SOLAR PANELS

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What Can Solar Power Do?

- Depending on the solar intensity, solar power can do one of three things
- A) Solar power can **augment** your station power
- B) Solar power can **meet** all your station power needs
- C) Solar power can **exceed** all your station power needs and you will have excess power that can be used to charge additional batteries

What About The Cost Of Solar Panels?

- Solar panel prices have come down a lot over the last 10 years
- Solar panels were pretty expensive when they were first made available to the public in the 1970s

Solar Panels Are Finally More Affordable, Look At Price Per Watt

- 1975 price was $101.05/watt
- 1977 price was $77.00/watt
- 2008 price was ~ $4.00/watt
- 2015 price was $0.64/watt
- 2017 price is $0.53/watt
- The 2017 pricing is based on the **large** grid-tie panels

Renogy 100 Watt Solar Panel Selling For $127.99, Is About $1.28 Per Watt

Construction Of Solar Panels

- Each solar cell produces about 0.5-0.6 volts
- The solar cells are **wired in series** which **adds up all the voltages** and the **amperage** stays the same as the lowest amperage cell in the string (they are all the same size)
- Early solar panels were just 36 cells and used for charging batteries…36 cells x 0.5 volts = 18 volts

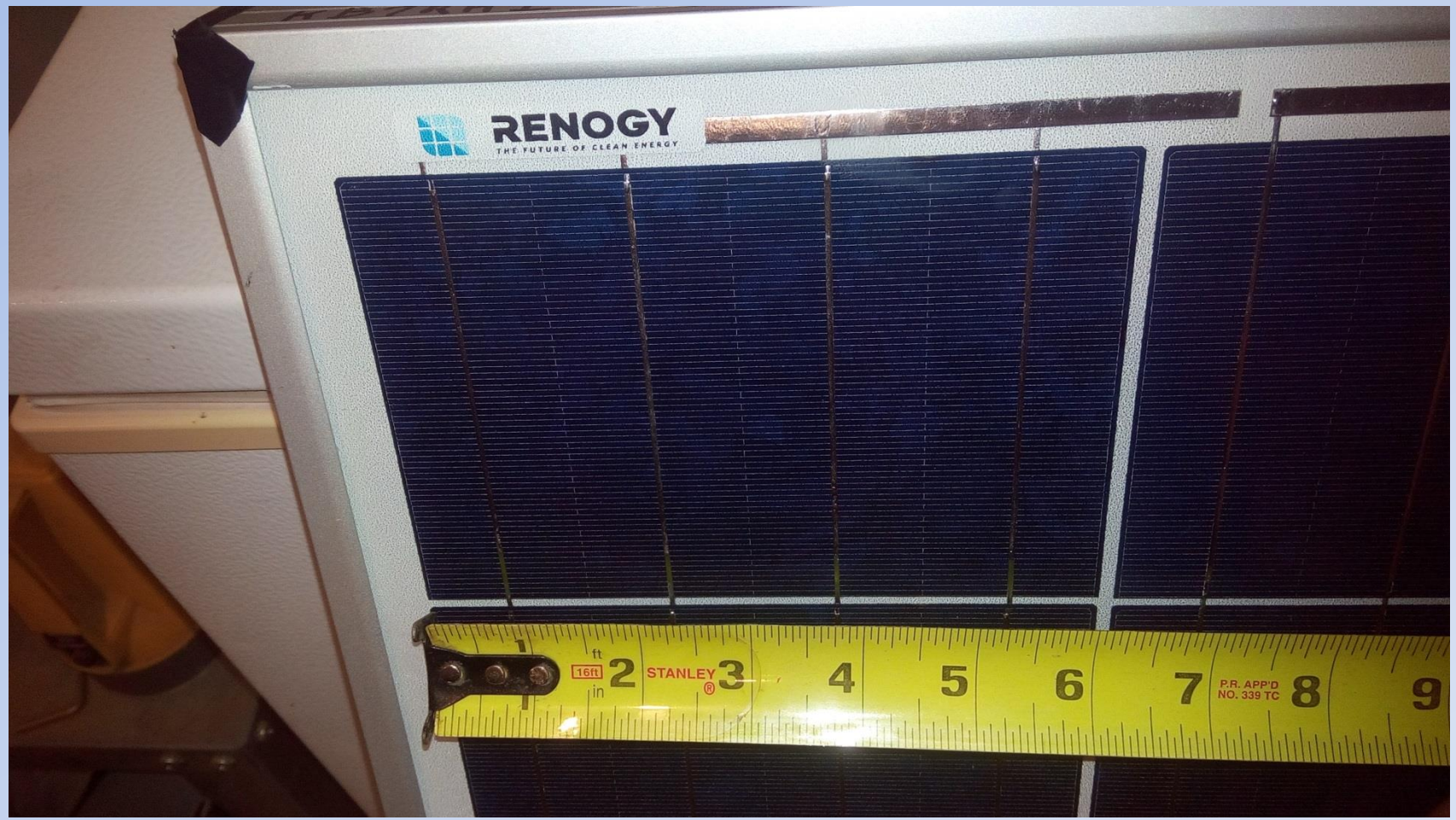
Construction Of Solar Panels

- **Grid-tie** systems were for **DC power to be converted to AC power**, the number of cells was not tied to charging batteries
- So **more power output for each solar panel** made sense, just add more cells to each panel to increase the voltage…so **60, 72, and 96 cell panels** are for grid-tie solar were made
- Solar panels with **larger sized cells** will produce **more amperage**

Solar Cell Size That Produces 2.35 Amps

Solar Cell Size That Produces 3.35 Amps

Solar Cell Size That Produces 5.62 Amps



Energy From Photons Of Light

- **Sunlight** has tiny particles of energy called "**photons**"
- Photon energy levels vary from **low energy infrared** photons, to **midrange energy visible light** photons, to **high energy ultraviolet** photons
- Our solar panels use **mostly the midrange energy** photons to make electricity

Energy From Photons Of Light

- Sunlight striking the earth has approximately 1,000 watts/M2 in **total energy**, a **portion** of the sunlight has the **right energy level** for solar panels to make power

Energy From Photons Of Light

- We are interested in the photon of light that has enough energy to knock an electron(valence) out of its **regular orbit** and into what is called the **Conduction Band**…think of it as an "**electron highway**" in the crystalline solar cell
- From there the electron travels in the solar cell in a circuit to our power cable

Energy From Photons Of Light

- There is a Band Gap between the “electron orbit” and the “electron highway”, if **one photon** has the right energy(wavelength must be 380-750nm), it can bump **one electron** out of its “orbit” and allow the electron to travel down the “electron highway” through our electrical circuit
- If the photon has too much energy, it knocks the electron **beyond the conduction band** and that electron can not travel on to our power cable

Sunlight Spectrum

- 52-54% is **infrared**…longer wavelength light, 700nm-1mm
- 42-43% is **visible** to the naked eye...medium wavelength light, 400-700nm
- 3-5% is **ultraviolet**…shorter wavelength light, 100-400nm
- Our solar panels can make DC power with sunlight that is 380-750nm in wavelength

Wavelengths Of Light That Solar Panels Can Use To Make Power

Infrared **Visible** **Ultraviolet**

1mm – 700nm....I....700nm-400nm....I....400nm-100nm

750nm----------380nm

Solar panels make power here

Low energy>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>high energy

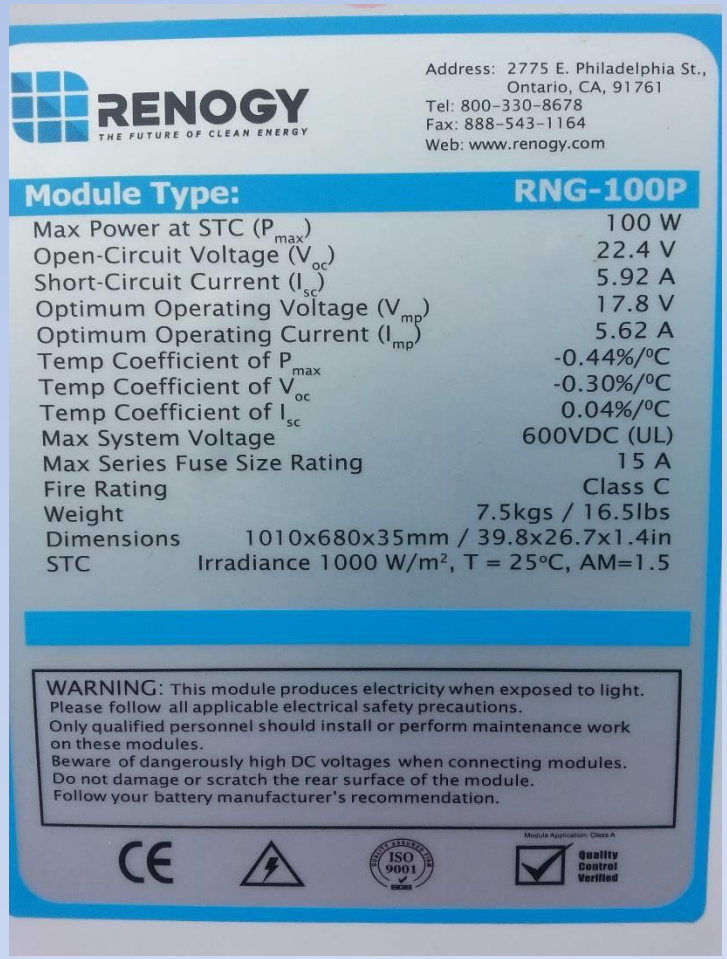
Sunlight Spectrum And Photon Energy Levels

- The shorter the sunlight wavelength, the more energy the photon has
- Solar panels use a little of the **upper end infrared**, **all of the visible light** and a little of the **lower ultraviolet light** to make power

Nominal 12 Volt Solar Panel

- Has 36 cells wired in series (monocrystalline panels show the cells)
- Be aware that some manufacturers years ago tried to wire less than 36 cells in series(say 32) in an attempt to avoid using a charge controller
- Problem with that…solar panel output drops some, the warmer they get…the 32 cell panel voltage dropped too low to charge a battery

Solar Panel Nameplate



Understanding Your Solar Panel Label

- Solar panel power is measured in **Watts**
- **Watts** = **Amps** x **Volts**
- Example…100W solar panel = 5.62 **Amps** x 17.8 **Volts**
- Optimum operating voltage is 17.8 **volts (Vmp)**
- Optimum operating current is 5.62 **amps (Imp)**

Factory **Flash Testing** Of Our Solar Panels

- Every solar panel undergoes a factory test using **STC** (**S**tandard **T**est **C**onditions), which does not resemble “Real Life” conditions
- Flash tests can show a **variation** of about 5-6% for each panel from the **same batch**
- The panels are sorted according to the results of this test

Solar Panel **S**tandard **T**est **C**onditions (**STC)**

- **Air temp** and solar **panel temp** is set to 25 C or 77 F
- They **flash** the panel with a light intensity or **irradiance** set to **1,000 W/M2**
- **AM 1.5** = Air mass of 1.5

Irradiance In Watts Per Square Meter

- Irradiance describes how much power is coming down from the sun
- Back in the 1970s, a **benchmark sunlight intensity** (**irradiance**) was selected for STC ratings on solar panels
- **1000 watts per square meter** was to represent the amount of sunlight energy striking a mid latitude location in the US at sea level on a clear day

Irradiance In Watts Per Square Meter

- A one meter square solar panel at 20% efficiency can produce 200 watts of energy
- This is about the best conditions you will find in real life, often your sunlight intensity may be closer to 800 watts of energy per square meter
- The **irradiance** directly influences the **amperage output** of your solar panel

What Does **AM 1.5** Mean?

- "**AM 1.5**" on a solar panel spec sheet is talking about the **air mass** coefficient
- "**AM 1.0**" represents **the air mass that a photon of light would travel through** if you were at sea level and looking straight up and the sun was **directly overhead** (zenith angle)

What Does **AM 1.5** Mean?

- **AM 1.5** (1.5 x atmosphere thickness) represents the amount of air mass that a photon of light would travel through if starting directly overhead (zenith), you dropped **down about 48 degrees**, as sunlight travels through more atmosphere thickness, there is some attenuation
- AM 1.5 takes into account the losses that occur when photons travel through more of Earth's atmosphere to reach your solar panel

Air Mass Reference From The Solar Panel Starting Out Facing Straight Up

Sky Sun Angle in degrees starting from overhead	Air Mass Coefficient	W/m2 range due to pollution, Avg = Bold
0 Looking straight up	1	840-1130 = **990** +/- 15%
23 The sun is down 23 degrees	1.09	800-1110 = **960** +/- 16%
30	1.15	780-1100 = **940** +/- 17%
45 halfway down	1.41	710-1060 = **880** +/- 20%
48.2	1.5	680-1050 = **870** +/- 21%
60	2	560-970 = **770** +/- 27%
70	2.9	430-880 = **650** +/- 34%
75	3.8	330-800 = **560** +/- 41%
80	5.6	200-660 = **430** +/- 53%
85 is 5 degrees above the horizon	10	85-480 = **280** +/- 70%

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More Solar Power Terms

- Voc = open circuit voltage
- Isc = short circuit amperage
- Another solar panel rating called PTC
- Sun hour

Testing Your Solar Panel **Voc** (Voltage)

- **Voc** = **O**pen **C**ircuit **V**oltage, that is the voltage reading you get when the solar panel is not connected to a load
- Off-grid(36 cell) solar panel **Voc** is around 22 volts, no load = no resistance
- To measure **Voc**, place your solar panel in full sun and check the voltage reading with a volt meter

Factors That Impact Solar Panel **Voc** (Voltage)

1) Temperature of the solar panel
2) Light intensity or illumination
3) Solar cell material

Temperature Impact On The Voltage Of Your Solar Panel

- Temperature has the biggest impact on the output voltage of your solar panel
- The **hotter** a solar panel gets, the **lower the voltage** output
- Batteries could need up to 15 volts for an equalization charge, and up to 14.6 volts for LFP batteries
- Solar cells output about 0.5-0.6 volts per cell, so wire 36 cells in series to get ~18 volts in perfect conditions, then when it is really hot and the voltage drops some, you still have enough voltage to charge your battery

How To Calculate The Temp Coefficient

- Solar panel temp is **ambient air** temp **plus** about **20C** due to being in direct sunlight
- Hot 95 degree day is 35C
- Direct sunlight adds 20C to the solar panel temp
- So 35C + 20C = 55C solar panel cell temp
- That is **30 C above the STC of 25 C**
- When the Renogy 100 watt solar panel was at STC, the Voc was 22.4 volts

Renogy 100 Watt Solar Panel Temp Coefficient

- Solar panel label shows that for every degree Celsius the solar panel is above 25 C, the voltage will drop by 0.30%
- Hot panel temp of 55 C - STC 25 C = **30 C difference**
- 30 x 0.30% = 9% drop
- 22.4v (open circuit voltage) x 0.09 = 2.01v
- Solar panel voltage output has dropped by 2 volts
- Your solar panel went from ~18v to ~16v

Solar Panel Temperature And Overall Power Efficiency

- Temp related “Coefficient of Pmax” = -0.44%/C
- STC = 25 C, for every **1 C above the panel temp** of 25 C, your **solar panel efficiency** (wattage) **drops by 0.44%**
- If your solar cell temp is **55 C**, then 55 C – 25 C (STC) = 30 C hotter

Solar Panel Temperature And Overall Power Efficiency

- 30 C x -0.44% = **13.2% less power** from your solar panel with cell temp = 55 C
- Your 100 watt solar panel now has a max power of 87 watts on a 95 degree F day

Does The **Intensity** Of The Sunlight Affect The Voltage Of The Solar Panel Much?

- Panel voltage may drop by 10% with an 80% drop in illumination (solar light intensity)
- That is **GOOD NEWS**, **low sunlight intensity does not have a big influence on panel voltage**
- It means you probably will have enough voltage to charge your battery when there is low sunlight levels, your amps may be low, but the voltage will be enough to still charge your battery
- **Light intensity** does not have a big influence on the **voltage** coming from your solar panel, **big influence is panel temp**

Testing Your Solar Panel **Isc** (Current)

- The **Isc** is the reading in **amps** you get when the solar panel output is shorted
- **Isc** = **S**hort **C**ircuit **current** (capital **I** is the symbol for current)
- To test the **Isc**, have your multimeter black lead plugged into the COM port and the red lead plugged into a high current port…note the limit in amperage your meter can read, Fluke 26III is 10 amps max

Testing Your Solar Panel **Isc** (Current)

- First cover the solar panel or turn it to **keep away from direct sunlight**, to prevent power from flowing
- **Connect** your multimeter leads to the solar panel output and select the amperage reading

Testing Your Solar Panel **Isc** (Current)

- Uncover or turn the solar panel back around to **face directly into the sun**, adjust the solar panel to find a peak reading, then cover or **keep away from the sun**
- Be careful not to connect or disconnect the leads while the solar panel is in the sun, or you will do some “DC arc welding of your connections”

Help Your Solar Panel Stay **Cool**

- Of course your solar panel is going to get warm in direct sun, but allowing the back side to get some ventilation will allow you to get more power
- If you lean your 100 watt solar panel next to something to direct it at the sun, be careful if the wind picks up in the afternoon, you may want to anchor it somehow?


NOTICE

Solar Panels Rated Using **PTC, California Requires This For Grid-Tie**

- **PTC** or **P**VUSA **T**est **C**ondition= **P**hoto**v**oltaics for **U**tility **S**ystems **A**pplications
- **PTC** was developed in the mid 1990s by the **NREL** (**N**ational **R**enewable **E**nergy **L**aboratory) Federal Government laboratory
- Designed to be a set of conditions that measure solar panel performance under **real world conditions**

Comparing STC Benchmark Conditions To The Newer PTC Benchmark Conditions For Panels

	STC	PTC
Solar cell temp	77F or 25C	113F or 45C
Ambient air temp	77F or 25C	68F or 20C
Cooling wind temp	none	2.2 mph or 1m/s

Solar Panels Rated Using **PTC**

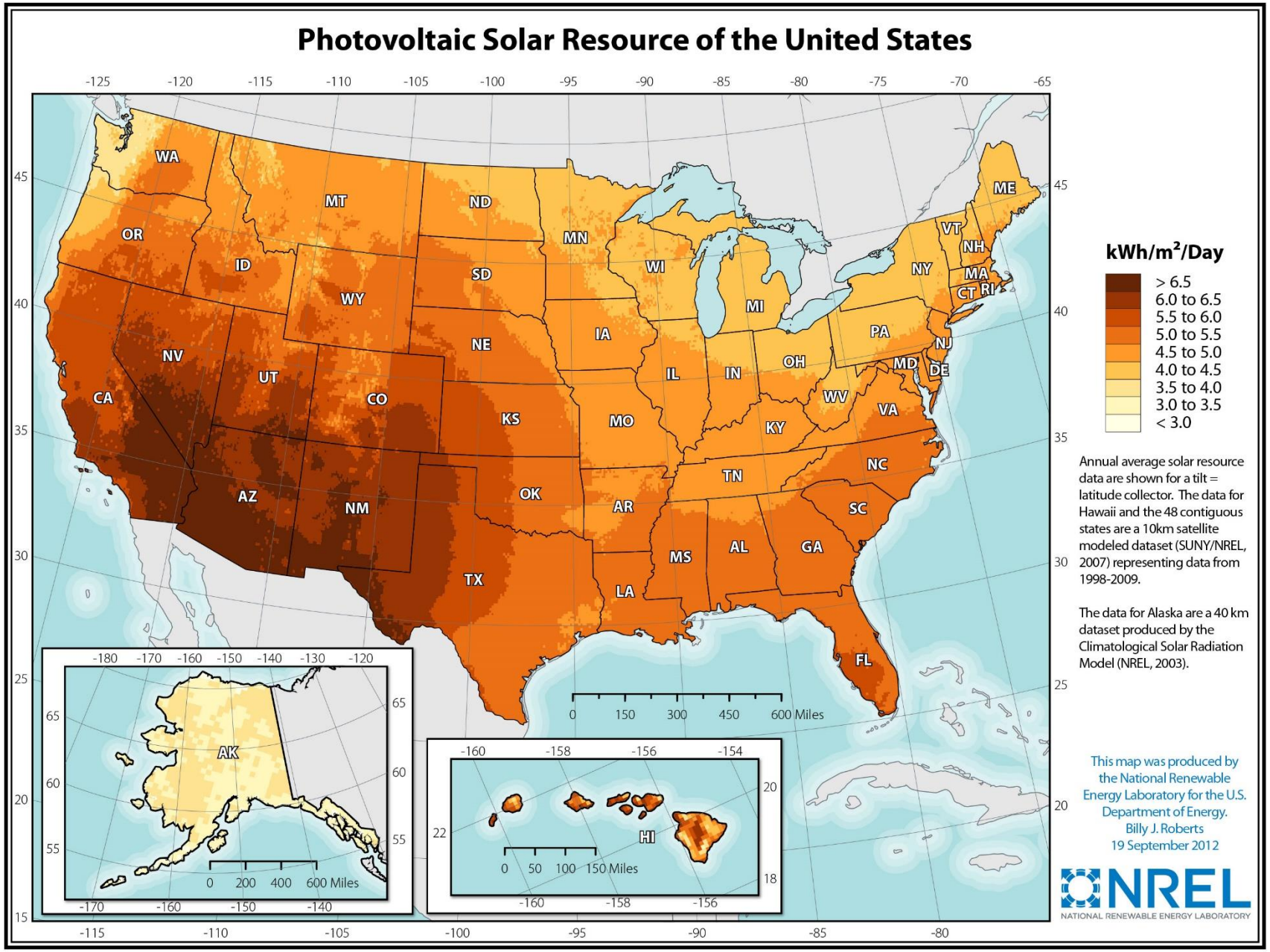
- **PTC** looks at the solar panels with a more realistic temperature rating, it uses 25C higher panel temp in direct sunlight
- Ambient **air temp** = 20 C or **68 F**
- Solar **cell surface temp** is estimated at 45 C or 113 F
- **Cooling wind** is 1 meter/second or 2.2 MPH
- **Inclination** is 45 degrees with the panel back open
- California State uses **PTC**

Does **PTC** Make A Difference?

- As a solar panel gets hotter, the power output decreases some
- Of 655 different solar panels listed as **260W STC** in the California Energy Commission database
- The **PTC** ranged from **217.1** watts to **239.8** watts, a 23 watt difference or ~9%
- Customers would want to know which “260W” panel is more efficient

Sun Hour

- “Sun hour” – if we collected all the sun energy in a bucket from 30 minutes before noon to 30 minutes after noon, we would have one “sun hour” of energy
- Assume the sun energy around noon is 1000 watts per square meter, (clear summer day)
- One sun hour is equal to one kilowatt-hour
- In solar power, instead of saying how many kilowatt-hours per square meter per day, it is easier just to say how many “sun hours/day”


Photovoltaic Solar Resource of the United States
kWh/m²/Day
> 6.5
6.0 to 6.5
5.5 to 6.0
5.0 to 5.5
4.5 to 5.0
4.0 to 4.5
3.5 to 4.0
3.0 to 3.5
< 3.0
Annual average solar resource data are shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.
The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Billy J. Roberts
19 September 2012
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
0 150 300 450 600 Miles
0 200 400 600 Miles
0 50 100 150 Miles
WA
OR
CA
ID
NV
MT
WY
UT
AZ
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MS
MI
IN
KY
TN
AL
OH
WV
GA
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SC
NC
VA
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MA
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HI

The Sun Moves Across The Sky, Should I Move My Solar Panel To Follow The Sun?

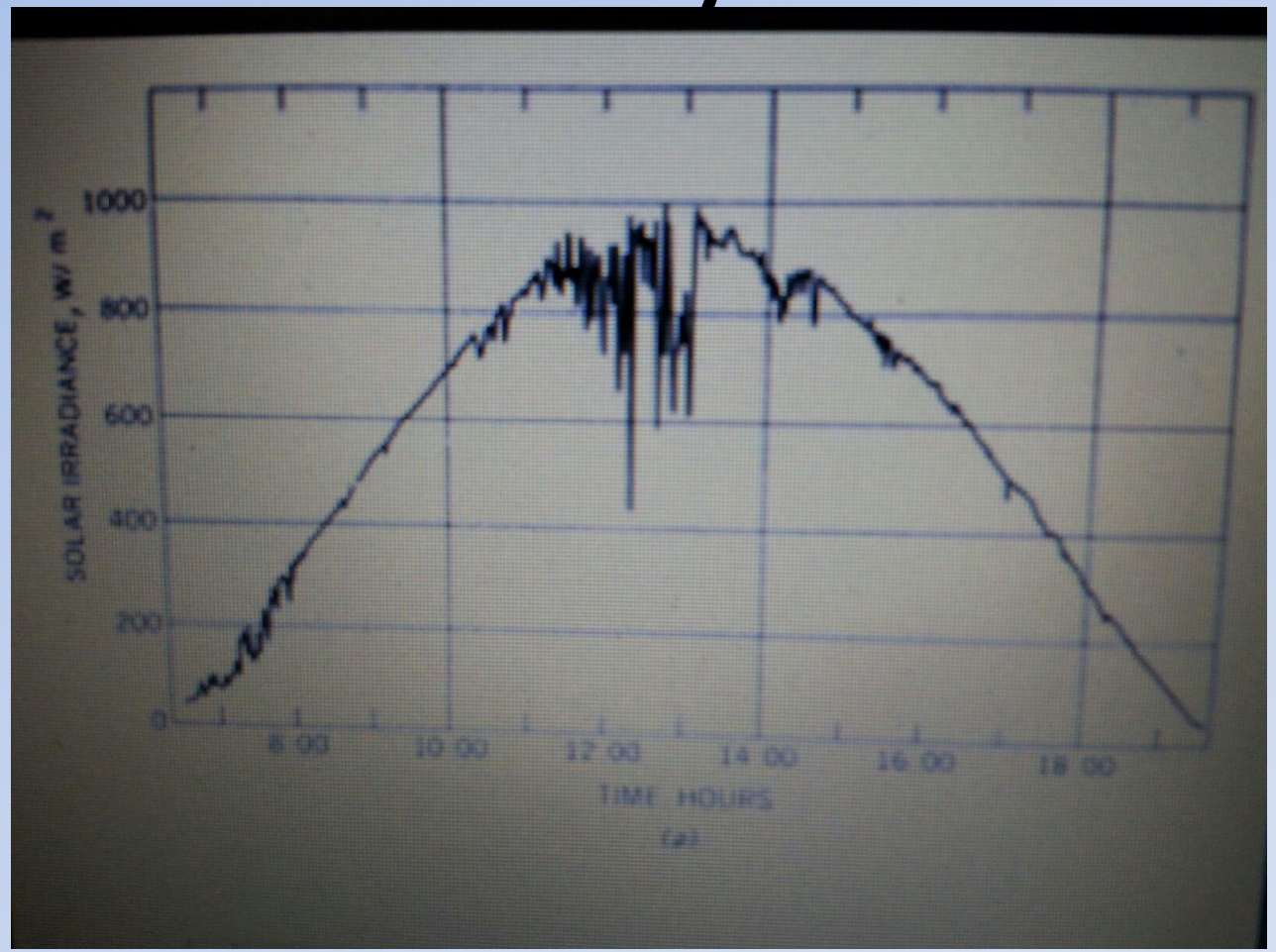
- The angle I **place my solar panel to the sun** does make some difference
- Would recommend pointing the panel at the sun and then rotate the face about 30 degrees west
- The sun will start at 30 degrees to the left of the panel, then be directly in front, and then travel 30 degrees to the right of the panel, then it is time move it again

Mid Day In March Sun Angle Test

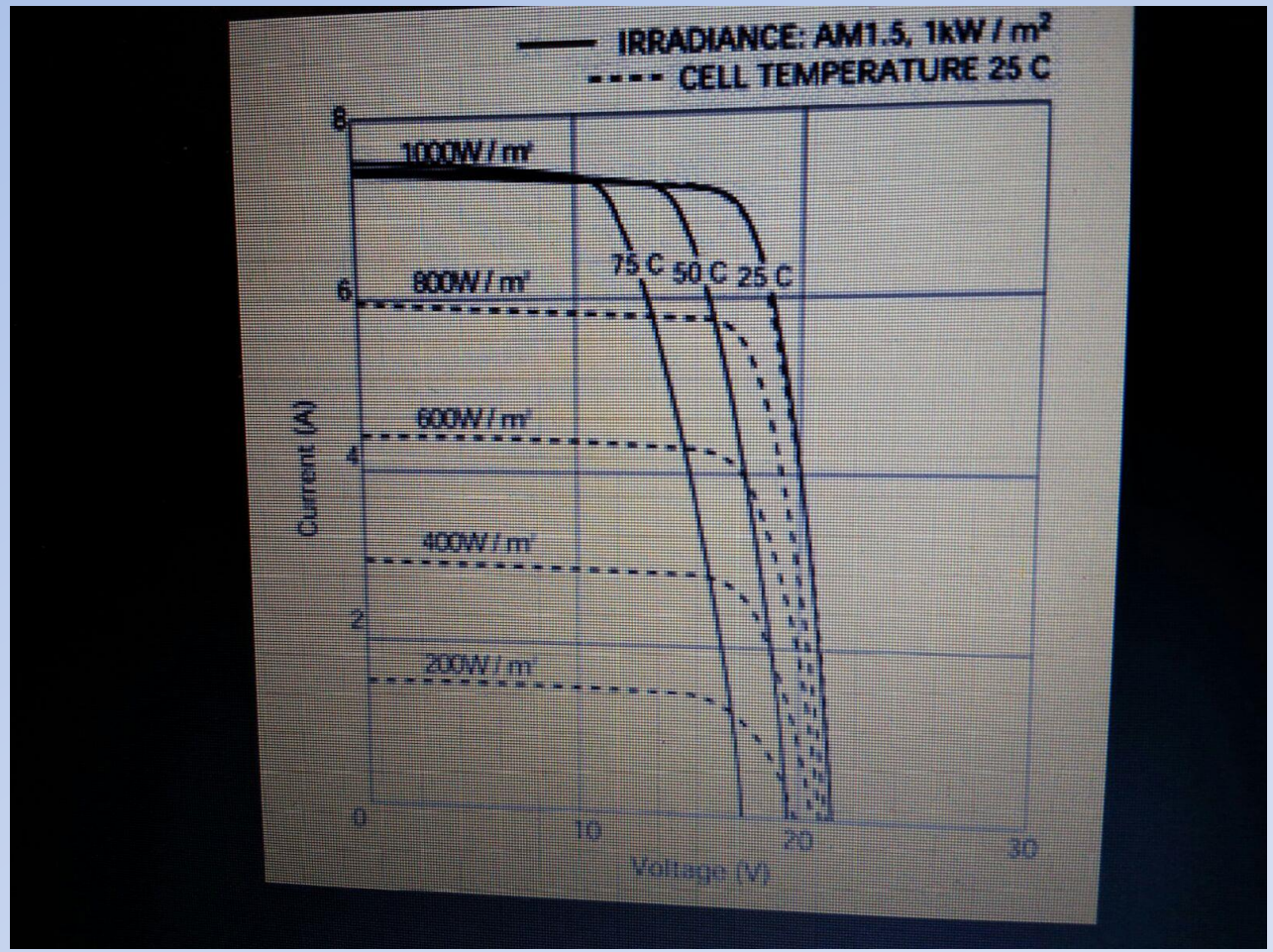
- 40 watt monocrystalline solar panel
- Facing directly at the sun = 2.3 amps
- Angled 15 degrees away from the sun = 2.23 amps
- Angled 20 degrees away from the sun = 2.19 amps
- Angled 30 degrees away from the sun = 2.0 amps


STOP

Sunlight Intensity Over A Mostly Sunny Day



Solar Panel Output Based On Irradiance Levels



Three Major Types Of Solar Panels

- 1) Monocrystalline
- 2) Polycrystalline
- 3) Thin film or Amorphous

100 Watt Monocrystalline Solar Panel

Monocrystalline Solar Panel

- The solar “cells” are silicon material that is grown into a single crystal and then sliced
- You can see each solar cell
- **They are the most efficient**, and have up to 10 year workmanship and up to 25 year output warranties
- Monocrystalline solar panels from the 1970s are still making power

Monocrystalline Solar Panel

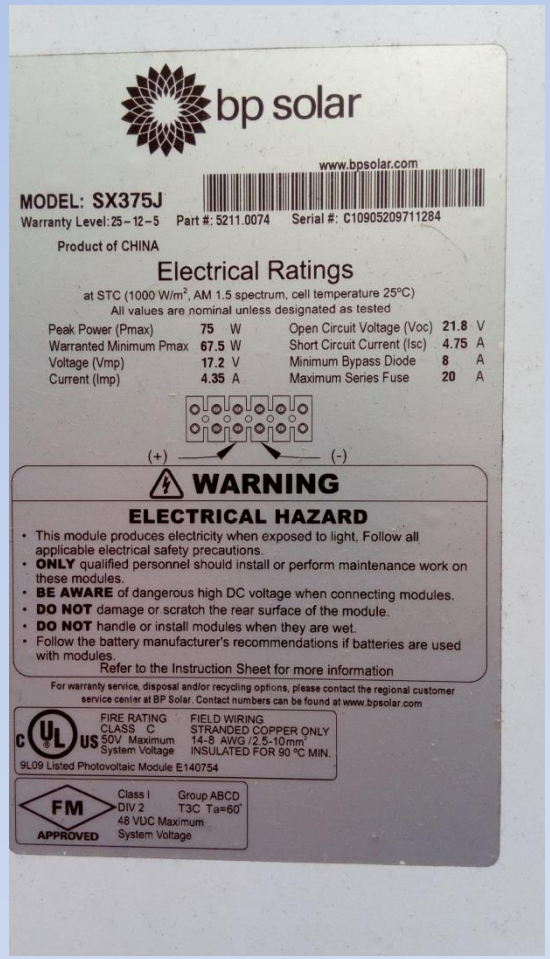
- Like most panels, they do not tolerate **shading** or getting **dirty**, causes power output to drop a lot, just keep clean and in full sun
- Excellent choice for portable power

Polycrystalline Solar Panel

- The material is melted and poured into a mold
- **Slightly less efficient** than the monocrystalline
- Good choice for portable operations
- Keep them in full sun and clean

75 Watt Polycrystalline Solar Panel

75 Watt Polycrystalline Solar Panel Label



Thin Film Solar Panel

- Low efficiency
- Ok if you have lots of room for a fixed location installation and you are not planning to move them around a lot
- The Harbor Freight version is heavy and the efficiency for the amount of weight could be disappointing
- Lot of effort for less output, if you are going portable
- solar

Harbor Freight 25 Watt Solar Panel…66% More Power? I Do Not Think So

Harbor Freight Amorphous Solar Panel Claims

- Harbor Freight makes the claim that their 25 watt solar panel produces 66% more power
- 66% more power than what?
- I could not find what this claim was referencing
- The amorphous solar panels are an **ok choice**, but I believe someone would be much happier and have **more joy** using a **monocrystalline solar panel**

Thin Film Solar Panel

- Targeted for the “consumer market”, not a best choice for critical applications
- **Thin film** could degrade more quickly over time, the jury is out
- They do lose less power on warmer days, >25 C, about .25% per C, versus about 0.5% per C with crystalline panels

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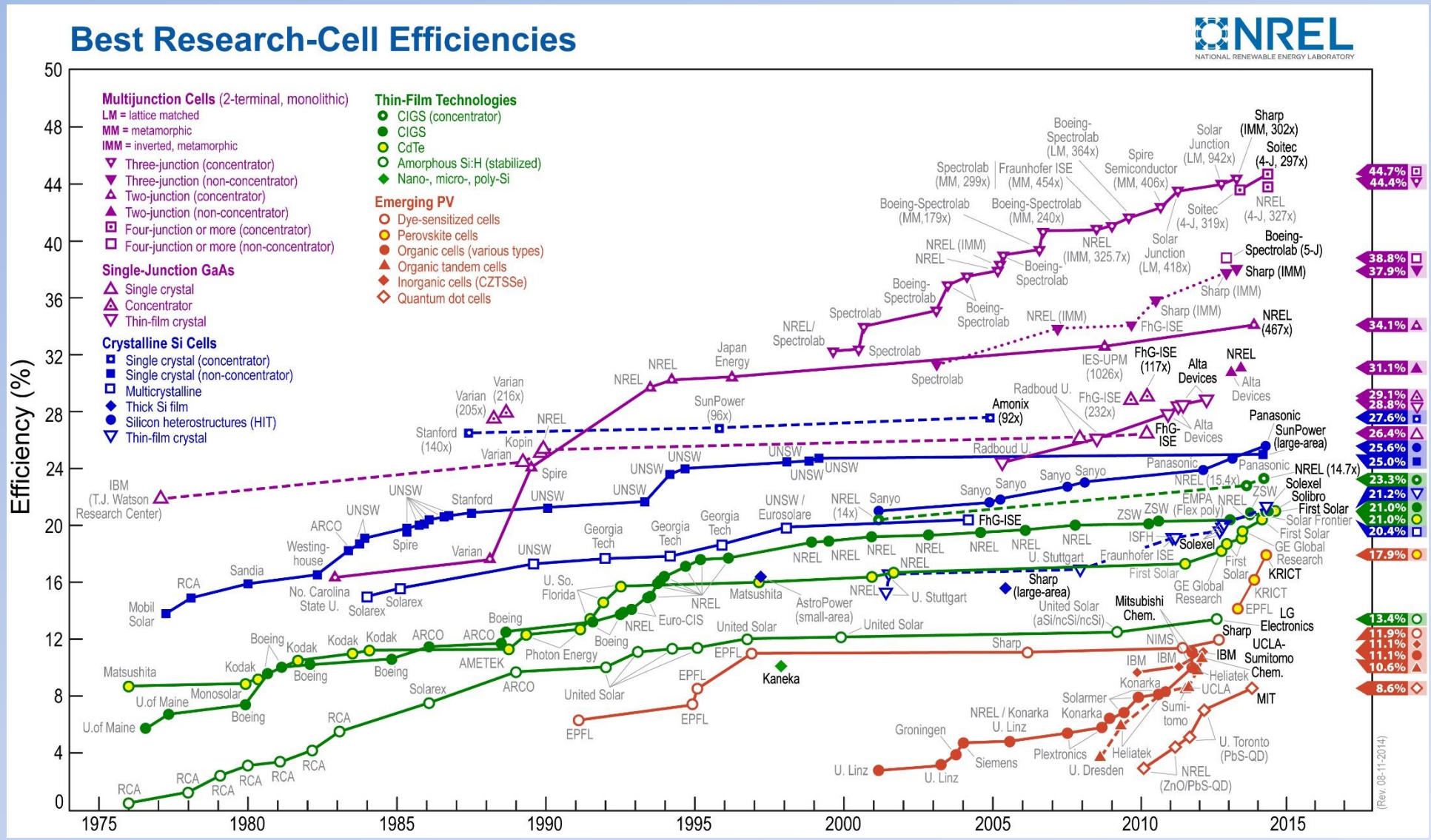
Solar Panel Efficiency

- High tech…“think very expensive”, satellites
- Multi-junction (4 junction or more, non-concentrator) 38.8%
- Multi-junction (4 junction or more, concentrator) 44.7%


Best Research-Cell Efficiencies
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Thick Si film
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Emerging PV
Dye-sensitized cells
Perovskite cells
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells
Efficiency (%)
0
4
8
12
16
20
24
28
32
36
40
44
48
50
1975
1980
1985
1990
1995
2000
2005
2010
2015
44.7%
44.4%
38.8%
37.9%
34.1%
31.1%
29.1%
28.8%
27.6%
26.4%
25.6%
25.0%
23.3%
21.2%
21.0%
21.0%
20.4%
17.9%
13.4%
11.9%
11.1%
11.1%
10.6%
8.6%
(Rev 08-11-2014)

Solar Panel Efficiency

- 1) Monocrystalline…efficiency is about 15 to 22%
- 2) Polycrystalline…efficiency is about 12 to 18%
- 3) Thin film…efficiency is about 7 to 14%

- Solar cell efficiency
- Solar panel efficiency

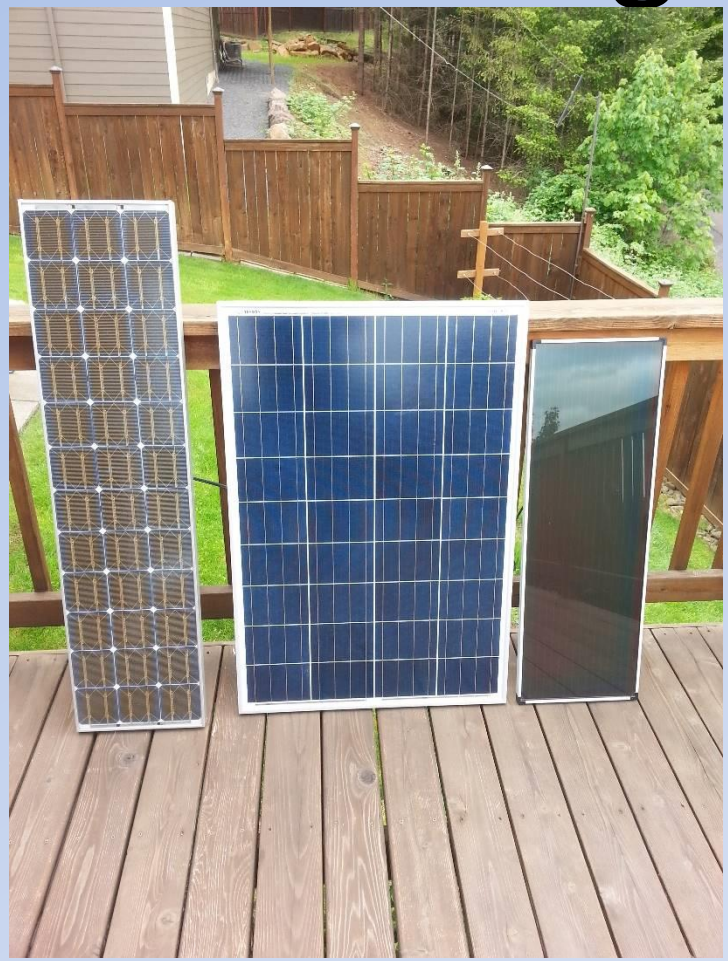
Grid-Tie And Off-Grid Solar Panels

Solar Panel Nominal voltage	Number of cells in the solar panel	Voc (Open circuit voltage, not under load)	Vmp (Max voltage under load)
12 volt	36	22 volts	18 volts
20 volt	60	38 volts	30 volts
24 volt	72	44 volts	36 volts

Grid-Tie And Off-Grid Panels

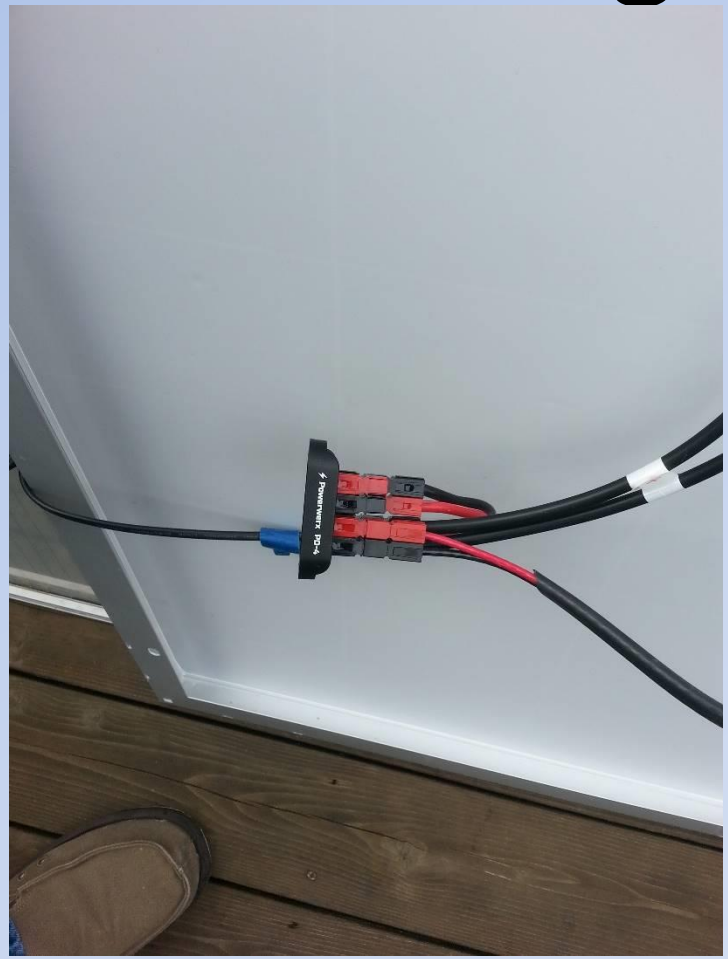
- The 12 volt and 24 volt panels are designed for charging batteries
- Grid-Tie systems went mainly to 20 volt panels
- 20 volt panel, too much voltage for 12 volt battery and not quite enough for 24 volt batteries if using PWM charge controller
- Each solar cell produces about 0.5 volts, all the cells are connected in series
- Bigger size cell means more amperage

Want **More Power**, Just Connect Some Solar Panels Together



Parallel Connection Of Solar Panels

Using A Distribution Block To Connect Solar Panels Together



Parallel Connecting Solar Panels Of Different Sizes

- Solar array **current** output is the **sum** of all the **amps** provided by each solar panel
- Solar array **voltage** is the **lowest voltage panel** in the array
- Adding a low voltage solar panel to the array could negatively effect the power output depending on the type of solar charge controller used

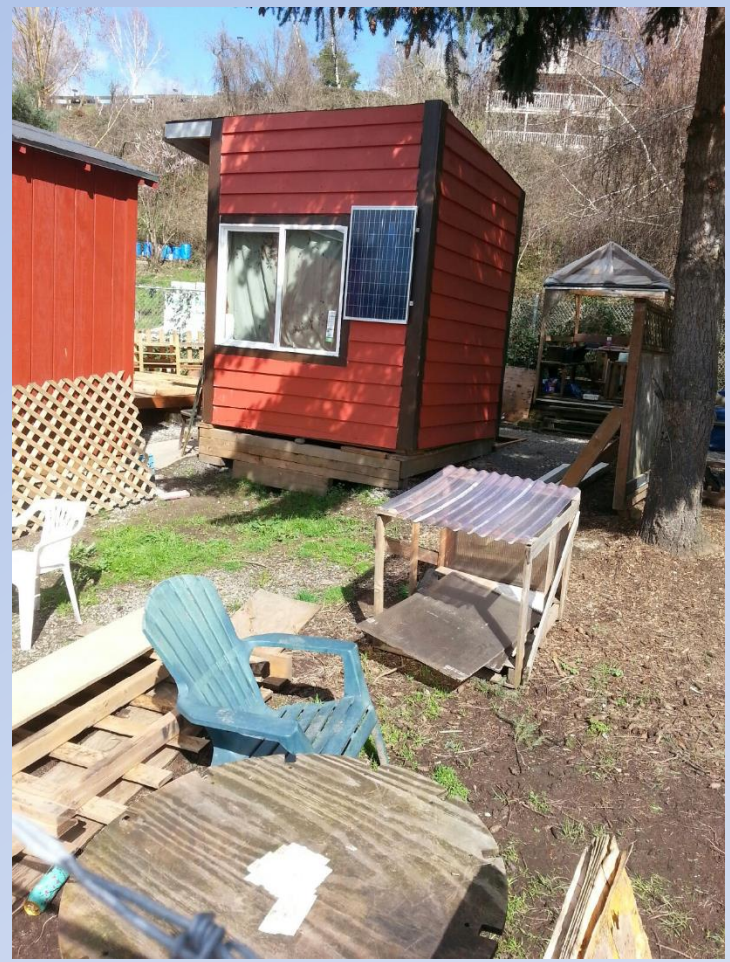
Series Connections Of Mixed Solar Panels

- Must be careful doing series connections due to **higher voltages** involved which **could exceed safe human contact levels…know what you are doing**
- If you connect solar panels in series with different sizes of amperage output, the **lowest amperage panel** determines the **amperage of the array**
- Mixing solar panels and connecting in series, the total **array voltage** is the **sum** of all the solar panel **voltages added together**

Solar Panel Shading

- Just a small amount of shade on your solar panel will severely drop the panel output
- Place your panels in full sun and point them at the sun
- There is about 3-4 blocking diodes in each solar panel to the limit power drops in the solar cell strings wired in series

Tiny Houses In Portland, OR With Shading



Tiny Houses In Portland, OR With Shading

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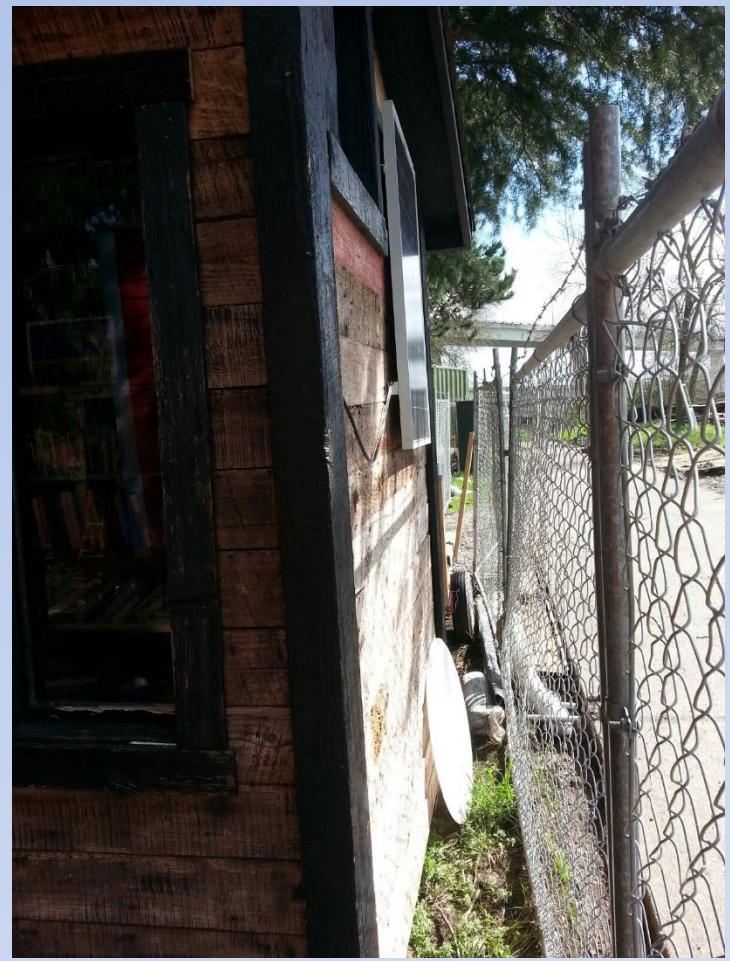

WHAT SIZE SOLAR PANELS SHOULD I GET FOR OFF GRID SOLAR CHARGING?

- Most solar panels over 140 watts are not designed for off grid solar
- Ideal choice for off grid solar panels are from 40 to 100 watts, smaller sized panels can be paralleled together

OFF GRID SOLAR PANELS

- Some solar panels have two solar panels hinged so you get more solar output, but they fold up to take up less space when transporting them
- Good example is the Bioenno Power 120 watt foldable solar panel
- Two hinged 60 watt solar panels wired in parallel

Buying A Used Solar Panel

- Look at the label on the back
- Note the **Voc** listed…**now test the solar panel in full sun**, is the voltage close to the STC Voc?
- Note the **Isc**, now **test the amps with your VOM**, is it close to the listed Isc?
- Note if any moisture under the glass, check the entire frame

Buying A Used Solar Panel

- Ask why the panel was taken out of service? Communication site upgrade?
- Look up the type and brand of solar panel
- Are there any reviews?

Buying A New Solar Panel

- Decide on what wattage panel you want
- Note the Imp which is the maximum power you should get with that panel in full sun
- Look up a number of panels with that wattage
- Note the average price for that wattage group
- Avoid the really low priced models
- Renogy 100 watt and Bioenno Power 120 watt are great choices, I like the 120 watt the best

Buying A New Solar Panel

- A 100 watt panel will be around $110-130, if someone wants to sell a new one for about $85, unless name brand, beware! I have read numerous complaints about Mighty Max panels for example
- Watch out for fake reviews, reviews that are not even in proper English, are a clue that the review might be fake

Hawaii unveils largest solar+storage system in the state and possibly the world

By Kelly Pickerel | January 9, 2019

AES Distributed Energy and Kaua'i Island Utility Cooperative (KIUC) held a site blessing yesterday for completion of the Lāwa'i Solar and Energy Storage facility on Kaua'i's south shore. The facility consists of 28 MW solar PV and a 100 MWh, five-hour duration energy storage system that will help Hawaii meet its goal of reaching 100% renewable energy by 2045. The new PV Peaker will deliver roughly 11% of the Kaua'i's power, making the island more than 50% powered by renewables.

Image courtesy of AES twitter

"AES DE is incredibly proud to have reached this important and historic milestone with KIUC now that the AES Lāwa'i Solar and Energy Storage Project is on-line and delivering clean, affordable and dispatchable energy to Kauai community," said Woody Rubin, President of AES Distributed Energy. "This innovative project will be a reliable source of firm renewable energy for decades to come and serve as an example for markets across the globe. We thank KIUC for their

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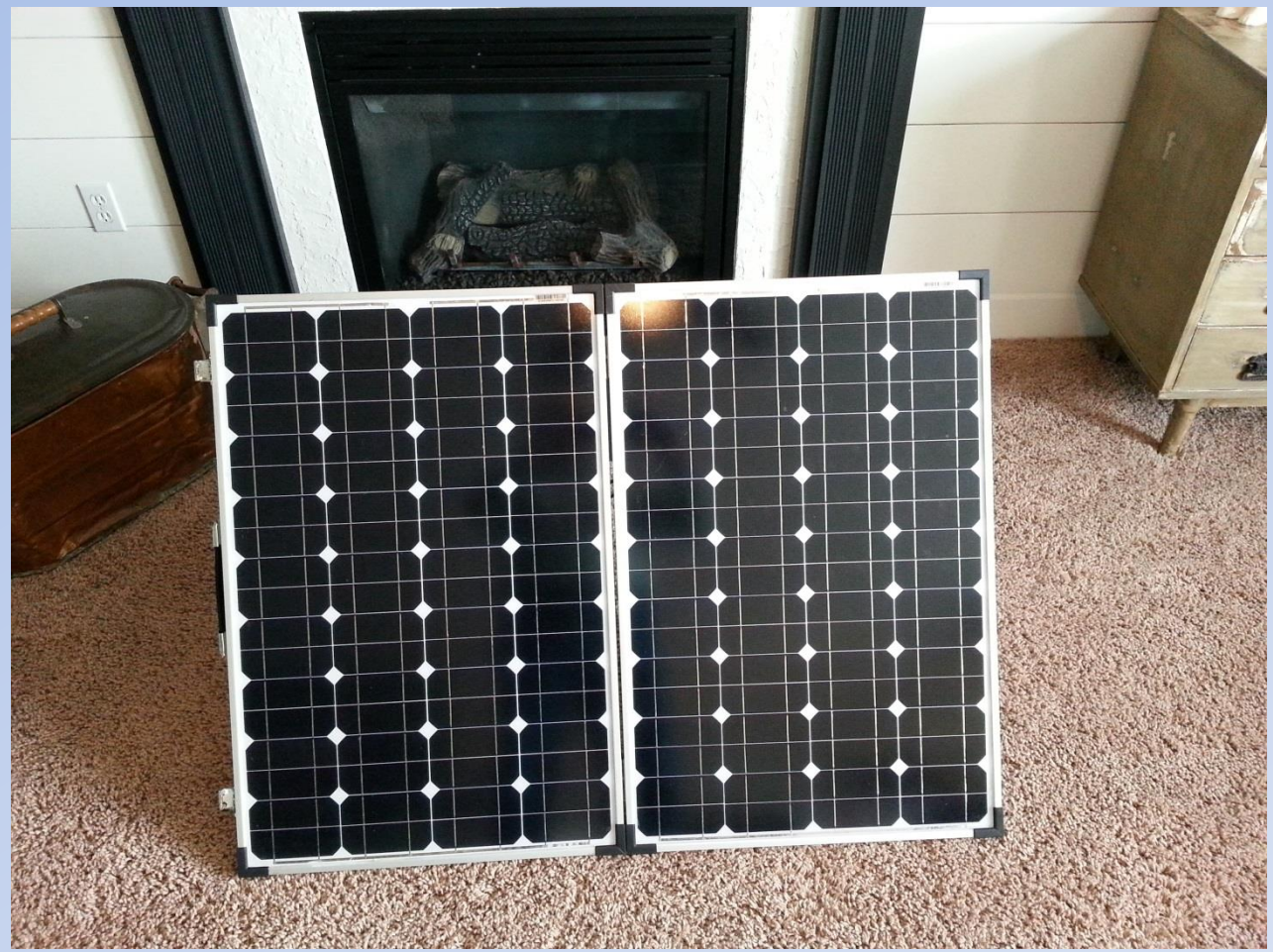
City Of Utqiagvik

- City population is 4,300 people
- November 18, 2018 to January 23, 2019
- Period of 66 days, what happened?

Utqiagvik Is The Northern Most City In The World

- Has 66 days of polar night or no sunshine
- Anybody above the Artic Circle could be out of luck until the sun rises above the horizon at local noon around the time of the winter solstice

BIOENNO POWER 120 WATT FOLDABLE SOLAR PANEL, MAX CURRENT IS 6.7 AMPS



BIOENNO POWER 120 WATT FOLDABLE SOLAR PANEL BACKSIDE VIEW

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