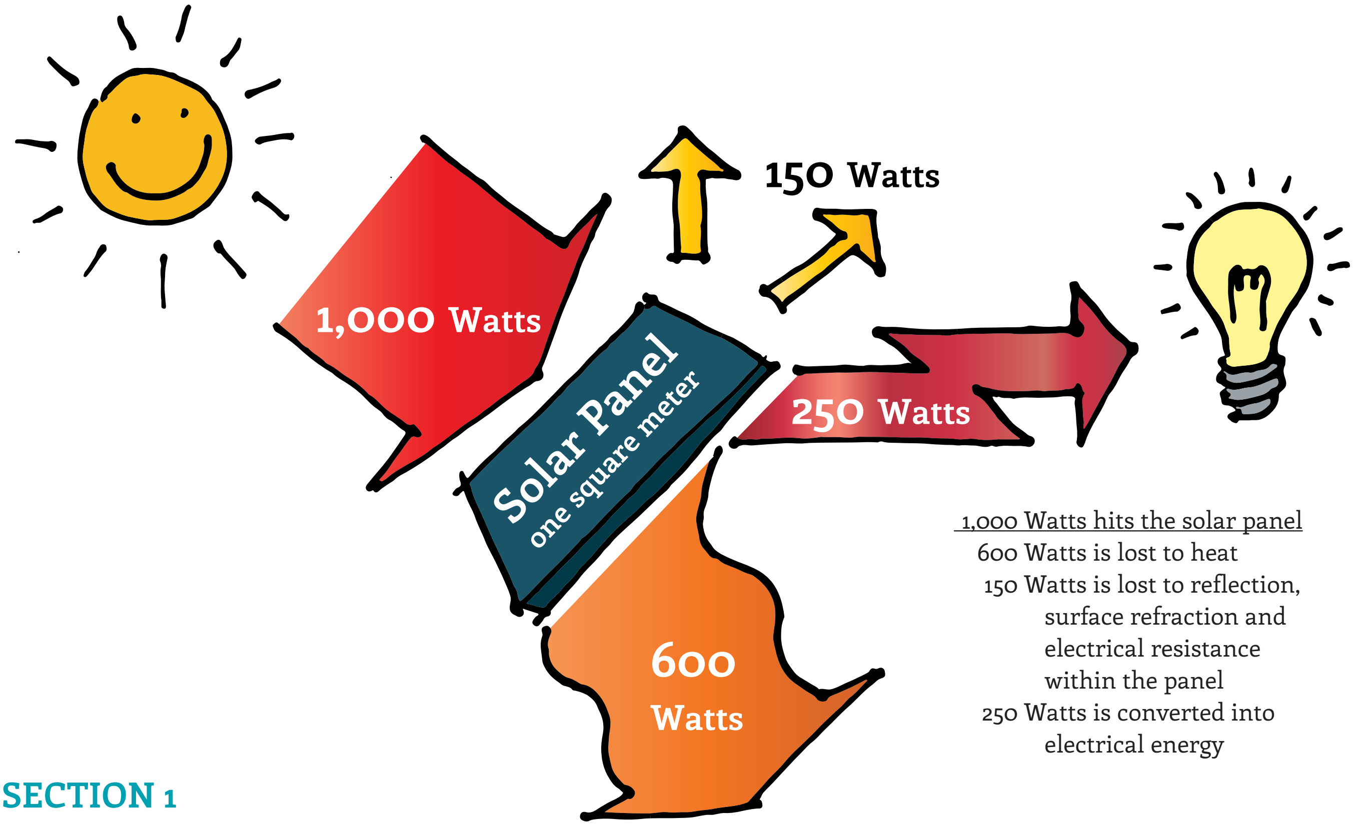
Tool

ENERGY OUTPUT WORKSHEET

land art generator initiative **powered by art!**

USE WITH
Activity 5: Energy Fundamentals



1,000 Watts hits the solar panel
600 Watts is lost to heat
150 Watts is lost to reflection, surface refraction and electrical resistance within the panel
250 Watts is converted into electrical energy

SECTION 1
ENERGY EFFICIENCY

Above is an example showing the conversion efficiency of a solar panel that is one square meter in surface area. The sun beams down onto the surface of the earth a fairly consistent amount of energy. For each square meter of ground surface, about 1,000 watts makes it through our atmosphere as electromagnetic radiation energy. A solar panel is designed to convert electromagnetic radiation energy into electrical energy. But as you can see in the diagram above, we haven't yet figured out a way to convert all 1,000 watts.

Every technology that is designed to convert natural energy into electrical energy has a conversion **efficiency** associated with it. The efficiency is a property of the technology and the materials. Scientists are constantly working to increase the efficiency of technologies, because by increasing efficiency, we can convert more available energy and potentially save money.

With current crystalline silicon technology, we're able to turn about **25%** of the sun's energy into electricity. The other 75% is either reflected (still as electromagnetic radiation) or turns into radiant heat energy (causing the solar panel to get hot).

This kind of solar cell is 25% efficient.

It's called monocrystalline silicon.

1000 Watts **x** **25%** Efficiency **=** **250** Watts Peak Capacity (**250** Wp)

available solar power

electrical power

DIFFERENT TECHNOLOGIES HAVE DIFFERENT EFFICIENCIES

There are other kinds of solar cells that have greater efficiencies, but Single Crystal (or monocrystalline) Silicon (Si) is one of the more commonly used because it is not super expensive and it has a pretty good efficiency. Some solar technologies have efficiencies of up to 42% but they are very expensive. Others are less expensive than monocrystalline silicon, but only have a 10%–15% conversion efficiency.

RECAP QUESTIONS

1.

What happens when sunlight (electromagnetic radiation) hits the surface of a solar panel? Is all of the energy converted into electricity?

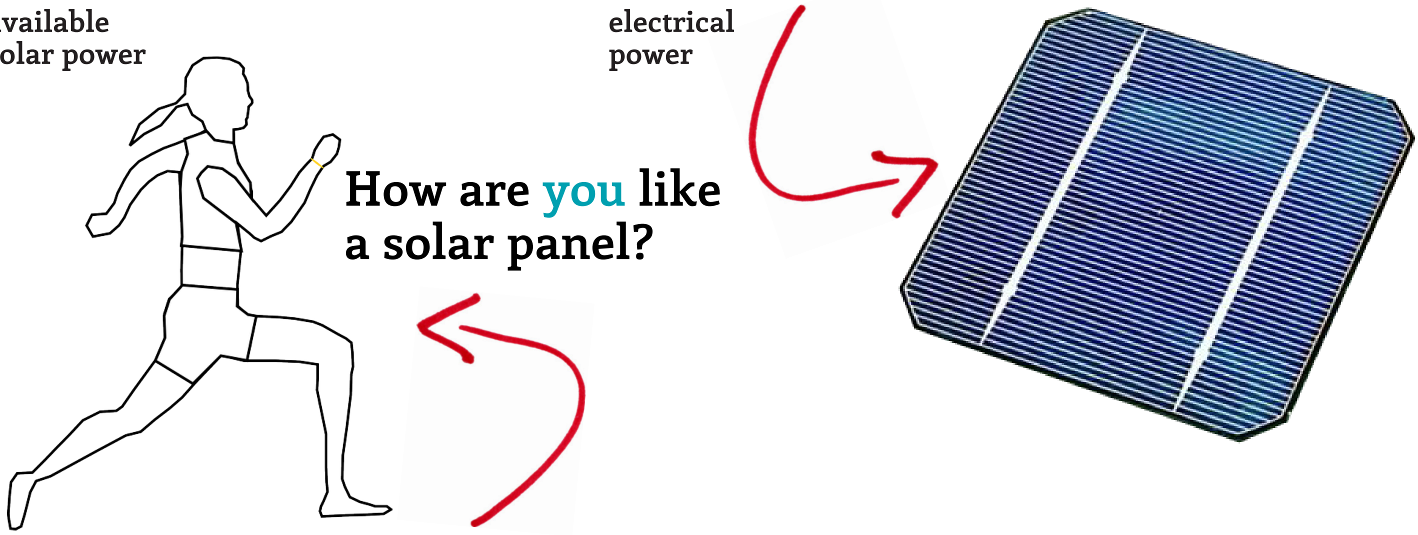
2.

If a solar panel has a 20% energy conversion efficiency and it is exposed to 800 watts of solar energy, how many watts are actually converted into electricity?

1000 Watts **x** **25%** Efficiency **=** **250** Watts Peak Capacity (**250** Wp)

available
solar power

electrical
power



How are you like a solar panel?

400 Watts **x** **25%** Efficiency **=** **100** Watts Peak Capacity

your body
uses inside

your body exerts
in the world

SECTION 2:
PEAK CAPACITY

Peak Capacity = Wp

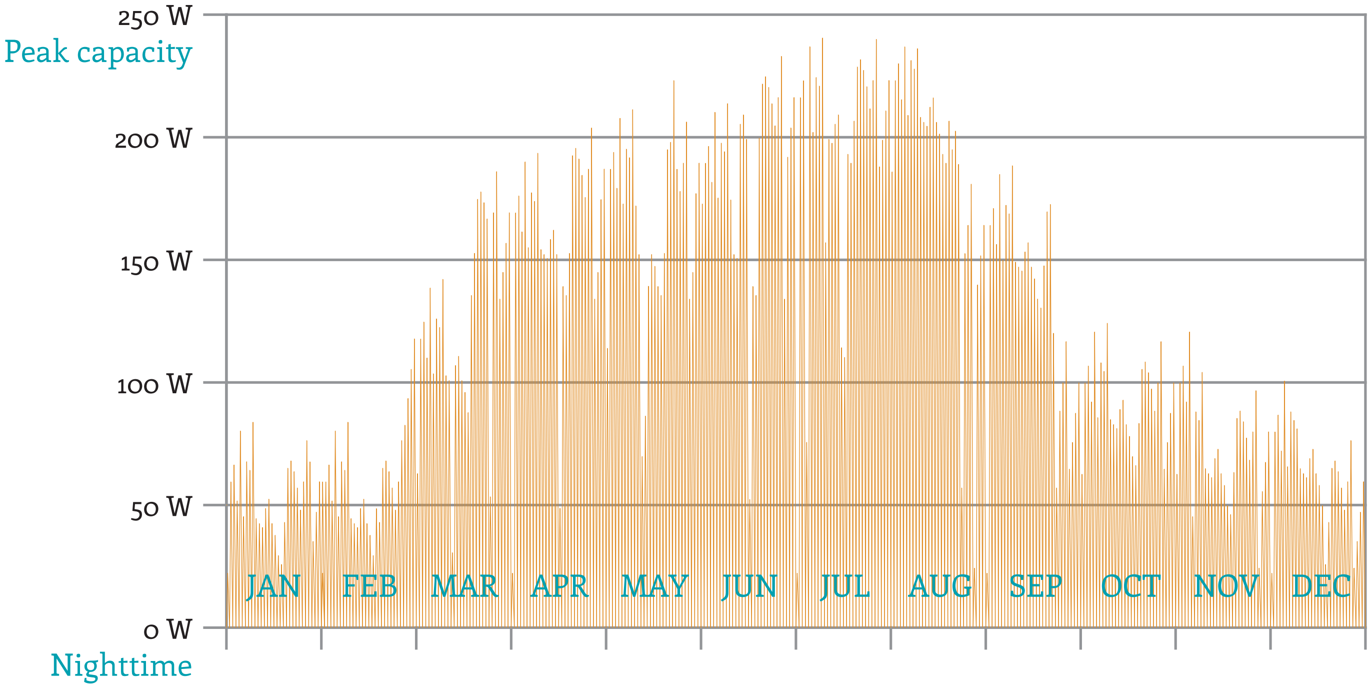
Every day we eat food that contains chemical energy. We measure this energy in calories or joules. Our bodies are about as efficient at converting that food energy into moving (kinetic) energy as a solar panel is at converting the sun into electricity (your body is about 18%–26% efficient).

A Watt can be defined as the amount of power equal to one joule of energy per second. In order to produce 100 Watts of power in the world (whether you are pushing a bike pedal or running forward), you may need to spend about 400 Watts of power in your body. You could do this by burning 400 joules in one second. There are 4186 joules in a nutritional calorie so if you kept that power level up for one hour you would burn about 344 calories and you would generate 100 Watt-hours (Wh) of energy.

If you look on the back of any solar panel you will find a number there listed as P_{MAX} or Maximum Power. This is referred to as the Peak Capacity of the solar panel and can also be written as Wp (Watts peak output).

This is a "performance rating" and it tells us how much power we can expect out of this solar panel under **ideal** weather conditions. Ideal conditions are when we can expect all 1,000 watts of the sun's electromagnetic radiation to reach each square meter of the earth's surface.

But we all know that sometimes it is very cloudy or raining, or what about night time? And some places (northern latitudes) never get 1,000 watts even on their best day. They may only get 800 watts, or even less.



This is a chart that shows the energy production of our 250 Wp solar panel throughout the year. Every night the production drops down to zero. Some days in the summer it peaks up closer to the peak capacity. Other days it's cloudy.

SECTION 3:
CAPACITY FACTOR

So how can we estimate how much electricity will ACTUALLY be generated by our 25% efficient solar panel over the course of an entire year? It's a year full of rainy days and dark nights, along with hopefully its fair share of sunny days.

This is where **Capacity Factor** comes in. Every energy technology (both renewable and nonrenewable) has a capacity factor. It tells you how close to the nameplate capacity the solar panel will be working on average over the course of the entire year.

To use our solar panel example: Sometimes (at noon on a clear summer day) the power it generates will be getting close the same as its peak capacity. Sometimes (at night) the power it generates will be zero. In between those two extremes there will also be twilight and dusk, and there will be cloudy days throughout the year.

There are 8,760 hours in a year (365 days x 24 hours). If our 25% efficient solar panel (250 Wp nameplate) could operate at its peak capacity the entire year, it would generate 2,190,000 Wh or 2,190 kWh of electricity (8,760 x 250). We know that's not going to happen. Instead, we can use a capacity factor of 18% and estimate that it will generate 394,200 Wh or 394 kWh (8,760 x 250 x 0.18). You would need about twenty of these panels to power your house if it consumes 8 MWh (8,000 kWh) per year.

Capacity factors for solar vary by geographic region (based on weather patterns and latitude) and typically are between 15 – 22%.

Questions

1.

An array of 100 solar panels is properly installed in Somerset where the capacity factor for that kind of solar panel is 18%. Each of the solar panels in the array has a nameplate capacity of 200 Wp. How much electricity in kWh can you expect the solar panels to generate in a typical year?

2.

A 50 kW wind turbine is installed in Cornwall. A study of the wind conditions at that location has determined that a 35% capacity factor is to be expected. How many kWh will the wind turbine produce each year?

3.

500 wave energy generating devices with a nameplate capacity of 5 kWp are installed off the coast of Rhode Island. The weather conditions in those coastal waters lead to a capacity factor for wave energy of 30%. How many MWh of electricity will be produced in an average year by this wave energy installation?

4.

Concentrated solar power (CSP) plants convert the sun's energy into electricity via steam turbines that use heat energy. They can have very high capacity factors because they are able to store thermal energy even after the sun goes down. A 100 MW CSP plant recently installed in Arizona has a capacity factor of 65%. How much electricity in MWh does this new power plant make in a year?

Answers

1.

100 panels
x **200** Wp
x **8,760** hours/year
x **0.18** capacity factor

= **31,536,000** Wh or **31,536** kWh
(bonus question: how many homes that use 8 MWh/year does this power?)

2.

1 turbine
x **50** kWp
x **8,760** hours/year
x **0.35** capacity factor

= **153,300** kWh

3.

500 wave energy devices
x **5** kWp
x **8,760** hours/year
x **0.30** capacity factor

= **6,570,000** kWh or **6,570** MWh

4.

1 CSP plant
x **100** MWp
x **8,760** hours/year
x **0.65** capacity factor

= **569,400** MWh
(bonus question: how many homes that use 8 MWh/year does this power?)

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Activity 5: Energy Fundamentals
and the Art + Energy Flash Cards

Answers to Art + Energy Flash Card Questions

1. BEYOND THE WAVE

2. LIGHT SANCTUARY

3. WINDNEST

4. FRESH HILLS

5. HELIOFIELD

6. TRANSPIRE

7. PV DUST

8. SHIFTING ALGAE FOREST

9. BLOSSOMINGS

10. WIND GRAZERS

11. SOLAR (ECO) SYSTEM

12. SUPER CLOUD

13. THE CLOUD

14. THE SOUND OF DENMARK