THE BASICS: SOLAR ENERGY

CAN I USE SOLAR (PV) TO OFFSET MY ENERGY COSTS?

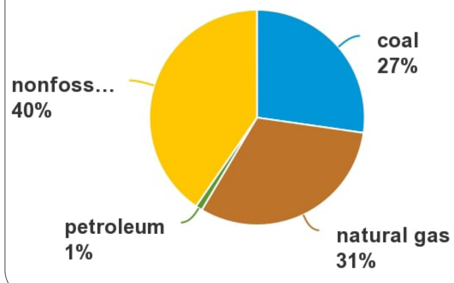
WHY SOLAR?

Electrical power generation is major contributor of greenhouse gas (GHG) emissions in our atmosphere. Of all harmful GHG emissions, Carbon Dioxide (CO_2) accounts for nearly 75%, which can largely be attributed to the sources of fuel being used (e.g. fossil fuels – mainly coal and natural gas – generate roughly 60% of electricity produced in the U.S.). Although coal is used for only 27% of electricity generation, it accounts for 60% of CO_2 emissions from the electric power sector. This suggests that non-GHG-emitting, renewable electric sources like wind, hydro, and solar provide great opportunities to reduce CO_2 emissions. As an example, if such sources were used to replace the 27% of electric demand that coal generates, 60% of GHG emissions would be eliminated from the electric power sector.

Solar energy can be converted to electricity using either photovoltaic (PV) panels to directly create electricity, or by concentrating the sun's thermal energy to create steam and rotate a turbine similar to coal power plants. Unlike the solar-thermal method, photovoltaic systems can easily be adapted for utility purposes and building or load scale, and can often utilize unused roof or site area rather than planning for a specific location (although planning will improve success). This is one reason why PV systems have become popular in recent years as a go-to solution resulting from heightened environmental awareness and increasingly stringent energy code requirements.

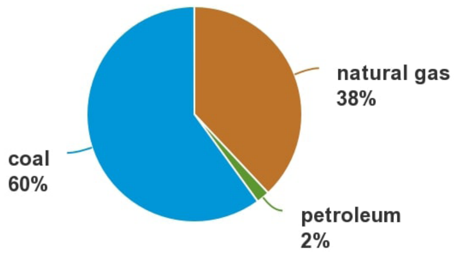
MAJOR FUEL / ENERGY SOURCES FOR U.S. ELECTRIC POWER SECTOR, 2019

TOTAL = 37.1 quadrillion British Thermal Units



ELECTRIC POWER SECTOR EMISSIONS BY SOURCE, 2019

TOTAL = 1,691 million metric tons



Note: nonfossil includes nuclear, hydropower and renewable energy.

Source: US Energy Information Administration, *Monthly Energy Review*, Table 2.6 and 11.6, July 2020, preliminary data

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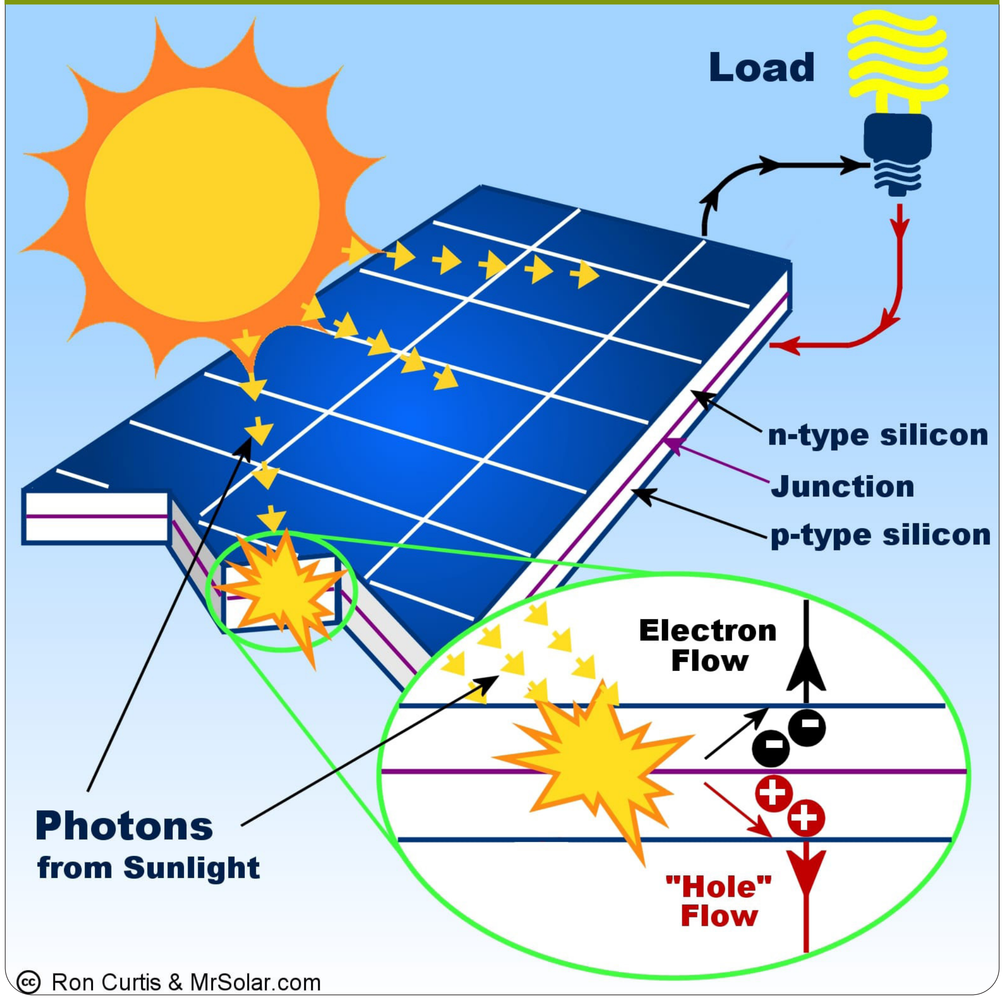
SOLAR PHOTOVOLTAIC (PV) TECHNOLOGY BASICS:

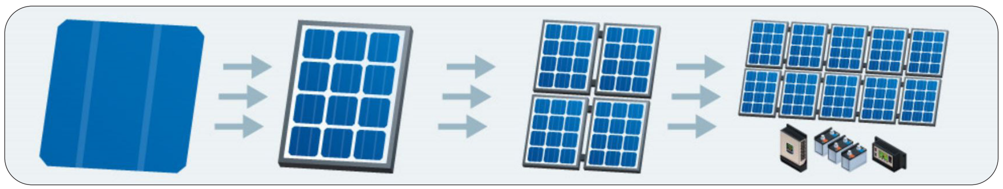
Photovoltaics are descriptively named for the way they convert energy from the sun into electrical energy (i.e. photons create voltage). Photons emitted from the sun collide with the semiconductor materials in a solar cell. When this collision happens, the energy that is contained in the sun's photons transfers to electrons in the solar cell, causing them to be "excited." This simply means the electrons have more energy than they usually do, and because of this, potential energy is created in the form of a voltage difference. Once a voltage difference is created and potential energy exists, it can be utilized. By their nature, PV panels can only create direct current (DC) power systems. For commercial buildings, this most often means that the PV systems must be provided with inverters to create AC power before utilizing.

Photovoltaic panels are made up of many individual solar cells. Each cell produces between 0.5-0.6 volts and approximately 5 watts. Then, many cells are connected in series to form 'strings' until a desired voltage is reached. These strings are then connected in parallel to increase power output. Common voltage outputs of PV panels are approximately 18V for 12V systems and approximately 36V for 24V systems, which exceed the system voltages for the ability to charge batteries that are often involved. Typical commercial PV panels measure roughly 78"x39" and contain 72 individual cells, which produce between 350-400 watts. They are larger than panels used for residential applications, which measure 65"x39", have 60 cells, and produce between 270-320 watts. The panels are then placed in rows side-by-side, and in multiple rows creating an array.

According to NASA, the amount of the sun's energy that reaches the earth is approximately 1,360 watts per square meter. However, PV industry guidelines dictate Standard Testing Conditions (STC) of $1 kW/m^2$, or about ($100 W/ft^2$). Solar panels, on average, can achieve between 15-20% efficiency. The National Renewable Energy Laboratory (NREL) uses 16% as a standard efficiency. Modern PV panels produce about 17 watts per square foot (W/ft^2), considering only the panel's surface area.

ANATOMY OF A SOLAR CELL





SOLAR CELL — *6" x 6"*

SOLAR PANEL — *60 or 72 cells together create 250-400w panel*

SOLAR ARRAY — *Panels wired together*

SOLAR PANEL SYSTEM — *Complete PV system with inverter, wiring, etc.*

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WATTS / SQ. FT. CAPACITY OF PHOTOVOLTAIC (PV) ARRAYS

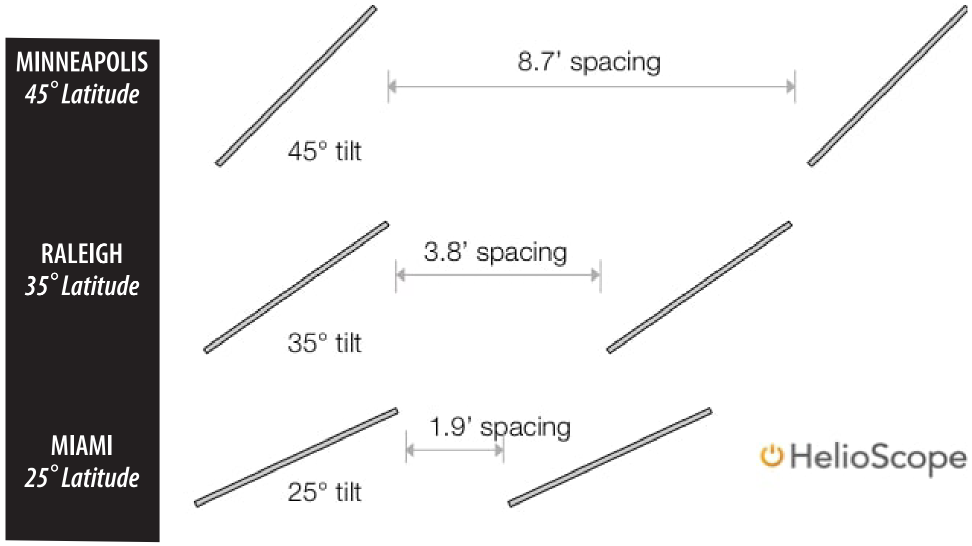
A PV array, whether roof or ground mounted, will not produce the nominal 17W/ft^2 quoted above, primarily due to spacing between rows of the array. This spacing, which should be as close as possible, is impacted by the angle which the panels are tilted. The higher the tilt angle (more vertical), the more shading created by a row of panels, therefore increasing the spacing between rows. Conversely, the lower the tilt angle (more horizontal), the closer the rows may be spaced. Intuitively, closer row spacing will increase W/ft^2 capacity compared to rows that are spaced further apart.

The tilt angle of a panel is traditionally based on latitude of the location. For example, Minneapolis has a latitude of roughly 45°, and Miami has a latitude of roughly 25°. An array in Minneapolis might have a tilt of 45° and a row spacing of 8' to 9', capable of producing approximately 12 W/ft^2. An array in Miami might have a tilt of 25° and row spacing of 2', capable of producing approximately 15 W/ft^2. Other locations would have tilt angles based on their latitude, and therefore W/ft^2 capabilities would be proportionate to those listed for Minneapolis and Miami. Raleigh, NC, has a latitude about halfway between Minneapolis (45°) and Miami (35°) and therefore has a capacity halfway between the PV arrays (13.5 W/ft^2) of the two cities.

Some solar developers are beginning to move away from this historical method of design. Rather than setting the tilt angle based on latitude and adjusting the row spacing accordingly, the tilt angle is designed between 10° and 15° with only slightly larger row spacing for northern installations (1-2 feet). This allows for minimal row spacing and maximum installed capacity, although power output produced by each panel is sacrificed. This will increase the cost of installation but it can be advantageous when pursuing financial incentives, as many programs are based on kW of installed capacity. Each method should be investigated with careful consideration for ROI, which can vary greatly for different designs and locations. As the cost of PV installations continues to decrease, we will see this new method become increasingly common.

ROW SPACING VS. TILT ANGLE AND LATITUDE

Row spacing will be affected by the tilt angle of the panels. Tilt angle is typically based on the angle of latitude at the location of the PV array.



Although row spacing and tilt angles based on latitude is a tried-and-true historical practice, it is not the only method used to design PV systems today. Many installations are now optimizing for total installed capacity, rather than optimizing for maximum output of each panel.

FUN FACT:
Some tilt angles can be adjusted to optimize for seasons, decreasing the angle by 15° in the summer (more horizontal), or increasing by 15° (more vertical) for winter – although, adjustable tilt arrays are not common for rooftop solar installations.

HOW MUCH ENERGY CONSUMPTION CAN PV OFFSET?

The W/ft^2 discussed in the **Summary and Rules of Thumb** (at right) can be used when actual square footage of the PV array is known. **Because we are often asked hypothetical questions early in design, a conservative estimate of 10 W/ft^2 can be used.** The National Renewable Energy Laboratory (NREL) uses 1kW/m^2, which is approximately 10.7W/ft^2.

It is important to note that power capacity of a PV array can only be reached during peak hours of sunlight. Peak sunlight hours occur when the solar irradiance reaches or exceeds an average of 1,000 W/m^2. The amount of peak sunlight each day is typically between 4-5 hours, depending on your exact location. Most of the time, the actual power produced is much less than the nominal capacity. Whether the PV array can offset the energy of a building depends on the building location, uses, and mechanical systems even more than the size of the PV array. It's not likely that a PV array will offset the peak energy consumed by a building. However, a properly designed PV array may be able to offset or exceed the amount of electric energy consumed over time.

SUMMARY AND RULES OF THUMB:

PV Basics:

- Solar Cells produce 5 watts, 0.5 volts.
- 1 Commercial PV Panel produces 360 watts
  - 72 cells - 78"x39"

PV Capabilities:

- Southern U.S. ––> 15 W/ft^2
  - 25° Latitude: 2' row spacing
- Middle U.S. ––> 13.5 W/ft^2
  - 35° Latitude ––> 4' row spacing
- Northern U.S. ––> 12 W/ft^2
  - 45° Latitude ––> 8' row spacing

- Conservative Estimate ––> 10 W/ft^2
  - Use if the location is unknown or if you know the area of the roof that is available for solar array, but it is too early in design to know if RTUs or other obstacles.
  - Do NOT use if you have enough information for a more accurate estimate.

Cost of PV Systems:

- Currently less than $2 per watt installed.

Other Considerations:

- Rooftop equipment location and size.
- Roofing construction and installation methods.
- Shading from surrounding buildings and trees.
- Maintenance, cleaning and snow removal.

AND ONE MORE THING...

Maintenance is an important aspect to consider for PV arrays. The equipment, components, and roof penetrations need to be routinely inspected. In addition, the arrays will need to remain clean for best results. Dirt, dust, leaves, animal waste, and vegetation can build up over time. Also, snow buildup will diminish the production of the array. Cleaning the panels can be done at regular intervals, but snow will need to be removed as it accumulates in order to keep producing power through the winter. Installations with low tilt angles result in substantially more time with snow-preventing production. The owner and/or operator could choose to not remove snow, but any forecast of savings should take into account the potential for reduced production due to snow buildup.

emanuelson-podas
consulting engineers