**Title:** Renewable Power: Getting power when you need it

**Type:** Energy

**Provided by:** Hathaway Brown School, Shaker Heights, OH

**Grade Levels:** 7-8

**Lesson Topic:** Determining demand and power production for PV systems. PV system design.

**Learning Standards Addressed:** Hathaway Brown does not align curriculum to state standards.

**Performance Objectives:**

* Students will become familiar with a variety of mechanisms for producing renewable power.
* Students will calculate electricity demand and electricity production potential in different scenarios.
* Students will assess the pros and cons of different PV system designs and will assess scenarios to determine the appropriate system design.
* Students will consider the impacts of peak demand on regional electrical production and distribution networks.

**Required Materials:**

* Access to HB’s solar charging station and weather station data (web-based)
* Internet access (<http://www.nrel.gov/gis/solar.html> to access peak sun maps of the US)

**Anticipatory Activity:**

* Visit HB’s solar charging station. Review the system structure using the educational signs overhead. (Alternatively, project the signs explaining the system (see [www.hb.edu/chargingstation](http://www.hb.edu/chargingstation) under “Charging Station Lessons” for the signs) and review them in the classroom.
  + Note the flow of electricity.
  + Review key vocabulary
    - Photovoltaic
    - solar panel/solar module
    - direct current vs. alternating current
    - inverter
    - solar panel/solar module
    - the grid
    - peak demand
    - peak energy hours/peak demand hours
    - energy efficiency
  + Either answer as a class or have students answer on their own the questions on the *Solar* *Charging Station System Exploration* handout.
* View the data showing how much power our charging station has produced by going to [www.hb.edu/chargingstation](http://www.hb.edu/chargingstation) and clicking on the link for real time energy production of the system (this can also be accessed at <https://enlighten.enphaseenergy.com/pv/public_systems/ScUR341484>). You will see a chart of blue blocks in different shades of blue. Light blue represents higher periods of energy production and dark blue represents lower periods of production. Click on the “Hours” button at the top of the blue grid. This will show hour-by-hour energy production on the grid. Each row represents a day. Below the blue grid is a histogram showing the hourly production for whatever day you have selected in the grid above. Have the students look at the hourly production for June 15th, 2014.
  + Have them describe the pattern they see. Why do they think it looks the way it does? Based on the solar production, what do they think the weather was like that day?
  + Now look at the chart for June 28th, 2014. How is this different? What might explain the differences?
  + Have students explore the daily and monthly charts. What is the maximum daily and monthly energy production they can find in the past 12 months? What was the minimum? Is there a “typical” amount of energy produced each day?
  + Have students discuss why it is important to understand the daily and seasonal variations in electricity production in a PV system?

**Lesson Activities and Procedures:**

* Once the class has reviewed the solar charging station system structure and the questions on the handout, explain that there are four possible system designs one can use when building a solar power system:
  + Stand-alone/Off-grid systems rely on batteries to store the power produced by the PV panels. Energy is produced, stored, and then drawn from the batteries when needed. When the batteries run out of charge, if the sun is not shining, you have no power. All power available in this system comes from the solar panels. These are the least efficient systems in terms of converting solar power to usable electricity. Approximately 65% of the power produced by the solar panels is makes it through the system to become useable electricity.
  + Grid-tied systems are connected to the larger electrical utility grid. Power generated by the solar panels is used on-site first, but if more is generated at any given moment than is demanded on-site, the excess power is sold back to the utility. Conversely, if more is demanded than is generated at any given moment, the additional power is drawn from the grid. These are the most efficient systems, converting approximately 77% of the power generated by the solar panels into useable electricity.
  + Grid-tied with power back-up (aka grid interactive) systems are connected to the utility grid as described above, but also have a back-up battery system that is charged by the solar panels. Power is drawn first from the panels, then from the grid. If neither of these sources is sufficient/available, then power is drawn from the batteries. Grid-tied systems with battery power back-up are less efficient than grid-tied only systems, and more efficient than systems that rely on batteries alone.
  + Grid fallback systems also have both a tie-in to the grid and a battery bank. However, the solar panels charge the batteries, which are the primary source of power in the system. Only when the batteries are run down does the system revert to using power from the grid. Grid fallback systems are more efficient than stand alone, battery-only systems, but less efficient than systems that rely primarily on a grid-tied approach.
* Have the students generate a list of pros and cons of each system type. As they generate this list, prompt them to think about and discuss with them:
  + System cost (batteries are expensive; having back-up systems adds 12-20% to the total system cost)
  + System size/installation (if you have batteries, you need a place to put them. The batteries we are talking about are more like car batteries than flashlight batteries.)
  + System reliability (will you have power when you need/want it?)
  + Use of renewable energy (grid-tied systems will draw electricity produced from conventional power sources, not just renewable sources)
  + System efficiency (power is lost at many points in the system.
    - Each time you convert power from one form to another, you lose some of it because of inefficiencies in the system. Solar radiation🡪 DC electricity 🡪 AC electricity has two points of conversion. Solar radiation 🡪 DC electricity 🡪 chemical potential (stored in batteries) 🡪 DC electricity 🡪 AC electricity has 4 points of conversion. In storing electricity in batteries a significant amount of the power is also lost as heat.
    - Systems running on high voltage lose less power in the transmission of that electricity along the wires than systems running on low voltage. Grid-based systems are typically 120V or 240V systems. Battery-based systems typically run at between 12V and 48V because batteries are low voltage.
* Based on what they learned when reviewing the signs, what type of system did we install for the charging station?
  + Ask students if they think this was the best system to install for HB’s charging station. Why? Why not?
  + Practice calculating the number of panels we needed for the system by reviewing the procedure outlined on the “Process” section of the charging station website. Be sure to highlight the power losses to system inefficiencies.
  + Tell students they will be working in groups to design a PV system for a client. They will need to take the client’s needs and desires into account as they design the system. The process is outlined in the *Design Your PV System* handout. (Note: There are 5 scenarios provided. Distribute the different scenarios among the class.)

**Plans for Independent Practice:**

Complete the *Design Your PV System* handout.

Use <http://www.bigfrogmountain.com/SunHoursPerDay.html> to determine the peak sun hours for each location.

**Closure:**

Have the students present their system designs to the class as if the class were their client. They should review the client’s needs and wants, describe the location in which the system will be used, and explain why the chose the particular system type that they did and how they determined the number of panels needed.

**Assessment and Follow-up:**

Assessment should be based on the quality of the student presentations and their written letter to clients, explaining the system design and size. Students should show their mathematical calculations and should be able to defend their system design both in terms of the client’s individual situations and the energy needs they describe.

**Adaptations and Accommodations:**

* Provide students with a “fill-in-the-blank” worksheet for calculating both energy demand and energy production for a given system.
* Rather than having students calculate how much power each module will generate annually, provide them with annual energy production per module.

**Enrichment Activities:**

* Have students design a system for Hathaway Brown that would supply all our electricity needs. How much space would we needs for the panels for such a system?
* Have students compare the benefits and drawbacks of other renewable energy sources such as wind power with solar power for the different scenarios. If they were to design a system for each of the scenarios that used any/all of the different renewable energy options, what would it look like? Justify the design.

**Solar Charging Station System Exploration**

1. What type of current do solar panels produce?
2. What type of current is provided from “the grid”?
3. Does our charging station have power when the sun is not shining? Why or why not?
4. If we use more power at the charging station than the solar panels produce, will the charging station stop working? Why or why not?
5. How can we tell if we are using more power at the charging station than the panels are producing?
6. Where does the power from the panels go?
7. How much electricity does HB use annually?
8. How much electricity do our solar panels produce annually?
9. Why did we install the number of panels that we did? How did we choose this number of panels?

**Design Your PV System**

Client: Mr. and Mrs. Evergreen

Client statement: We want our house to be self-sufficient in terms of electricity. We are building a tiny house near a river running through a sagebrush plain 90 minutes outside of Lander, Wyoming. We want the house to be carbon neutral in terms of its carbon footprint. The only things we will need electricity for in the house are 3 LED lights (each uses 5 watts), a small fan for days over 100 degrees, our laptop computer (Macbook Pro, 15 inch screen), 2 cell phones (both iPhone 5s) and an iPod charger. We will live in the house year-round.

*Calculating Demand:*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Item | Watts used | Hours/day | Days/year | Total Watt\*Hours/year |
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|  |  |  |  |  |
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How many Watt\*hours (Wh) will your system need to produce each year?

What will your peak demand be?

Does your system require continuous, reliable power, regardless of time or day or time of year? If so, how will you ensure this is available?

What type of system will you install? Grid-tied, stand-alone, grid-tied with power back-up, or grid-fallback? Explain why you selected the system type that you chose.

With the system design you have selected, what percentage of the power generated by the solar panels will be lost to system inefficiencies? What percentage will be available after losses to system inefficiencies? (It is okay to estimate based on the information you have been given.)

*Calculating Power Production:*

Watts/module:

Peak sun hours/day for your location (see <http://www.nrel.gov/gis/solar.html> for maps to estimate peak sun hours):

% power loss to system inefficiencies:

% power available after losses to system inefficiencies:

(\_\_\_\_\_ W/module)(\_\_\_\_\_\_peak sun hours/day)(365 days/yr)(\_\_\_\_\_\_\_\_\_ W available after losses to system inefficiencies)=

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Wh/yr/module

Now you know how many Wh you need to produce each year, and you know how many Wh each module will produce in your region in a given year. Using this information, calculate how many modules you need.

Write a short business letter to your clients describing the system you would like to install for them. Be sure to explain why you chose the particular system style that you did, how many modules you will need to install, and how you arrived at this number.

**Design Your PV System**

Client: Mr. Pennywise

Client statement: I live in Austin, Texas. In an effort to reduce the peak demand in our region, our electricity utility company has a creative program that allows their customers to install a thermostat that the utility can override when they urgently need to reduce the demand on the system (this happens during the summer on hot days when everyone’s air conditioning kicks in hard). I signed up for this program last year because if we can prevent the utility from having to build new power plants to supply enough power during these peak demand times, then I think the cost of power will not rise as fast as it would otherwise (see <http://www.texastribune.org/2012/08/01/texas-push-save-power-peak-times/> to read more about this program and learn more about peak demand management). I like the idea of reducing peak demand, so I’m interested in installing a solar electricity system that can help do this. I am not trying to power any particular devices from my system. I just want to reduce my overall energy use during peak demand times of day and year by 25%. Currently, in the heat of the day in August, my home typically uses about 7500 Watts.

How many Watt\*hours (Wh) will your system need to produce each year?

What will your peak demand be?

Does your system require continuous, reliable power, regardless of time or day or time of year? If so, how will you ensure this is available?

What type of system will you install? Grid-tied, stand-alone, grid-tied with power back-up, or grid-fallback? Explain why you selected the system type that you chose.

With the system design you have selected, what percentage of the power generated by the solar panels will be lost to system inefficiencies? What percentage will be available after losses to system inefficiencies? (It is okay to estimate based on the information you have been given.)

*Calculating Power Production:*

Watts/module:

Peak sun hours/day for your location (see <http://www.nrel.gov/gis/solar.html> for maps to estimate peak sun hours):

% power loss to system inefficiencies:

% power available after losses to system inefficiencies:

(\_\_\_\_\_ W/module)(\_\_\_\_\_\_peak sun hours/day)(365 days/yr)(\_\_\_\_\_\_\_\_\_ W available after losses to system inefficiencies)=

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Wh/yr/module

Now you know how many Wh you need to produce each year, and you know how many Wh each module will produce in your region in a given year. Using this information, calculate how many modules you need.

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**Design Your PV System**

Client: Natural Disaster Emergency Shelter

Client statement: We run a community center that is also designed to serve as a shelter in case of natural disasters. Based southeast of the San Francisco Bay area, the threat of earthquakes is real. As an emergency shelter, we want to be sure we have power in the event of a natural disaster. For this reason, we would like to install a PV system. The system would provide power for lighting (1 kW), communications equipment (e.g. satellite enabled Internet, computers, charging for cell phones and laptops, radios, etc.) (500 W), and some basic medical equipment (600 W).

*Calculating Demand:*

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| --- | --- | --- | --- | --- |
| Item | Watts used | Hours/day | Days/year | Total Watt\*Hours/year |
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How many Watt\*hours (Wh) will your system need to produce each year?

What will your peak demand be?

Does your system require continuous, reliable power, regardless of time or day or time of year? If so, how will you ensure this is available?

What type of system will you install? Grid-tied, stand-alone, grid-tied with power back-up, or grid-fallback? Explain why you selected the system type that you chose.

With the system design you have selected, what percentage of the power generated by the solar panels will be lost to system inefficiencies? What percentage will be available after losses to system inefficiencies? (It is okay to estimate based on the information you have been given.)

*Calculating Power Production:*

Watts/module:

Peak sun hours/day for your location (see <http://www.nrel.gov/gis/solar.html> for maps to estimate peak sun hours):

% power loss to system inefficiencies:

% power available after losses to system inefficiencies:

(\_\_\_\_\_ W/module)(\_\_\_\_\_\_peak sun hours/day)(365 days/yr)(\_\_\_\_\_\_\_\_\_ W available after losses to system inefficiencies)=

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Wh/yr/module

Now you know how many Wh you need to produce each year, and you know how many Wh each module will produce in your region in a given year. Using this information, calculate how many modules you need.

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