

- CCSS.ELA-LITERACY.SL.11-12.1
  Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

  - CCSS.ELA-LITERACY.SL.11-12.1.A
    Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.
  - CCSS.ELA-LITERACY.SL.11-12.1.C
    Propel conversations by posing and responding to questions that probe reasoning and evidence; ensure a hearing for a full range of positions on a topic or issue; clarify, verify, or challenge ideas and conclusions; and promote divergent and creative perspectives.
  - CCSS.ELA-LITERACY.SL.11-12.1.D
    Respond thoughtfully to diverse perspectives; synthesize comments, claims, and evidence made on all sides of an issue; resolve contradictions when possible; and determine what additional information or research is required to deepen the investigation or complete the task.
- NGSS SEP8: Obtaining, Evaluating and Communicating Information
  - Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
  - Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.
  - Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

LESSON EXTENSIONS

A second seminar works well after Lesson #9 in the unit, when the students are beginning their research into their own solar cell designs. The driving question for the seminar can be:

What new solar cell technologies are being implemented?

Because the solar cell technology is rapidly changing, current event articles are highly suggested. Some possible topics in 2019 included:

- Perovskite nanocrystals
- Organic Photovoltaic systems (OPVs)
- Cadmium-Telluride solar cells
- Thin film solar cells
- Wearable solar cells
- Graphene nanotubes
- CZTS solar cells