Introduction to Rooftop Solar

PDH Now, LLC.
www.PDH*Now*.com

Couse Description

This course satisfies 6-hours of continuing education requirement for Professional Engineer license renewal.

This program has been specifically written for engineers or other building professionals to learn the fundamentals of solar electric design, with an emphasis on rooftop solar. You will learn site analysis, material selection, budgets, and pro tips. Pay careful attention and you will learn the steps needed to generate project permit documentation, specialty material lists including supply chain navigation, and even which general items might be bought at a local electrical supply store.

This course has no pre-requisites, but is part of a series of programs written by NABCEP-certified PV Installer John Cromer, an Ivy League mechanical engineer who left the oil industry in 2008 to become a residential solar installer. Since then, he has obtained a master electrician certificate, led residential and commercial installation projects both on the roof and on the ground, as well as taught versions of this program live in all 50 states. This program now comes to you as an updated course recording and text.

If you are a building professional thinking about solar scope, whether professionally or as a DIY expansion to your home, this is the best place to get started. Experienced residential solar installers should consider skipping this program and moving onto other courses in the series, which include dedicated content on batteries, electric code, off-grid, and commercial solar.

Objectives

At the conclusion of this course, the student will be able to:

- PVWatts solar performance estimation and detail
- Molecular fundaments as related to product warranty
- Remote site analysis techniques using Google Earth imagery
- Equipment selection overview including specification sheet details
- Roofing structural and fire code
- Different rooftop and ground mounting approaches
- Supply chain discussion as related to the design process
- Compare and contrast different styles of inverters and racking
- Specialty balance-of-system material items
- Residential project budgets
- Interconnection strategy
- Circuit layouts
- Simple payback including tax credit and depreciation details

How to Read this Course

The student is required to thoroughly read and comprehend the course content.

In order to complete the course, the student must pass the quiz in the final chapter of the course. It is recommended that the student keep these questions in mind as the course is read.

Topics Covered

Introduction, Rooftop solar design, installation, and construction.

Grading

Students must achieve a minimum score of 70% on the online quiz to pass this course.
The quiz may be taken three times.
The student will be asked at the end of the quiz to attest that he or she has personally and successfully completed all chapters of instruction.
The quiz may be viewed in the final chapter of this course.

Couse Inquiry

This course is designed to be interactive. The student is encouraged to contact us to discuss any questions that arise while taking this course. All inquiries will be answered within two days or less. The reader can contact PDH*Now* as follows:
By Email: info@pdhnow.com
By Phone: 1-833-PDHNOW9

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Contents

Introduction

My name is John Cromer, and I am an Ivy League mechanical engineer. I have been working in all aspects of solar, from teaching continuing education, to designing residential and commercial systems, to now installing off grid smart homes, with twelve years of industry experience.

It might surprise you to learn that I am a Texan who left the oil industry where I was doing control system engineering and contract management in order to pursue a career path in renewable energy in general, and solar in particular. We are in an expanding industry, one which will substantially change our power grid, and I hope that you too will decide to get involved!

Let’s dive right in! As we talk about solar, I think the most important thing to keep in the back of your mind is that the value of solar power has less to do with how much sunlight is available where you plan to locate an array and more to do with how much that electricity is worth. For example, the desert in the southwest United States gets great sunlight while the Northeast gets comparatively little.

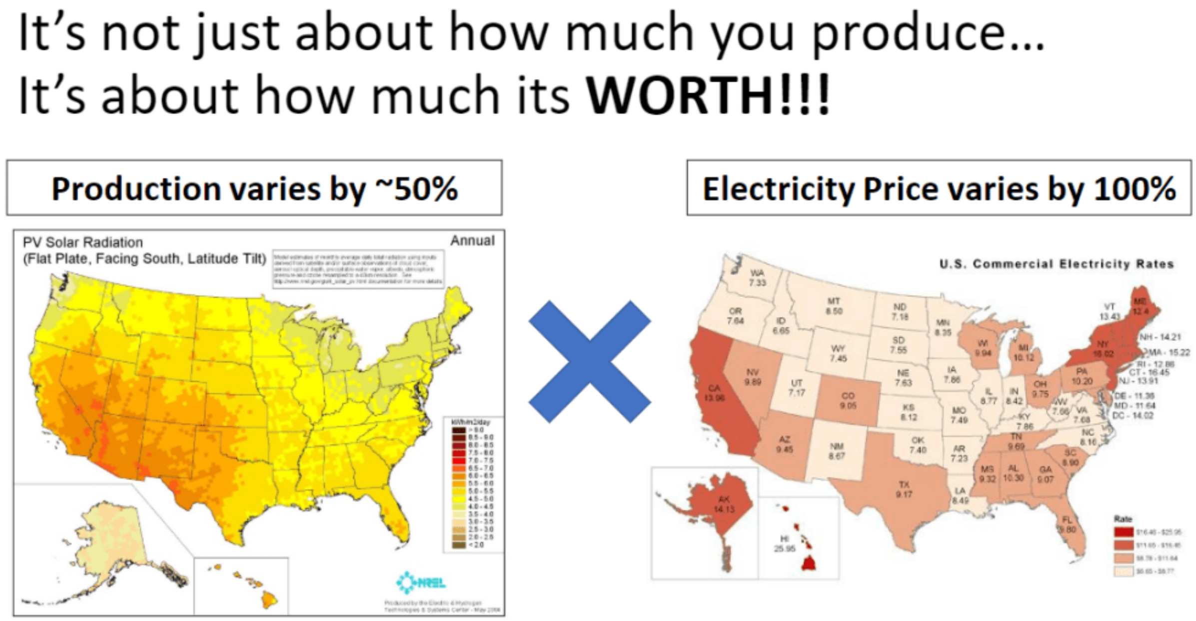


Figure 1 - Solar Production vs. Electricity Price

People think that more solar arrays would exist in very sunny places. Not so. Places like Germany, and the Northeast of the United States have far more solar arrays than what you will find in a desert, because solar is more valuable where the price of electricity is very expensive. I happen to be working a lot in Mississippi and other southern states. Mississippi has plenty of sunlight year-round. There is very little, if any, snow in the deep South. The price of electricity is average.

However, this brings us to our second point, which is about the how much solar electricity is worth, or more specifically, the **grid buyback rate**. Sometimes referred to as **net-metering**, this is a very important variable for how valuable solar is to an array owner. Net-metering is basically about how much you get from your power company when your solar array pushes its excess solar energy onto the grid.

If you are trying to offset 100% of your energy use, perhaps 2/3rds of that production will be pushed onto the grid. After all, solar only produces during the day, but we use electricity in the morning, evening, and at night as well. So, offsetting 100% of your energy use is not the same as eliminating 100% of your electric bill, and it has to do with your buyback rate.

When a Mississippi solar array owner backfeeds her excess electricity, she only gets back about 20% of retail value of electricity. Other states have much higher buyback rates, sometimes near full retail value. Since net-metering policy is determined by each individual state, what drives the solar industry is not so much the amount of sunlight available, but rather the raw cost of electricity in a region as well as how the utility compensates the user for back-feeding onto the grid.

There is a third, more nuanced issue regarding how users are billed for the electricity that they use from the grid, which requires that understand our electric bill. We'll get to that later on in the program.

It all comes down to money, so first things first: let's do a budget review.

Recent Residential Project – 15kW

Dollar Per Watt Cost	Target Budget
Balance of System Material	$0.14
Solar Modules	$0.44
Inverters	$0.33
Racking	$0.15
Direct Manhours (Subcontract)	$0.59
Soft Cost (supply chain markup, shipping, profit)	$0.70
Sales Tax @ 8%	$0.16
Total	$2.51/W

Figure 2 - Sample Product Budget

This is a real project that I did at the end of 2018, using the components which fit into a design aesthetic focused on both cost-effectiveness and future-proofing, which is ultimately completed in the residential off-grid section of the program. For example, I upgraded the inverter to a lithium ion battery inverter, even though I did not include a lithium ion battery which could be added later. Perhaps my favorite standard upgrade from traditional solar is to use "all black" modules, even though these aren't necessarily the most expensive or top shelf solar panels.

I am still seeking a cost-effective solar panel, but paying a bit more for all black panels results in a more aesthetically-pleasing rooftop, which is important for resale value. I use internal cable runs through the attic, as well as fire-code friendly and shade tolerant "module-level panel electronics", with a small amount of additional infrastructure for system expansion.

In other words, this is not the cheapest system you could possibly do, nor is it the most expensive. In all projects, we must be razor-focused on budget, especially because they do not have good solar policy. Even so, I think it is worth spending a little more on small upgrades compared to limiting the system to the lowest possible budget. Hopefully you're interested in learning what those things are throughout the class.

So, these are real, hard installed costs which you can achieve on a quality, battery-less solar array while even allowing for some future expansion.

This was a 14-kilowatt array, comprising of two “pallets” of solar panels – another cost-cutting measure is to design in pallet quantities, as you get price breaks when ordering and shipping panels which have not been broken out from their manufacturer’s shipping containers. Maybe I could have fit a few more solar panels onto the roof, but instead I focused on an aesthetically pleasing design with two pallets worth of solar panels.

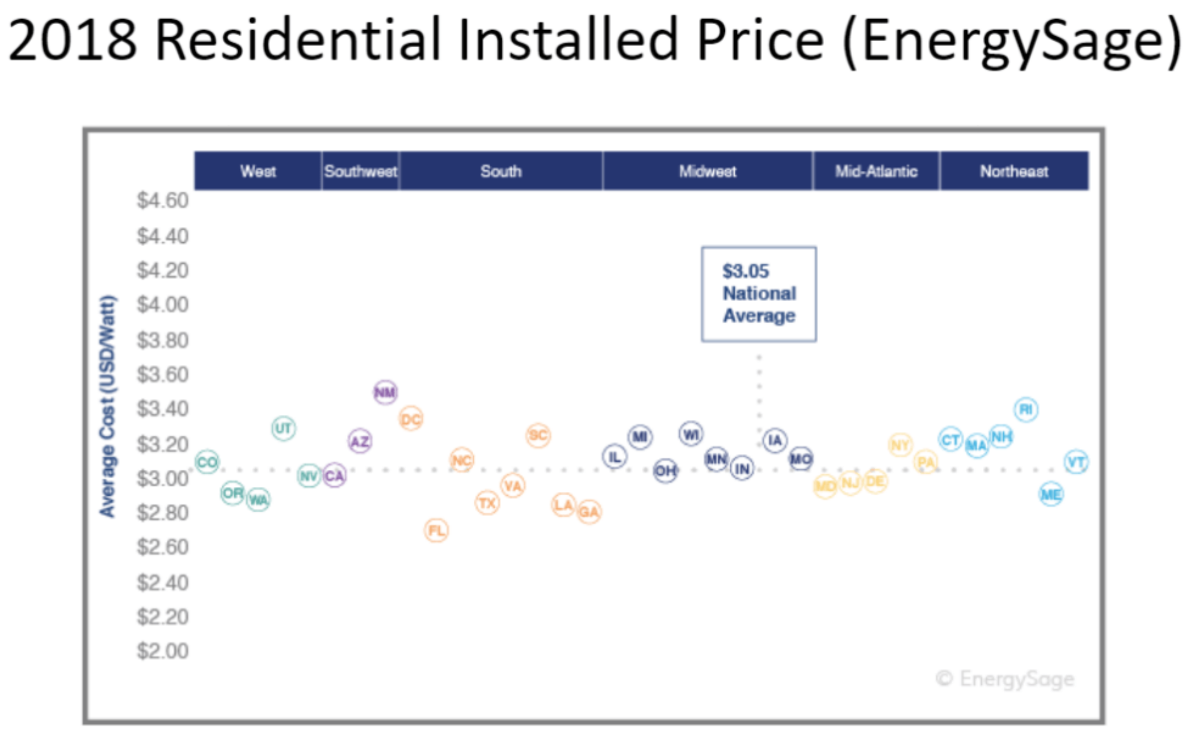


Figure 3 - Solar Installation Pricing

In the solar industry, we price by the watt, in a similar fashion to how a home builder prices by the square-foot. For this project, I achieved a total budget of $2.50 per watt. But if we look at what the national average pricing is for residential installed solar in 2018, there’s a very different picture. Some states do not have much competition, unlike crowded solar markets like New York or California, but rather the solar policy is so bad, the project budget is forced low to achieve minimally acceptable project economics for the end user.

We can see here that most residential solar installed in the United States hovers at a little over $3 per watt installed pricing. However, depending on your state, solar could be cheaper. In other states, it doesn’t have to be cheap to still be cost-effective and installers aim for higher margins and more expensive system components. Finding the right balance for your client is why there is opportunity in solar design and project development.

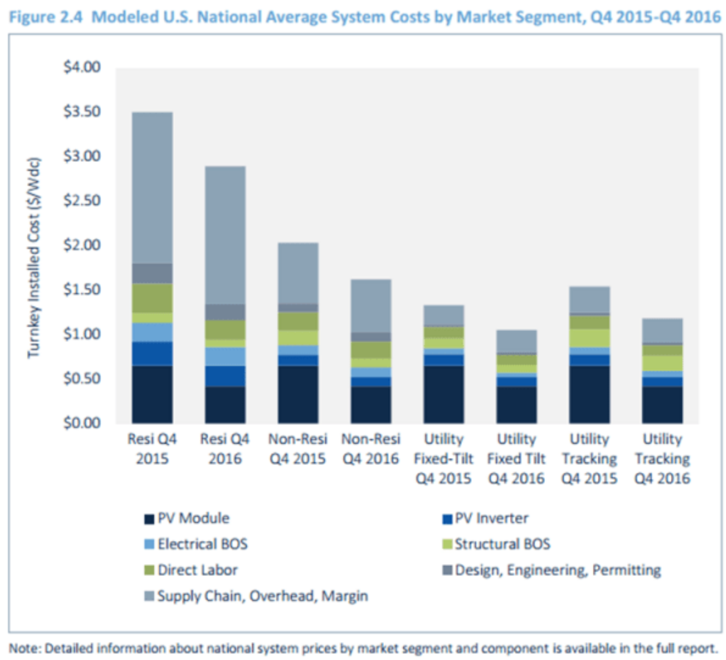


Figure 4 - Solar Costs by Market Segment

Let's take a look at what goes into solar pricing. This particular chart says 2015 and 2016 but it's still pretty good data. While solar has gotten cheaper, there have also been import tariffs which have kept the price of solar panels and inverters high. In dark blue we see the solar panel itself hovering around $0.45 to $0.50 per watt including the import tariffs, at the residential level, whereas the solar inverter is a little bit less than that, maybe around $0.30 cents per watt. These prices can be cheaper for low-end systems or more expensive when you get into battery components.

Here is your **electrical Balance-of-System** material that you should not get too cheap on, as there's some nice things you can do with balance-of-system material selection. We'll be talking about in class that really preserves system value, such as internal cable runs to keep the array looking nice. Most clients want their systems looking clean and polished. Minor upgrades will not increase your cost exorbitantly so it doesn't cost that much more to achieve a high-end look, regardless of what solar panels or inverter system you use.

Next, let's talk about **direct labor cost**. Direct labor cost is the take-home pay of the installer, excluding things like profit, overhead, and supply chain markup. So direct cost is what the guys out in the field are taking home in their wallets at the end of the project, not necessarily the total pay of the development company, sales rep commission, or project manager salary. Racking is around $0.20 a watt. Design, engineering and permitting is a modest cost.

The reset of the budget, which is pretty much half of your residential project cost, is called, "soft cost" which includes profit, overhead, and supply chain markup. That's also your sales commission, plus the 30% margin that the developer is charging to manage the project, do the construction, and other tasks to put it all together. So, if you can get rid of the **soft cost**.

If you are an ambitious do-it-yourselfer with some electrical competency, wanting to add solar to your own roof as a hobby, you might only pay a little bit in supply chain markup and see your cost drop below $2 a watt, even with enough budget to hire some qualified labor. You could also go through a competitive bid process and see some of these margins reduce. And by the end of the program, you will be able to do many project scope items such as array layouts, material lists, and performance estimation yourself.

Obviously, getting multiple quotes is a good idea. Last year, an online sales company targeting southern states, was selling above the $4 per watt for very basic systems, while grossly misrepresenting the economics and functions of batteryless solar to the customer. These customers would have saved both money and heartache if they had simply gotten local pricing. It's always good to have on your bid list a local installer who is more likely to be more knowledgeable of local buyback rates and utility solar policies.

	A	B	C	D
1		BILL OF MATERIALS		
2		Part Number	Description	Quantity
3	Racking	XR-10-132A	XR10, Rail 132" (11 Feet) Clear	2
4		XR-10-168A	XR10, Rail 168" (14 Feet) Clear	6
5		FM-LFT-003	Kit, 4pcs, Slotted L-Foot, Mill	14
6		XR-10-SPLC-BD	Kit, XR10 Bonded Splice	6
7		29-4000-077 ??? See not	Wire Clips, Molded PVC Black, Polybag 20	2
8		XR-10-CAP	Kit, End Cap XR10 (10 sets per bag)	1
9		FM-TB-BHW	Kit, 4pcs, T-Bolt Bonding Attachment Hardware	16
10		UFO-CL-001	Kit, 4pcs, Universal Module Clamp	9
11		MI-BHW	Kit, 1/4 x 3/4 Microinverter Bonding Hardware, T-Bolt	8
12		GD-LUG-003	Kit, 2pcs, Grounding Lug, Low Profile	2
13		UFO-STP-40MM	Kit, 4pcs, Stopper Sleeve, 40MM, Clear	1
14	Micros	M215	Enphase M215 micro-inverter	16
15		Portrait Drop Cable	240V Portrait Cable	16
16	Modules	Jinko 260W	JkM260P-40MM	16
17	Shipping	Liftgate + pallet jack required		

Figure 5 - Sample Racking and Inverter Material List

So far so good? One of the greatest challenges of doing a solar project is nailing down all the odds and ends. But by the end of this solar class, you should know enough to assemble a material list necessary to streamline the ordering process from online solar distributors without much design work needed on their end. This ultimately is what results in the cheapest solar project, regardless if it is top shelf, bargain bin, installed, or a DIY project.

Performance Estimation

Let's move onto **performance estimation**. How much power a solar array will produce in your area? First let's define some terminology. Here is a solar panel rated for 250 watts, which is a little bit small compared to what is being installed today. The greatest efficiency panels, which would be the same size but be more energy dense, can go all the way up to 350 watts, but they're also much more expensive.

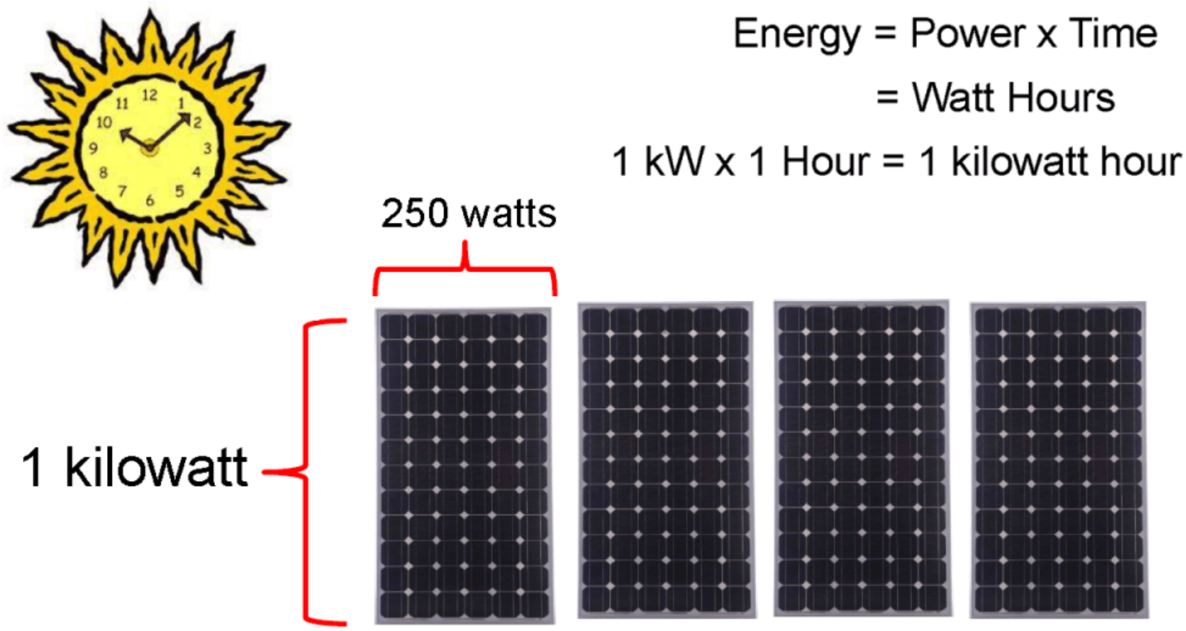


Figure 6 - Energy Basics

I typically recommend high efficiency panels in markets with limited, expensive real estate, such as New York City, or in other areas where there is very little room to put panels. The panels I commonly install are around 300 watts. If you are in a less densely populated area with easy rooftops and plenty of "real estate" for the roof or ground mounting, you can lower your pricing by going with a lower efficiency, more cost-effective solar panel. However, in this example, I use 250 watts for mathematical ease.

Remember: if a one-kilowatt solar array were exposed to full sunlight for one hour, it would produce one kilowatt hour. That sounds great but in reality, a full "sun hour" is only achieved under specific laboratory-controlled conditions, and so that is not what the solar panel will actually do outside. The amount of sunlight in the air varies greatly throughout the day. At high noon there is a lot of sunlight, and in the evening, not so much.

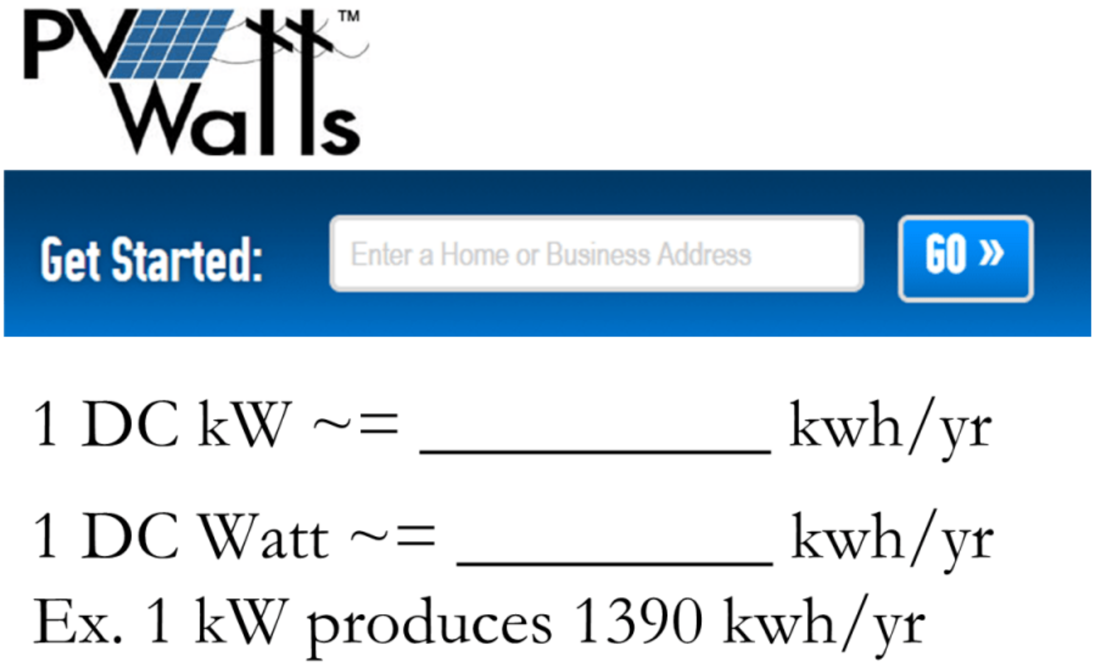


Figure 7 - Local Performance Ratio

So, how do we figure out how much sunlight is hitting the panel? What about temperature impact or humidity? These too can impact your solar array performance. So how do we actually get a good idea of what our solar array will produce? Thankfully, there is a free software put out by the Department of Energy called **PVWatts** and it's a very good starting point. In fact, I even use PVWatts to go all the way into off-grid building design. PVWatts has an almost misleadingly simple interface. I say that because the raw data that PVWatts uses is based on actual weather data in your area and many paid commercial solar design software use the same data sets that feed into PVWatts!

So, what I want to do now is a PVWatts example. I want to find out how much energy one kilowatt of solar will produce in a year, measured in kilowatt hours. Most residential solar rates are multiple kilowatts large. I recommend memorizing what one kilowatt of solar will produce in a year, because knowing that ratio creates a scalar you can use to quickly calculate all kinds of off-the-cuff energy estimates with your clients, sounding confident and cool when stating how much energy, say, an eight kilowatt solar array produces a year. In other words, knowing what one kilowatt of solar will produce can be multiplied by eight to get a production estimate for what eight kilowatts of solar will do.

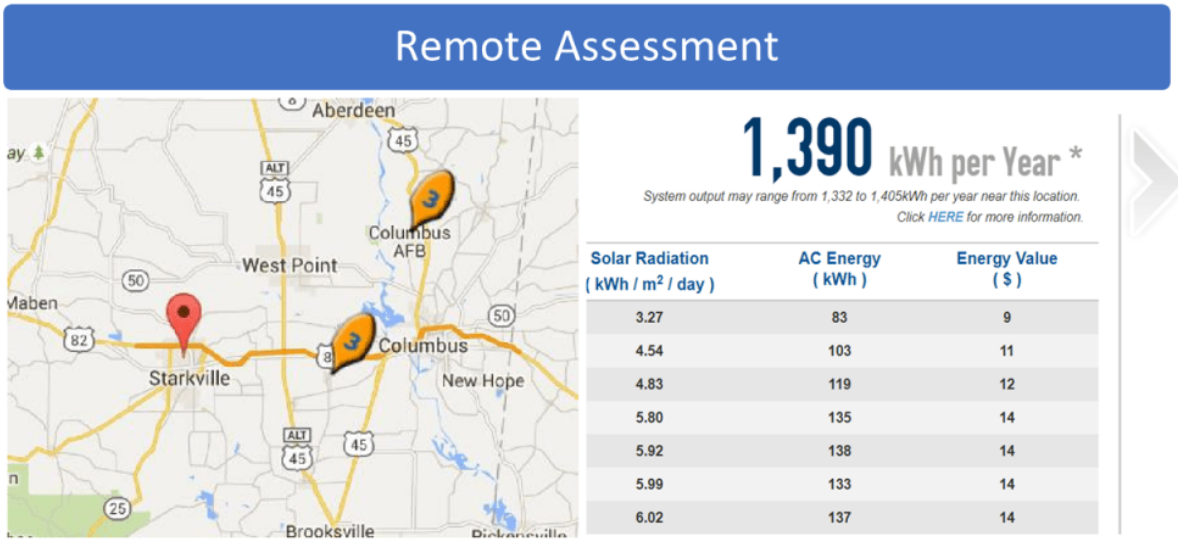
Ex. 1W = 1.7 kwh/W/yr
(single axis tracking)
8MW x 1.7 Gwh/W/yr = ~13.6 Gwh/yr

Ex. 1W = 1.4 kwh/W/yr
(fixed)
5kW x 1.4 kwh/W/yr = ~7000 kwh/yr

Figure 8 - Tracking vs. Fixed Performance Ratios

In my region, I know that one watt of a popular utility scale single-axis tracker will produce 1.7 kilowatt hours per year. Multiply by one thousand, a one kilowatt will produce 1.7 megawatt hours per year, or one megawatt will produce 1.7 gigawatt hours per year, and so an 8-megawatt utility scale solar array multiplied by 1.7 will produce 13.6 gigawatt hours of electricity per year.

I also know that for a residential rooftop array, 1 watt will produce 1.4 kilowatt hours per watt per year. So, if I determine five kilowatts can fit on a residential project site, I simply multiply 5 kilowatts by 1400 kilowatt hours per year to get 7000 kilowatt hours. Divide that by 12 to get a monthly average, although we will see that summer months produce about twice as much as the winter months. If I'm given an electric bill that says my client's house uses 14,000 kilowatt hours of electricity a year, and I know 1 kilowatt of solar produces 1.4 kilowatt hours per year, then 14,000 divided by 1.4 results in a 10,000 watt or 10-kilowatt solar array.



Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
3.27	83	9
4.54	103	11
4.83	119	12
5.80	135	14
5.92	138	14
5.99	133	14
6.02	137	14

Figure 9 - PVWatts Weather Stations

What this graphic illustrates is that **PVWatts** ties in to local weather stations, such as those found on military bases and airports, and it will base its performance estimate off of the most typical month of weather data for each month that has been recorded at that station. The records go back thirty years so it's a broad data set that results in a solid year-to-year running average of production, although weather anomalies do vary from year to year.

Austin, TX Pitch	Due South	+/- 45 Degrees	+/- 90 Degrees
0 Degrees	91%	91%	91%
10 Degrees	96%	95%	91%
30 Degrees	100%	97%	86%
50 Degrees	94%	90%	76%

Moderate deviations from "ideal" does not significantly impact performance

South is best for annual performance, but occasionally reconsider ALL angles and orientations

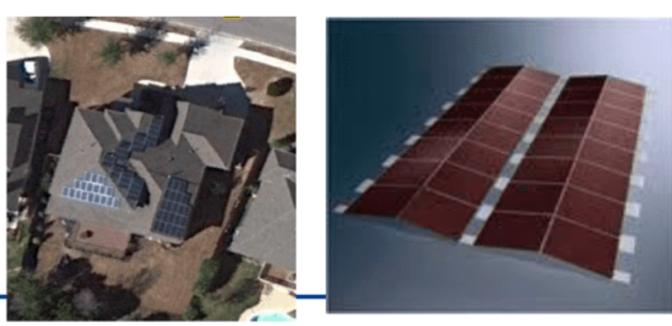


Figure 10 - Performance vs. Orientation + Tilt

You might be thinking, “If 1 watt will produce 1.4 kilowatt hours, how does the orientation or tilt angle impact system production?” and the answer is “Yes, it does matter, but not as much as you might think”. After all, if you draw a big circle around a rooftop, say, with an imaginary lasso, the same amount of sunlight is going to fall through that lasso, so capturing as much of that sunlight as possible is contained within a maximum limit, at which point it becomes how much surface area can you cover effectively.

So, in this example we take Austin, Texas with the theoretical ideal fixed tilt angle for maximum year-round production, which is facing due south at the line of latitude. With Austin, Texas being around a 30° line of latitude the ideal tilt angle for Austin Texas is 30° facing due south.

Of course, the ideal tilt angle does not factor in how much that electricity worth. If you have a perfect net metering policy and the utility is buying back every single kilowatt hour at retail price, the ideal tilt would produce the most amount of energy and therefore the most amount of money.

But let’s say the utility gives you a higher rate in the evening and a lower rate in the morning, known as time-of-day or time-of-use rate structures. In that case, the most cost-effective tilt angle might not be a line-of-latitude tilt. In reality, it is rare to see a solar array installed at the ideal tilt angle – economic and structural considerations will often result in the optimal tilt being simply to remain parallel to the existing tilt of the roof, known as a **flush mounting**. An ideal tilt angle might result in more outflow onto the grid, whereas a different angle might result in more of the electricity being consumed on site. So, absent a true net-metering policy, the most productive tilt angle is not necessarily the most economic.

Figure 11 - Performance vs. Orientation

If you take a solar panel in Austin, TX at a 30 ° tilt and adjust the tilt up to 50°, you will only lose about 9% of your system production. Likewise, if you take that 30° tilt and you tilt it down to a 10° angle you only lose about 9% of your production. And the flatter you go, the less orientation matters because if the module is flat and facing straight up in the air, how it rotates doesn't matter. In other words, at a shallower tilt angle, the impacts of orientation matter less, although some might advocate for steeper tilt angles to boost winter production. It seems to me that the trend in residential roofing is for steeper roofs, but it's much easier to install on a shallower roof than a steep roof. Not that you can't do a steep roof, but if designing a building from scratch, as an installer I'd much prefer a roof with a shallow tilt that you can walk on.

The orientation, whatever direction it faces can impact performance, but much more at steeper angles than shallow angles. If we go from due south to southeast or due south to southwest at a 30-degree tilt, we only lose 3% of the total system production. If I only lose 3% of system production, that will not impact my rough estimate of one watt producing 1.4 kilowatt hours very much. If we stay at a 30-degree tilt and go all the way to due east or all the way to due west, we start to see the performance drop more substantially but even so we're only losing about 15%. So, what we see is that in Austin, Texas an ideal orientation will produce 1370 kilowatt hours a year, whereas a southwest or southeast will produce pretty much the same thing.

There's an argument to say that a big open west and east roof surface is better than just installing on a small southern roof, due to economies-of-scale. Maybe the individual panels produce 15% less but by doing the larger project we get more than a 15% installation pricing discount. So, a large project that is off ideal can be more cost-effective than a small project that only faces ideal because of course only one of the four orientations of your roof surface is going to face south.

Some might even argue that going all the way to a north facing array can be justified depending on your installation price and your cost of electricity. The fact of the matter is, if I'm already up on the rooftop installing a dozen solar panels, moving on to the next roof surface and installing a dozen more solar panels is not going to double my project cost. I just double my solar panel price and I double my direct labor price and then maybe I make a little bit more money from the project but it's not doubling every single item because it's not doubling your soft cost. So, going back a few slides what we see is that as the projects get larger and we move into commercial scale and utility scale what we see is the soft cost in that light gray margin start to shrink and the project get cheaper, approaching $2 per watt or less.

With an east-facing array or a flat array you're losing ten to fifteen percent and with a north-facing array you're losing 30%, but it's not like there is a hard and fast rule that says the solar panels must face south. Taking what we've learned, you could argue covering the whole roof with solar would be best. Covering the whole roof certainly have both economies-of-scale and allow the roof to age in a uniform manner.

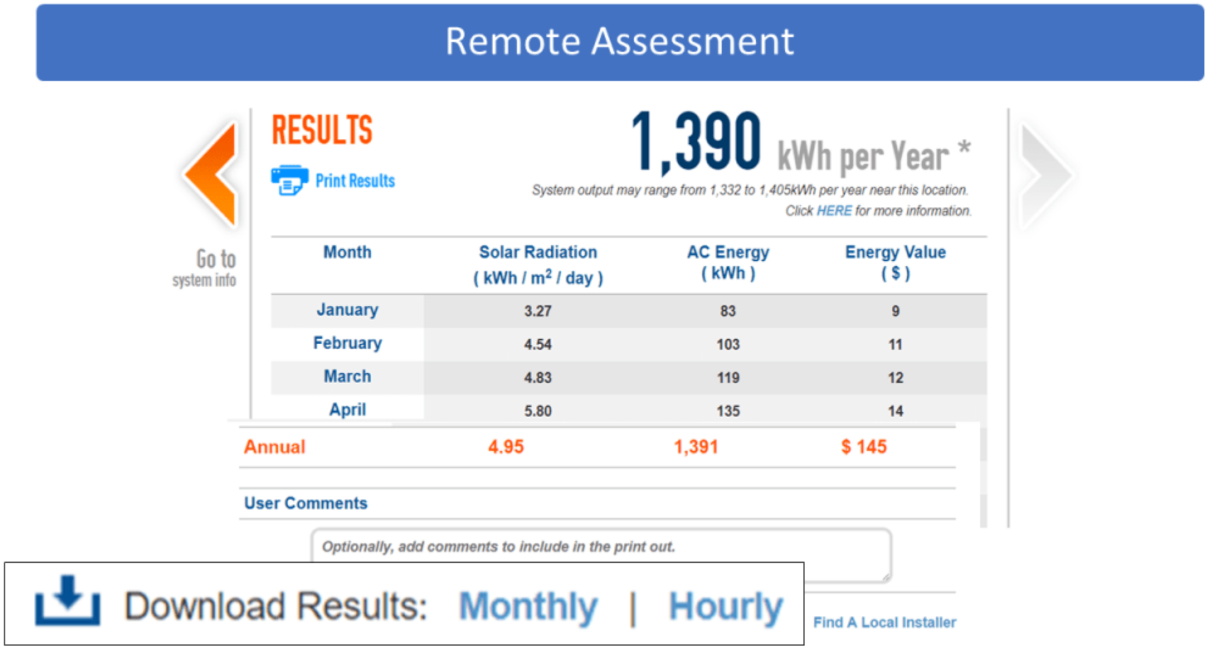
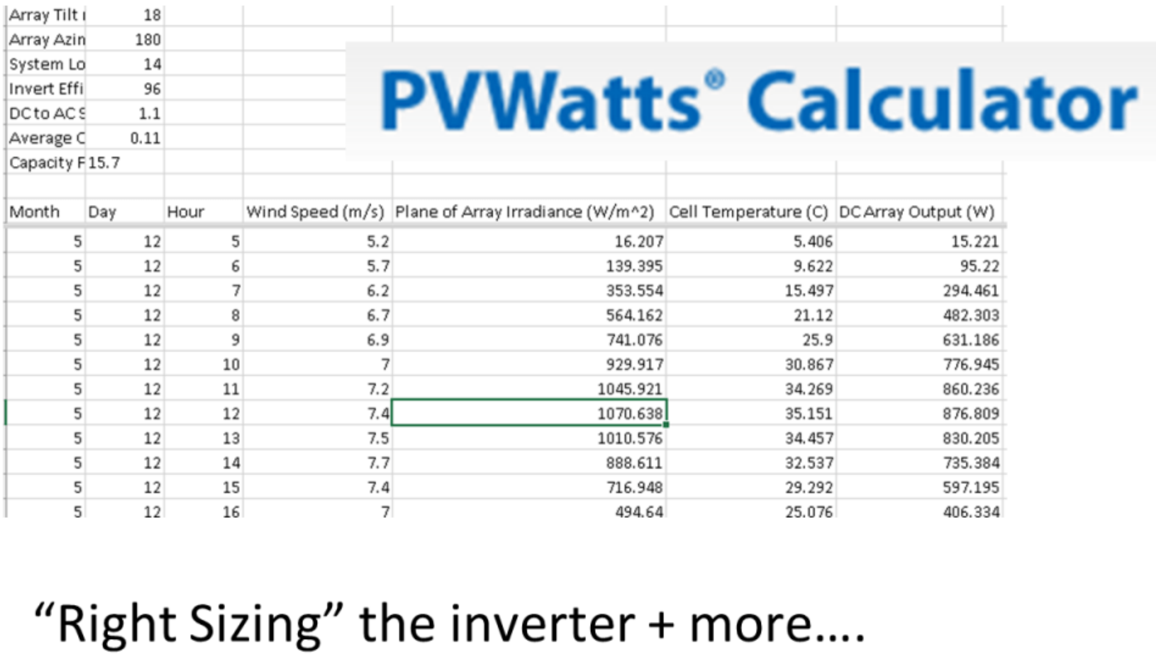


Figure 12 - Hourly Performance Data

At any rate, next we're going to use PVWatts to do a system performance estimate. When you get to the end screen of PVWatts, you will get a month-by-month printout of how much power the solar array will produce as well as an annual total. The number one mistake you can make is just to end right there, because there's a whole other aspect of PVWatts – if you download the hourly results you get all the raw data behind the calculations. So, you'd really like to get into the brass tacks of it don't forget to download that hourly information because that's where you get the environmental data.



Array Tilt	18
Array Azin	180
System Lo	14
Invert Effi	96
DC to AC S	1.1
Average C	0.11
Capacity F	15.7

Month	Day	Hour	Wind Speed (m/s)	Plane of Array Irradiance (W/m^2)	Cell Temperature (C)	DC Array Output (W)
5	12	5	5.2	16.207	5.406	15.221
5	12	6	5.7	139.395	9.622	95.22
5	12	7	6.2	353.554	15.497	294.461
5	12	8	6.7	564.162	21.12	482.303
5	12	9	6.9	741.076	25.9	631.186
5	12	10	7	929.917	30.867	776.945
5	12	11	7.2	1045.921	34.269	860.236
5	12	12	7.4	1070.638	35.151	876.809
5	12	13	7.5	1010.576	34.457	830.205
5	12	14	7.7	888.611	32.537	735.384
5	12	15	7.4	716.948	29.292	597.195
5	12	16	7	494.64	25.076	406.334

Figure 13 - Maximum System Output

That’s where you get how much solar **insolation** or array **irradiance** is in the air and on the module surface. These are synonyms, for a unit of energy measured in watts per meter square. So, array irradiance is how much energy is falling across the surface of the solar panel. And, there’s more information than that! There’s direct irradiance and diffuse irradiance which allows you to determine if it’s a cloudy day or a sunny day. We use this in our off-grid designs to tabulate how many days in a row of cloudy weather you get which impacts the size of your battery bank.

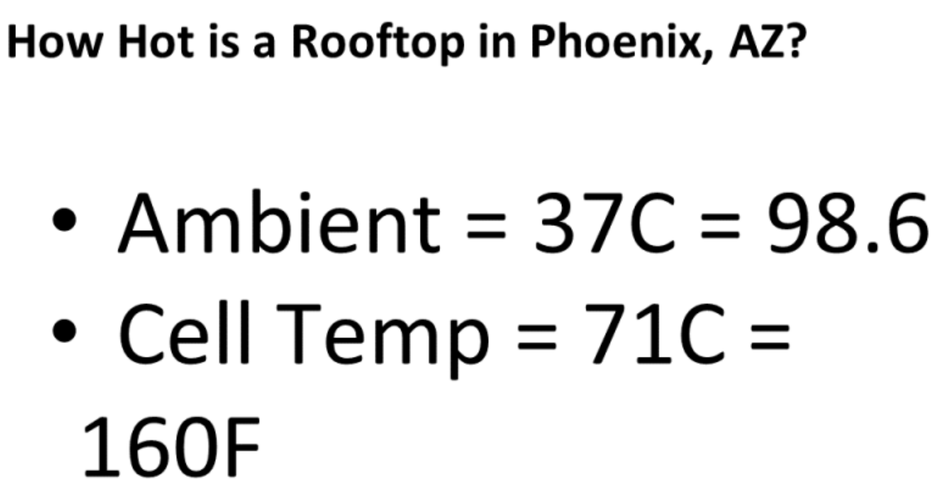
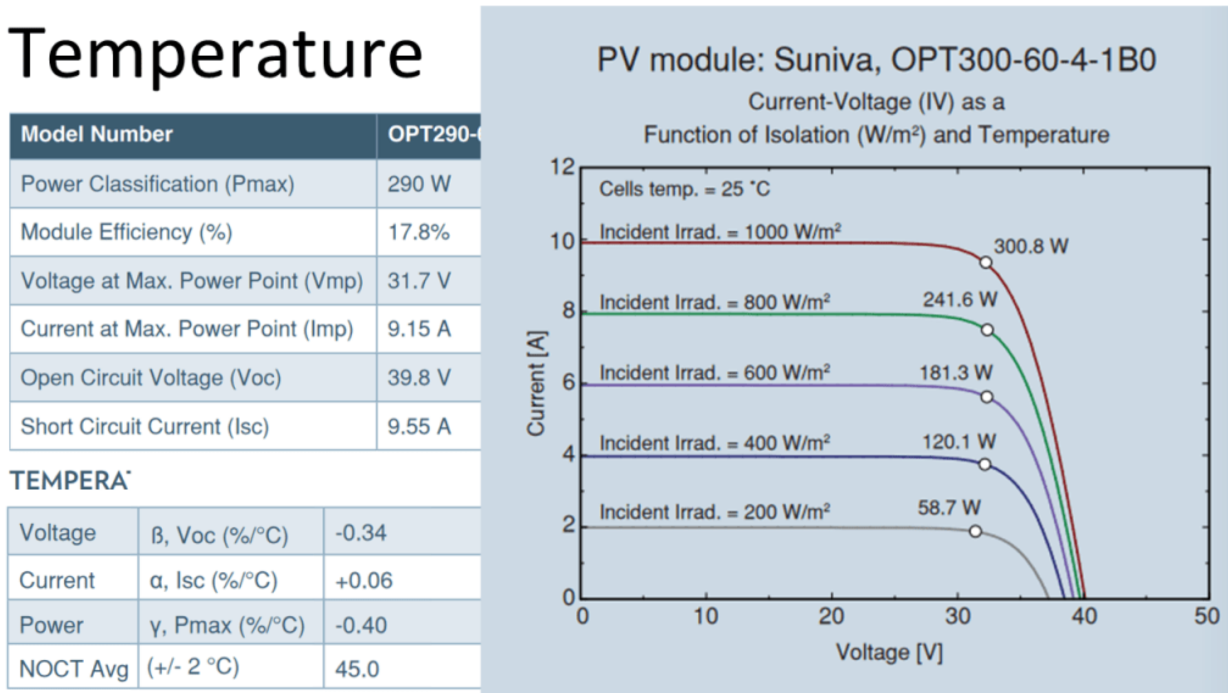


Figure 14 - Rooftop Temperature

Another useful bit of information is how hot the panels get up on the rooftop, something solar designers need to appreciate. Electrical components have temperature ratings as do wire termination lugs. Wire splice points tend to be the hot points of the system. Wire terminations are common when transitioning from the rooftop into the attic. Your boxes and cable ratings inside your house may only have a 75 C or even a 60 C temperature rating, whereas solar cable typically has a 90 C temperature rating. In other words, you don't want to just use any cable that you can buy at Home Depot for wiring up your outdoor roof-mounted solar array. You need to make sure that your boxes, terminals, and cables have a high enough temperature rating. On a 100° F day in Phoenix, Arizona the surface of that solar panel can be a160°F and that impacts your array performance and creates safety hazards for underrated or poorly installed cable terminations. Now, we can identify the maximum temperature of the solar panel on the roof because PVWatts does calculate that. PVWatts does make some assumptions about the data that a commercial software might fine tune, but typically it results in a conservative estimate.



Model Number	OPT290-
Power Classification (Pmax)	290 W
Module Efficiency (%)	17.8%
Voltage at Max. Power Point (Vmp)	31.7 V
Current at Max. Power Point (Imp)	9.15 A
Open Circuit Voltage (Voc)	39.8 V
Short Circuit Current (Isc)	9.55 A

Voltage	ß, Voc (%/°C)	-0.34
Current	α, Isc (%/°C)	+0.06
Power	γ, Pmax (%/°C)	-0.40
NOCT Avg	(+/- 2 °C)	45.0

Figure 15 - Temperature Impacts

Commercial software will use the actual solar panel that you're designing the system with in order to perform the energy calculation, whereas PVWatts gives you a couple of values that to switch between, regarding but what is called the t**emperature coefficients of voltage, current, and power.** So, what we see is in this temperature coefficient of voltage is -0.29 percent per degree Celsius. The temperature coefficient of current is a positive 0.06 percentage per degree Celsius that is an order of magnitude less than by how much voltage varies with temperature.

So, as temperature climbs the voltage is going to decrease and the current is going to increase. On cold days the opposite will happen.

Data provided on the spec sheet at what is called the **standard test condition.** The voltage of the module, the amperage of the panel, the combination of the two which is power, all of that data assumes a temperature of 25°C and so especially in your hotter climates, we see from the module temperature climbs substantially above 25°C.

What's the performance loss between the hot rooftop and the standard test condition? We look at a 25°C rating compared to a 65°C temperature to find a 40° C difference between the two. If our temperature coefficient of power is -0.34 percentage per degree Celsius. Then, we multiply it by our 40°C temperature difference between the lab condition and what we actually saw up on the rooftop, the result is a 13% energy loss due to heat alone. So, you take the wattage rating of your array and on these hot summer days in Arizona you already know that you're losing 13% from heat alone, before other factors are considered. One such factor is the friction of the electrons as they travel down the cable, called **voltage drop**. PVWatts takes all these factors into account to estimate the performance of solar in your area.

I use PVWatts because it's easy to produce a good enough estimate of an unshaded array. In summer you get greater production because of longer days, but you also have the temperature loss due to heat. In the winter it's colder so you don't have the temperature loss but the days are shorter. The Sun being further away is not as bright so you don't have as much energy hitting the surface of the panel. Using PVWatts to understand how the energy is reduced from the solar arrays standard test condition nameplate rating can help you pick the right inverter size for the solar array (We're going to get into this as the class progresses).

STC (Irradiance 1,000W/m², module temperature 25°C, AM=1.5)	SN285M-10
Rated Power (P_{max})	285W
Voltage at P_{max} (V_{mp})	32.1V
Current at P_{max} (I_{mp})	8.87A
Warranted Minimum P_{max}	285W
Short-Circuit Current (I_{sc})	9.46A
Open-Circuit Voltage (V_{oc})	40.5V
Module Efficiency	17.45%

Figure 16 – Electrical Characteristics

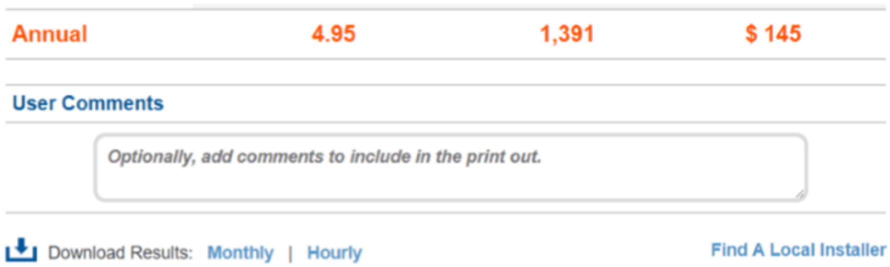
Here's your standard test condition rating, listed at 1000 watts per meter squared with a module temperature of 25°C. Another factor of standard test condition is called **air mass** or **atmosphere thickness** and that's the hardest one to nail down exactly. It relates to how far through the atmosphere the photon is traveling, and so the atmosphere thickness at noon would be 1. In the morning, the sunlight travels through a greater cross-section of the atmosphere and so you get a higher atmosphere thickness. That value will also be watered down with humidity, clouds, air pollution etc.

So, with an air mass rating of 1.5, standard test condition is not modeled at high noon with zero humidity, but assuming mid-morning sunshine with some humidity or high noon with heavy humidity, with a thousand watts per meter square of energy in the air. So, we go back to our PVWatts printout to get more detail of how that energy actually varies with hours of the day, as well as seasonal variations. We can see between 6 – 8 a.m. we we're only getting up to 500 watts per meter square. Then, around noon we get a little bit over 1000 watts per meter squared. And so, this 1kW solar array is turning on in May at 7 a.m. and staying on past 4 p.m., but it's not at full power all day. Its power curve is shaped like a camel's hump with maximum power occurring midday.

PVWatts redefines the days' worth of solar insolation into a number based on how many thousand watt per meter square hours the solar array effectively receives, which might be 4 hours a day even though the solar array is energized for 8 hours a day at a lower power level. This is a number that's referred to in the solar industry as **sun hours**, which again is how many standard test condition hours per day the solar array effectively receives. Be aware of this: some will confuse sun hours to say there's really only a 4-hour window when the solar array produces all of its electricity. That's not really the case. It's more of an average from the morning into the evening that gets compressed. Sun hours are really just a mathematical tool that the industry has used in the past to calculate daily solar performance, before tools like PVWatts were available. If I know that in March, I have 4.8 sun hours, then I know my 1kW array would average 4.8 kilowatt hours a day. It's not something you're really ever going to use when just getting into the solar industry. You might still use it today when trying to calculate the performance of a solar thermal hot water system.

Another spreadsheet line item is **module efficiency**. The module efficiency is an indication of how dense the solar array is. It's not necessarily indicating build quality or cost-effectiveness, as an efficient module can be made by a lower-end manufacturer and an inefficient module made by a higher end manufacturer. Although to some extent your most efficient solar panels are generally correlated with your higher end manufacturers.

Here we see short-circuit current Isc and open circuit voltage Voc, as compared to the maximum power current and voltage, which is a factor of not the maximum current or maximum voltage, but a happy medium between the two. Imp and Vmp are more realistic expectations of operating current and voltage, in layman's terms. When you do sizing calculations for the National Electric Code, you typically start the calculation by using the short circuit current and the open circuit voltage, so that when operating your system is performing underneath its maximum allowed rating, your safety calculations will not be exceeded unless something is going terribly wrong. So, if you are making design calculations and wonder, “Am I supposed to do my voltage and amperage calculations based off operating voltage and amperage as compared to open circuit voltage or short circuit?” Use the short-circuit current the open circuit voltage when performing your safety calculations.



- Sunny Days (direct insolation)
- Cloudy Days (indirect insolation) – good for off-grid
- Ambient Temperature
- Wind Speed
- Module Surface Temperature
- “Hours of Operation” for summer, spring, fall, winter
- Maximum System Output Power
- Economic Modeling in Excel etc.

Figure 17 - PVWatts Conclusions

PVWatts is a very useful tool. It will tell you how many sunny days and cloudy days you’re going to have. It’ll tell you your rooftop temperature, the surface temperature of the solar panel, and your hours of operation. As you can determine when the array is turning on and off, you can use that window for a shade analysis to determine how much clearing is needed to get all the possible energy out of the array. Or you can also download the hourly production and discount the production during shaded times. The hour-by-hour data is useful for calculating value of time variable rate structures where the cost of electricity is higher at certain times and lower at others.

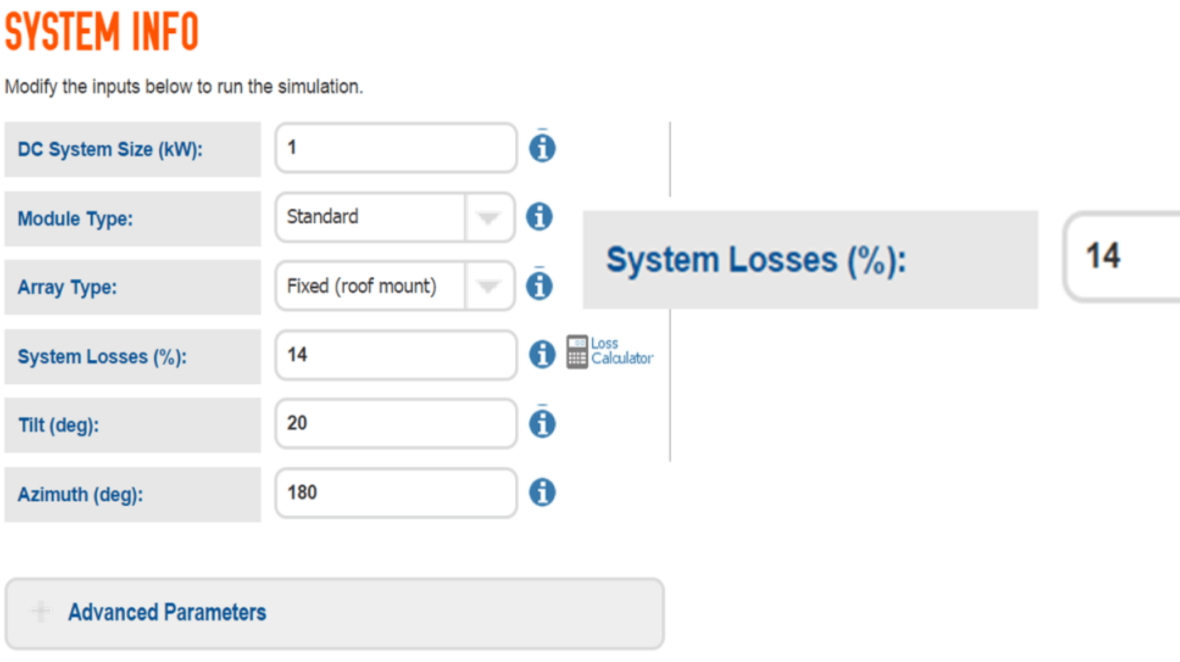


Figure 18 - PVWatts Interface

When you choose between different module types, like a premium module type verses a standard module, PVWatts slightly adjusts the temperature coefficient of power as further detailed in the PVWatts documentation. Although these are minor variables as silicon is silicon so there's only so much you can do with it. But PVWatts does allow for slight adjustments, such as selecting between a roof mount versus a ground mount, which will actually model the ground mount at a lower operating temperature with slightly increase airflow underneath. But if you actually run the math, you'll see the performance differences are negligible between most of these variables.

PVWatts allows you to do a single-axis or double-axis tracking array, and of course it allows you to adjust tilt angle and azimuth or compass orientation to fit your particular roof. And then, it posits a discount factor that accounts for all remaining production loss variables (assuming no shade) at a default value of 14%. I recommend just keeping that "as is" until you are more experienced with your designs, at which you point you can calibrate your discount factor to match field performance of arrays you have already installed.

When we talk about inverter selection, we'll discuss module level panel electronics like micro inverters and DC optimizers, that allow every single solar panel on the roof to operate independently of each other. That's going to reduce some of the mismatch losses know that might take that 14% number and improve it up to 11%, actually.

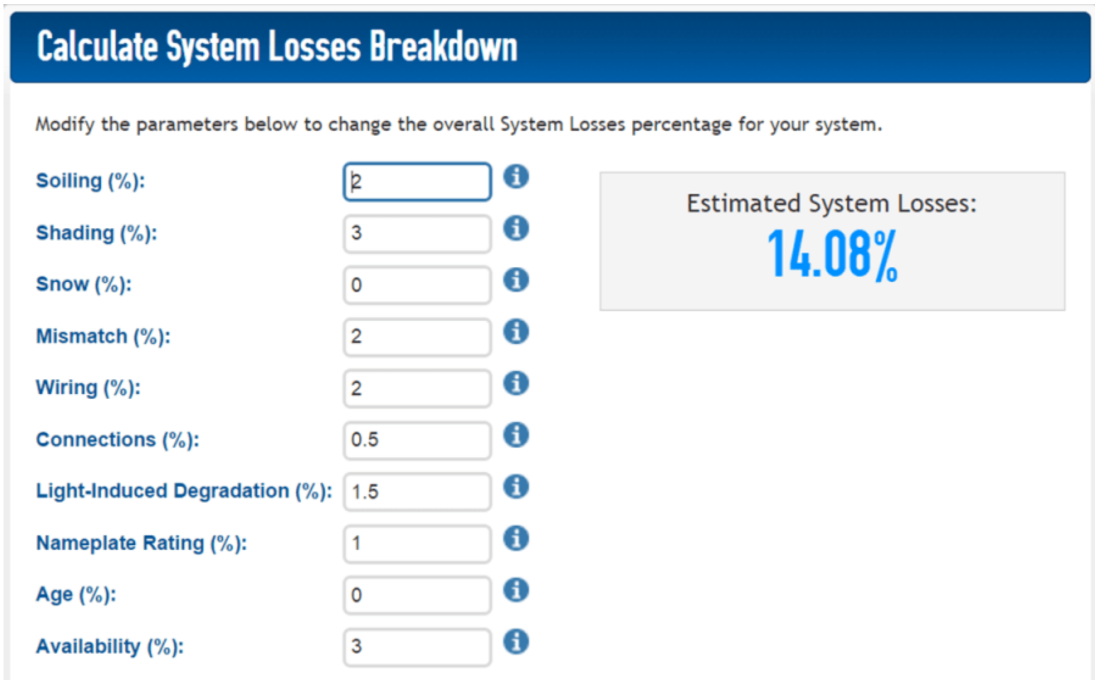


Figure 19 - PVWatts Derate Factor

Let's take a look at other factors of system losses that comprise the 14% derate factor. The first one is dust. Where I live, we get a lot of pollen in the air. A lot. You can see it in the morning on your front windshield. Then again, you're not going to be getting up on the rooftop and cleaning your solar panels! I might recommend doing that once every 10 years, perhaps more if you live alongside a dirt road, but not often in general. So, PVWatts is assuming that the surface of your modules will have some dirt or dust on them, and so they're going to be modeling a 2% loss from dust. They're also going to model a 3% loss from shading, but that really accounts for very long shadows in the morning and evening, or something similar in effect like minimum energy requirements for your system electronics to turn on and off in the morning and evening, rather than shading loss caused by nearby trees. In other words, PVWatts may show that at 6:00 a.m. your 1kW solar array is producing 6 watts of power, while in reality that's not going to be enough power to turn on and start up the system. So PVWatts accounts for that by throwing on a 3% shading discount factor, which I'd say is a good number for an unshaded array. If you're doing solar on a shaded rooftop, at that point you have to start doing a 3D model and running simulations that are in the realm of commercial design software. We'll take a look at some of that later.

PVWatts assumes that there will be no snow on your solar array. Here on the Gulf of Mexico, snow is not an issue. In Wisconsin, you could easily have a foot of snow on their roof for the entire month of January. So that means for your performance estimate, you may need to go out and just zero out the month of January, if there's going to be snow on the roof every year and your client is not going to do anything to clear the snow off.

Imagine solar panels on your roof are like a chain-link fence; the weakest link in the chain is going to be the one that fails. Well, it's not necessarily the solar panel that fails, but there is a tolerance that the panels have, meaning that some on the roof will be weaker than their neighbors. When I open a solar panel spec sheet, it'll be for a 290-watt panel but also panels that are 300, 310, and also a 320-watt panel. So, within the same form factor of the panel, I'll get four or five different wattage ratings, efficiencies, and voltage and amperage characteristics.

The reason for that is that solar is made either in a sheet or a cylinder and then is cut in individual cells, or the cylinder is sliced into individual cells, and the cells that are in the middle of the crystal are a little bit more pure than the cells that are around the edges. So, these individual cells then get placed onto your solar panel, it creates a variance between the cells that result in a variance between the modules. Now, manufacturers test and sort the cells resulting in higher 320-watt panels and the lower efficiency cells comprise the 290-watt panels. All the cells are the same size, so all the panels are the same size, but out of the same production run, you get a higher efficiency module that might be sold to someone in New Jersey then you get a lower efficiency panel and that might be sold to someone in Mississippi, albeit at a lower price point.

Even within that, a 290 panel might actually be rated for just under 300 watts. So, I open up a pallet of 290-watt panels and know all of them will produce at least 290 watts at standard test condition. The tolerances today are positive but used to be +/- 3% which is why PVWatts uses the 3% mismatch figure, which results in a discount factor that is too conservative. With most modules today, the mismatch is going to err on a production increase rather than a production decrease. But again, when presenting performance estimates your customers, it's better to err on the side of conservatism.

At the same time, if I were using module level panel electronics like microinverters or DC optimizers (which we'll talk about later), that mismatch would no longer exist at all. Weaker solar panels would no longer be dragging down the stronger solar panels. If I'm using microinverters or DC optimizers, I'm capturing 3% more energy, so instead of using a PV loss factor of 14% I might use a PV Watts loss factor of 11% and still feel like I'm still providing a conservative estimate.

Likewise, voltage drop depends on your particular project. if you're up-sizing your cable you might get your voltage drop down to 1% instead of 2%. National Electric Code wants you to be around 3% currently, and 2% is generally what solar installers will design around. Actually, I'm often up-sizing my cable to take advantage of pre bundled cables, which often come with an undersized ground, so my designs have even less voltage drop.

Every time you splice a cable, square one section of cable is connected to another such as when it lands on a breaker, or when one module plugs into its next-door neighbor, that's going to produce a little bit of resistance in the circuit. So, PVWatts is taking that into account.

There are two types of degradation that aren't fully considered by PVWatts, so while mismatch is being a little bit too conservative, leaving yourself some wiggle room in the discount factor well include other minor unaccounted for losses. The first type is called light induced degradation, and if that's accounted for in the "nameplate rating" derate, then dust is not accounted for. Both light induced aggregation and dust are degradation factors that are measured in 1% or 2%. Basically, this is saying that out of the box, your solar panels are going to degrade by ~2.5%, so while a 290-watt panel is going to test to 290 watts in the lab, when you unbox, leave it on the roof. It's "nameplate rating" (we're going to get into that with a warranty discussion and a chemistry discussion in just a minute) at year 1 will reduce at about .5% a year. So PVWatts assumes this is a new solar array but does not account for annual degradation with time. PVWatts is being a little bit too liberal in the fact that it's giving you the Year 1 production value but Year 2, Year 3, Year 4, and so on will decline. Generally, I don't worry about that too much, because I'll assume the price of electricity will increase over inflation by ~.5% a year. That's another thing you need to watch out for, some solar sales reps will grossly overstate how much the cost of electricity is supposed to increase. I've seen one company estimate as much as 7% year over year in a market where that number is under 2%. And even though the price of electricity may be going up, the value of your solar electricity may be flat, because that utility can monkey around with your value of solar through solar discriminatory rate adjustments.

Lastly, we get to "system availability", and this is where I think PVWatts is, again, being a little conservative. They're saying that the system is going to be unavailable for 3% of the year, which is 9 days. So, they're saying that for 9 days a year the solar array is going to be offline for maintenance and failure replacement EACH YEAR, and that's just not what's typical. If you do have a maintenance event or a failure of it, you may lose your production for a week while that replacement part is being bought, fixed, and installed, and then a couple of days for diagnosing it. So, 9 days might be typical for that, but if you're having a maintenance event like that every single year you probably picked the wrong installer. Call me, and we can work something out ;^)

And so, sum up all these factors and you get a very good, conservative estimate. Remember: it's better to underestimate and over-deliver then oversell and under perform. Take the normal 14% degradation factor with PVWatts and that's a solid number you can go to your client with. And I if you want to be a little bit more aggressive than that, just get rid of mismatch if you're using DC optimizers or microinverters and adjust to 11%.

Let's do an example. We'll go to PVWatts and put in an address. I'm putting in a one-kilowatt solar array with standard modules. By the way, the temperature coefficients used by PVWatts are conservative, and accounted for behind the scenes not being included in that 14% derate factor, so that's another area where PVWatts is being conservative and that it will model more heat loss than what you should experience and your climate. Unless the temperature rises in the future but that's another topic for another day. We select a roof mount, keep the system loss number the same, fixed tilt, and click this little info button to check your roof pitch. I do a lot of 5:12 rooftops at a 22-degree tilt angle. 12:12 is 45 degrees. I'll just put on a 5:12 roof pitch to be a little more accurate and then select a due south roof orientation and click go.

We can see, living on the Gulf of Mexico, a breeze coming in keeping the modules a little bit cooler, with less humid air than in North Mississippi where we have installs producing 1.4 kilowatt hours per watt per year, that we're getting a little more production on the gulf coast at 1.5 kilowatt hours per watt per year. See that in January I'm producing 105 kilowatt hours for my 1000-watt array, whereas in July I'm producing 132. So that's actually pretty stable production, reflecting a climate with sunny winters.

Then here, download the hourly information. Here's my performance data for every single hour of the year. I get direct irradiance and diffuse irradiance, temperature, and wind speed. PVWatts is taking the array orientation and tilt angle and direct and diffuse irradiance and converting it into the amount of irradiance on the panel itself. I have my cell temperature, DC output and AC output.

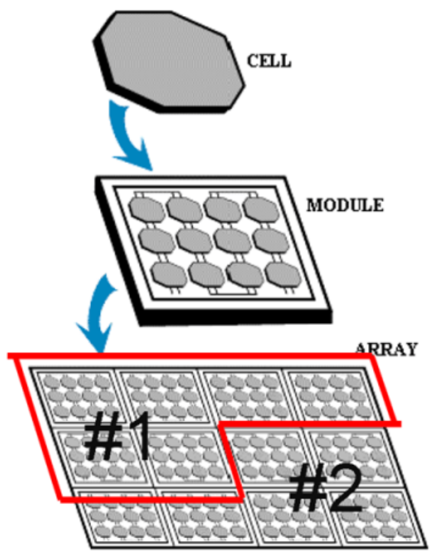
If I want to ask what is the maximum value that my 1,000-watt solar array is outputting, I can see as my maximum output is 828 watts. As I have a 1,000-watt solar array it's only giving me my 828 watts of maximum output, my inverter only needs to be 83% the size of my solar array. In other words, my solar array can be 20% larger than my inverter, and I won't lose any energy even though my inverter is smaller than my nameplate array capacity.

Why is this? Because in the summertime, let's scroll to July, I look at my system output in the middle of the day and I'm getting 560 watts out of 1000. The next day 650 watts then 500 Watts. 650 Watts, etc. If I put an 800-watt inverter on this system, I'm not getting up to my peak capacity in the summer at all. In the summertime I'm not hitting my peak capacity because of that temperature loss we talked about.

Instead, I hit the maximum 828 watts in April, with that lovely cool and sunny spring weather. For that matter in the summertime, the sun is more straight up in the sky so also a 20-degree tilt is better oriented for spring. Anyway, when choosing the relationship between my solar array and my inverter I am very comfortable under sizing my inverter by about 20%. By the way, if you do get up to the peak capacity, the inverter will simply leave that extra unconverted energy up on the array as voltage.

Solar Modules

Some terminology:



- Photovoltaic **cells** are wired together in series to create a Module (aka Panel).
- **Modules** are in turn wired together in series to form a "**String**", usually 7 – 14 modules long.
- Several Strings may be paralleled together to form a complete **array**.

Figure 20 - Solar Module Terminology

I've been referring to solar "panels" when what you call a solar panel the industry National Electric Code Book is a "module" not a panel.   That's because the term "panel" in Code is already reserved for your electric service panel or a roofing panel. We don't want any confusion, so what we say is you have individual "cells" and the "cells" are combined to a "module". Batteries are the same way. You have individual batteries "cells" and then the battery itself is called a "module" and they combine to form a solar "array". We call the DC Circuits "strings" although I'm not quite sure why. I guess that's what the cool kids say because code would refer to them as photovoltaic output circuits. We're going to come back to that and our inverter selection later.

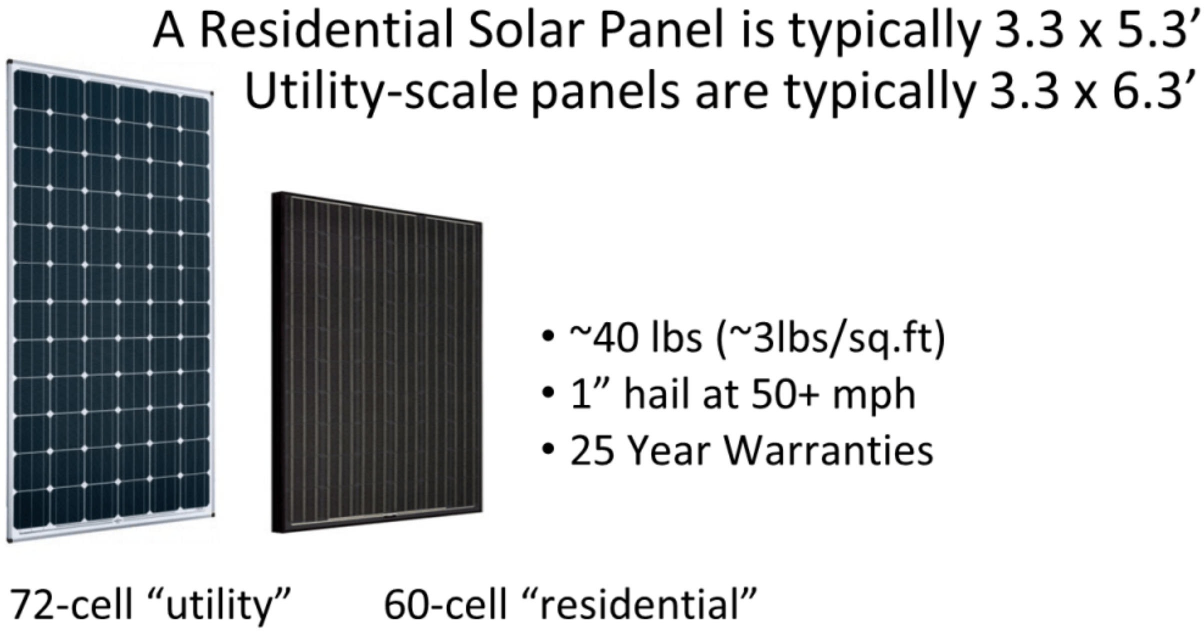


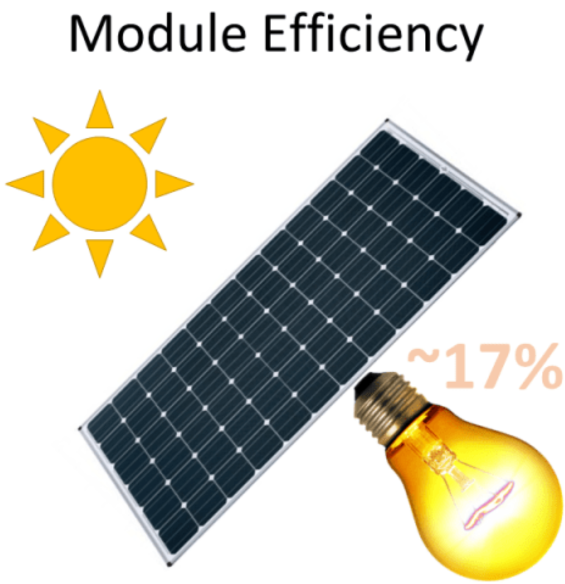
Figure 21 - Basic Module Characteristics

Solar modules are about the size of what one able-bodied construction worker can pick up and handle and set back down, which makes sense. A solar panel is 3.3 feet wide and about 5.3 feet tall. At the utility scale, they can be taller and heavier because you’re not handling them on a roof.

Typically, at the residential level solar modules are 6 cells across and 10 cells tall and that’s called a 60-cell module. The utility scale is a 72-cell module because literally they’ve added two more rows of cells to the panel and made them a little bit taller and slightly more cost-effective. Note: it’s not that you can’t use 72 cell panels on your rooftop but I don’t recommend it, particularly on slanted roofs for the obvious reason of rooftop safety.

Solar modules are rated to withstand 1-inch hail at 50 MPH which makes them seem invincible. Solar modules are so strong they often give the installer a false impression of module strength. Twist a solar panel the wrong way or drop it on concrete and it’ll shatter the glass. The installer might be surprised because he just threw the solar panel on the back of the truck and nothing happened, but handled it wrong with a forklift and the module shattered. It’s a very specific strength. Let’s not forget the modules President Jimmy Carter put on the White House were in use until very recently, as in the last few years. So, they do last. When you’re handling the solar panel on a rooftop there is some “give”. You can lean on them a little as you get more proficient at handling them (But don’t). Two tips are: first, try and put your weight on the frame rather than on the glass. You can spider-man across if you have to, but that is not a good idea. I’m trying to say solar modules more robust than weak.

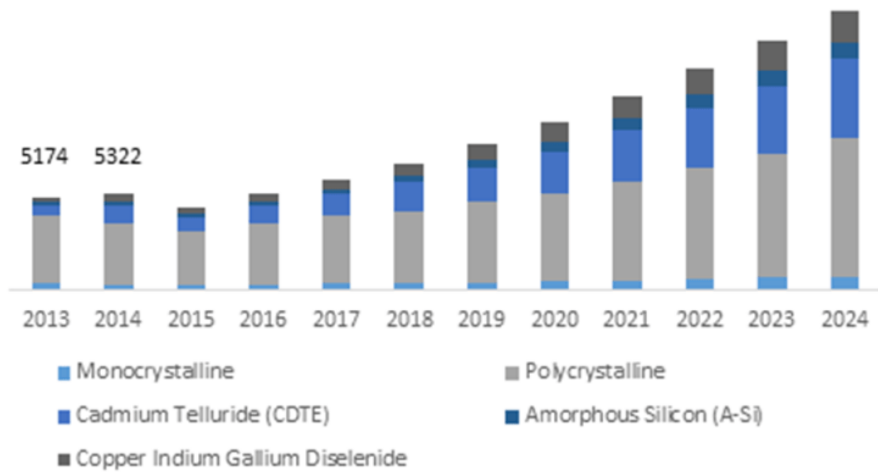
The other tip is, when you're installing is you want to make sure you're not dragging this metal edge across the glass surface of another module. I always remind my new guys to pick the module completely up. If you're sliding it like when you're unpacking a pallet, make sure at the very least you're sliding the module across the frame of the one underneath it and not across the glass. If (when) you leave a scratch the warranty (which is typically 25 years although some of the higher-end modules have thirty-year warranties) might come into question. They're their long-term robust panels, so remember they will be fine. But don't scratch them.



Sample Panel Efficiencies	STC
Manufacturer	Median
Canadian Solar	17%
Hanwha Q Cells	17%
LG	18%
Panasonic	21%
SolarWorld	16%
SunPower	21%

Figure 22 - Solar Module Efficiency

Now, module efficiency is how much power hits the surface v. how much power comes out. The backside efficiency ranges from 17% on the low end to 21-22 % on the high end of commonly used solar panels. Now, the thing about the higher end panels that are 22% efficient instead of 17% efficient is they can cost two to three times as much as the lower end efficiency panel. Typically, I don't go for high end panels. It's going to cost more, can be justified in certain locations. Generally, those reasons are more affluent clients who simply want the best and also, they have a higher real estate resale value, with higher electric rates and limited rooftop space. So, you're paying for the array not to take up as much space but do the same amount of work. But if you have a simpler rooftop, lower efficiency panels usually result in a more cost-effective project. As far solar panel technology goes, they're pretty much all silicon panels, so there isn't a ton of difference between low- and high-end panels, compared to other system components like inverters or racking.



https://www.gminsights.com/industry-analysis/solar-cells-market

Figure 23 - PV Cell Market Share by Material

There used to be more discussion over what panel technology would be dominant in the past than there is today. You do get some non-silicon solar panels in the utility-scale market. There's a big US manufacturer that makes them out of cadmium. This is not something you really want to put on your roof, because of environmental damage caused in the event your building burns down. Another global manufacturer makes CIGS panels which are: copper, indium, gallium, and selenium. Non-silicon panels are a little bit cheaper but they're usually less space efficient, so that they're really only used in large utility-scale projects in areas that are hot with cheap real estate.

Figure 24 - All Black Modules

This is my favorite upgrade. I don’t care about efficiency or brand names for solar. I am fine with solar panels that are generic. I’m *much* more particular about my inverter and my racking. But the one panel upgrade that I always recommend to my residential customers is to get all black panels. When you get low end all-black panels, there’s variations of all black and the grid lines show. (Although the further away you get from the array the more, they vanish). If you treat your client to high-end all-black panels that are high efficiency and it’s just like a sheet of black glass covering the surface. It is gorgeous, if a little bit more architectural. I’m concerned about the aesthetics of my solar arrays, because the customer has to love it, and I have to love it as well. The only error that this installer made in this picture is that there’s a plumbing vent right here on the middle of the array and obviously they did the design for it to be one continuous row but then found the vent when they got up on the roof and I just stick the module off the end of the array instead. Maybe the client says, “Well, it’s on the back of the house so you can’t see it.” But the further away I get from the rooftop I can turn around and see it. We’re going to talk about how you can fix that in a minute. (No, it’s no big deal you just have to replumb that vent underneath the array.) I do like the look of one big rectangular black surface, like an infinity pool for the sun, as compared to the silver frame with a white back sheet. This has a black frame and a black back sheet and that eliminates all these little white spots that would otherwise show up on the array. Now there’s exceptions to that of course. If you have a silver metal roof then the silver frame solar panels can look quite nice too.

Figure 25 - Solar Shingles

I'm very interested in is how to take a rooftop and build the roof out of solar panels rather than to use solar shingles for that reason. There's a lot of solar installers who will grumble about Tesla "solar shingles" because they're not available. I could be selling more installs but customers want to wait for "solar shingles". Actually, solar shingles have been around for the last ten years. Inevitably they're too expensive and the manufacturer goes out of business and stops making them and the solar shingle aesthetic really looks no better than having an all-black array.

There are frameless solar panels that do not have the metal frame that goes around them, which is interesting. That frame is pretty useful because it gives you a support edge when you're landing the module on the roof, when you're placing it, and when you're lifting it. That frame really helps give the installer something to hold on to. If you've ever picked up a fin framed television you, you know what I'm talking about. You have to be more delicate with a frameless solar panel. The frameless panels shatter easily, but you might find a reason why you need them. I mean you can get a frameless solar array and then there's no conductive edges. you might better fit them into a custom-building frame.

I was looking at frameless panels for a utility scale project back in 2014 and the idea was that they could just be glued directly to the racking system and not only save a couple pennies per watt by not having the frame but also improve the installation time. The frameless solar panels really got set back by the Obama era import tariffs. I've only seen them installed in Australia rather than in the US.

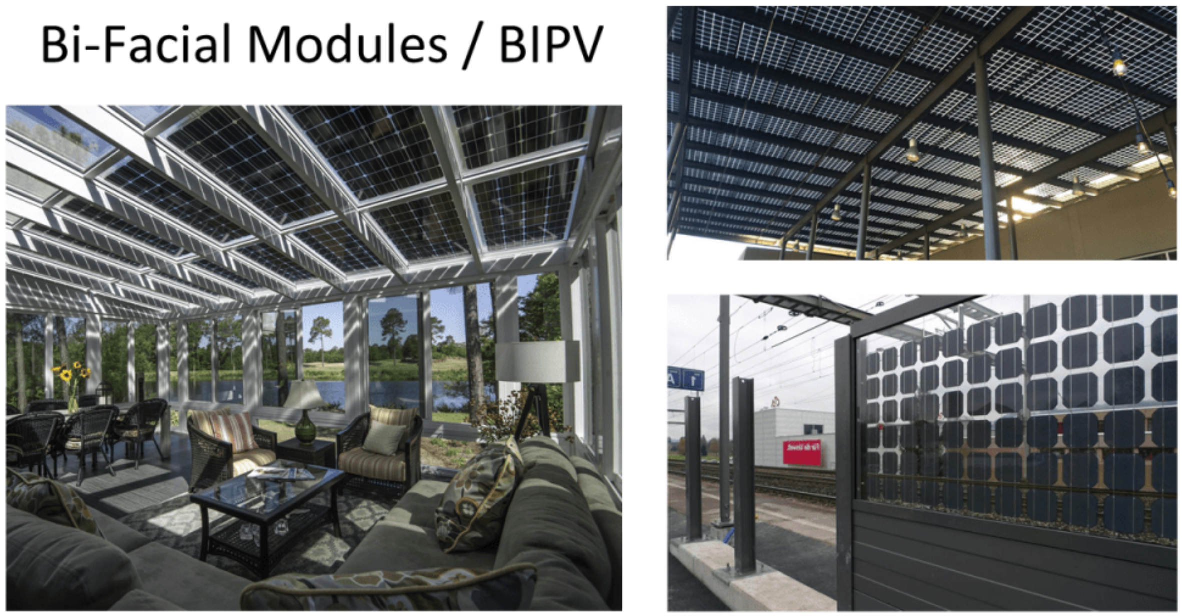


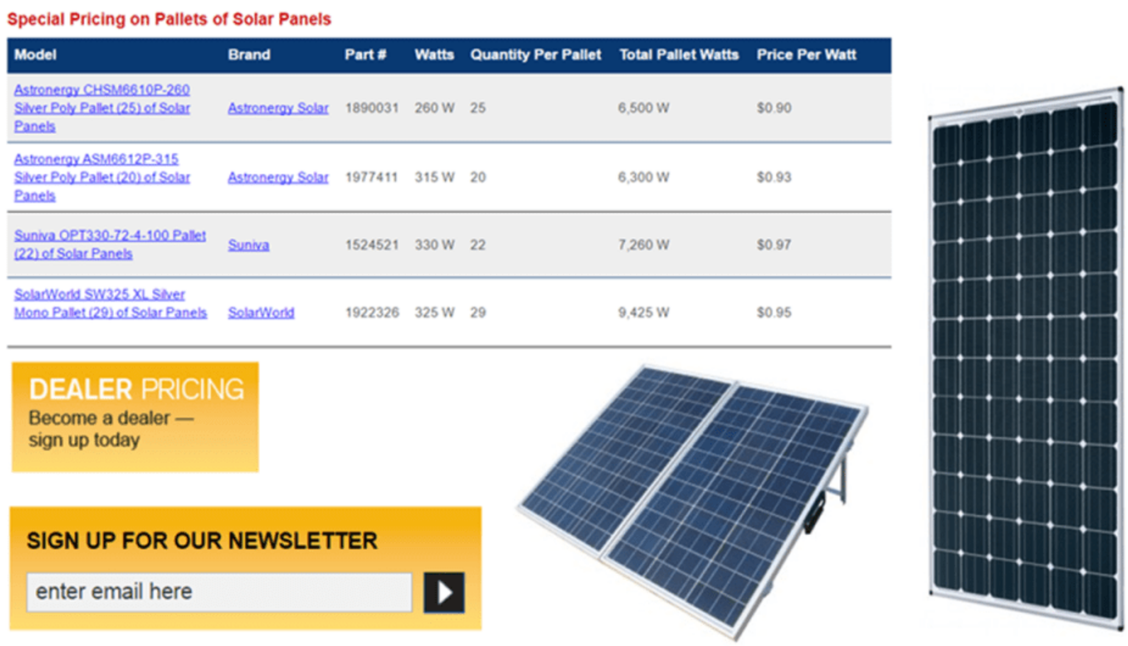
Figure 26 - Bifacial Modules

Architects probably like this: these are called bi-facial solar panels. Just like the all-black panels took what was a white plastic backing and made it a black plastic backing, the bi-facial solar panels have a glass backing and that allows you to see through the panel. Now, I think it has real architectural purpose. You can make a stunning custom design for a covered walkway and better connects the public to the solar and all because you can walk underneath them and look up and actually see the cells above you. They're more available than solar shingles and frameless solar panels, less available than all-black panels. They're being considered more on utility scale projects simply to improve the density of the project, because they can collect sunlight from underneath the array as well as on top.

But collecting sun from the underside of the panel really is in a huge improvement and you can use PVWatts to explain why. Going back to our direct beam irradiance and diffuse irradiance, diffuse irradiance means there's clouds in the sky. So here on January 1st it's really diffuse irradiance. We have zero direct sunlight and indirect sunlight at high noon on January 1 and then on January 2, the same thing. January 3 same thing and here's January 4th. A weather system had blown through and so what we see is that on this January 4th we got 964 watts of direct and 80 watts of diffuse and our solar panels are doing 728 Watts and then on January 1st we have no direct, all diffuse and we have 80 watts so 728 versus 80. So, let us assume that the underside of the panel is all diffuse light and so what we're saying is maybe the bi-facial panels will boost the performance of the array by about 10% and they cost more, so if you're trying to be cost effective you don't really go for bi-facial panels. Typically, they are a little more costly because the bottom is made from glass instead of plastic. But Jim pawns has been developing a clear plastic for solar panels that could really shake up the industry if it ever comes to market.

I would get bi-facial panels more for architectural reasons, like being incorporated into the building in beautiful ways, not necessarily in cost-effective ways. Think government building or community-based structures here, basically projects that would benefit from their visual beauty. At that point, it gets a little hard to find bi-facial panels because most of all are like this where the cells are really closely spaced together whereas I think that the ones with the cells spaced further apart are prettier and more logical because you want to let the sunlight through. But the further apart you space the cells, the more you're buying a sheet of glass and not buying the solar panel, and so it becomes even less cost effective for residential, of course.

So, where do you go to buy solar panels?


Special Pricing on Pallets of Solar Panels

Model	Brand	Part #	Watts	Quantity Per Pallet	Total Pallet Watts	Price Per Watt
Astronergy CHSM6610P-260 Silver Poly Pallet (25) of Solar Panels	Astronergy Solar	1890031	260 W	25	6,500 W	$0.90
Astronergy ASM6612P-315 Silver Poly Pallet (20) of Solar Panels	Astronergy Solar	1977411	315 W	20	6,300 W	$0.93
Suniva OPT330-72-4-100 Pallet (22) of Solar Panels	Suniva	1524521	330 W	22	7,260 W	$0.97
SolarWorld SW325 XL Silver Mono Pallet (29) of Solar Panels	SolarWorld	1922326	325 W	29	9,425 W	$0.95

Figure 27 - Supply Chain Tips

Well, my advice is to go to online wholesalers and then sign up for their newsletter or whatever. They may say they have dealer pricing but if you're not already a solar installer, they may not be so happy to give you dealer/installer pricing. So, put your email address in the newsletter because they'll email pricing that is cheaper than what they'll list online. So, let's say you want to do a solar project for yourself and it's at least a pallet large, work the supply chain and you'll be able to buy the solar panels at the same price that I do. It's worth the time.

Over the course of this class we will learn how to ask a distributor for line item pricing in an expeditious manner. Why is this important? At the beginning of class, we displayed a balance-of-system material list for a 4kW micro-inverter solar array. This was an expansion project – the original array was 8kW but designed for future expansion. A few years later the client was ready to expand the array and he was handy. He had built his house, including air conditioning system, truss assembly, and roofing. Plus, I had selected a micro-inverter system which is on the high end of cost, but also very easy to install and expand.

The best way to do solar ready is to run the internal cable and conduits ahead of tie and leave them up on site, disconnected. But micro-inverter circuits are AC cable which does not need to be in conduit, so running ROMEX through the roof to the junction box was simple. The main problem on the expansion was finding solar panels to match his four-year-old array. The original modules were no longer available and we needed an aesthetic match. There is overlap in manufacturer module sizes, but there are also subtle changes in product lines. Last year's solar panels maybe have a great price on clearance, but rare solar panels might not be available to purchase.

At that point, being able to work the supply chain comes in handy. I was able to find one distributor that had matching solar panels at a clearance price, but if one simply approaches this distributor, they are so large that they state explicitly that they do not sell to residential one-off customers. If you want to do a residential one time order you have to go to their residential distribution partner distributor. No surprise, they're more expensive!

I had never ordered from this distributor before, but I had signed up for their email list, so I knew which products they carried. I knew they had the modules, the micro-inverters are common, and I quickly designed a racking layout for the array expansion using a manufacturer they distributed. This way, when I approached them, I could simply email them the list and they quoted me within a half an hour, rather than referring me to their residential partner. So, I was able to get the modules at a clearance price rather than a scarcity price. So, doing the design legwork on your own can really open up the supply chain. The supply chain is not as rigid as other home building industries such as air conditioning where distributors rigidly adhere to manufacturer franchise dealer rules. The ability to put together a design and material list is a useful skill in the solar industry.

How does a solar panel work?

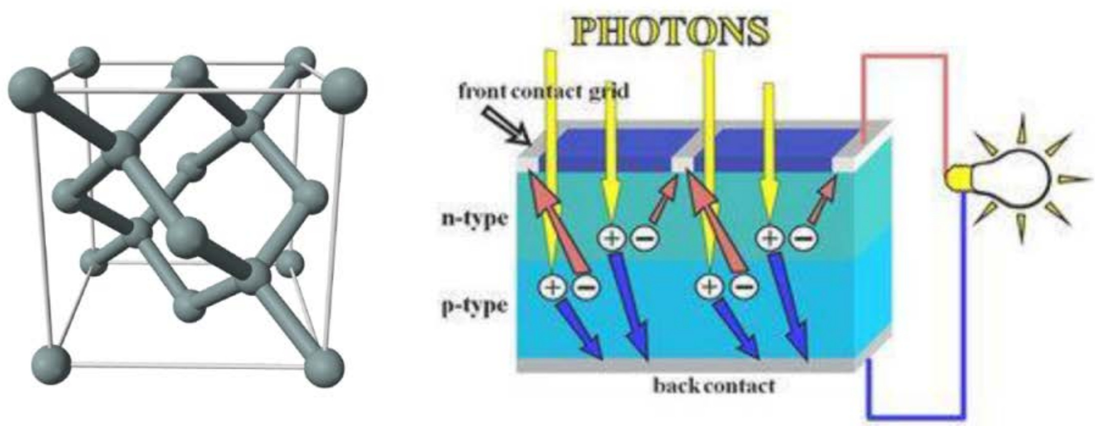


Figure 28 - How Solar Works

It's confusing because it just sits on the roof and generates electricity, but how? Well, to start out with, a solar panel is a semiconductor and semiconductors conduct electricity under certain conditions and do not conduct electricity under other conditions. So, a photovoltaic semiconductor works like this: when sunlight hits this crystalline structure, these electrons here are in this rigid crystal but when sunlight hits that crystal it's like a cue ball on a billiards table hitting the racked set of balls.

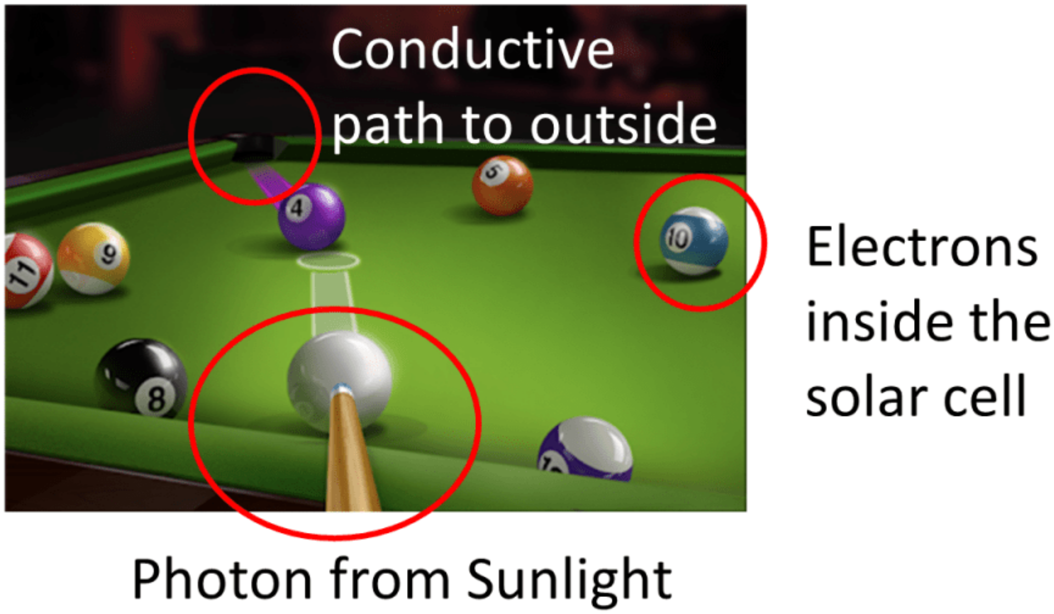


Figure 29 - Pool Table Analogy

The cue ball is the photon, an energy particle of sunlight that causes the electrons to break loose out of that crystal and start bouncing around the cell or in this analogy a pool table and so at that point, it becomes an exercise of how to get all the electrons that are careening around the cell to go in the direction we want them to go? Conductive pathways are put into the cell and then it becomes a trick to get all the electrons to flow into these conductive pathways.

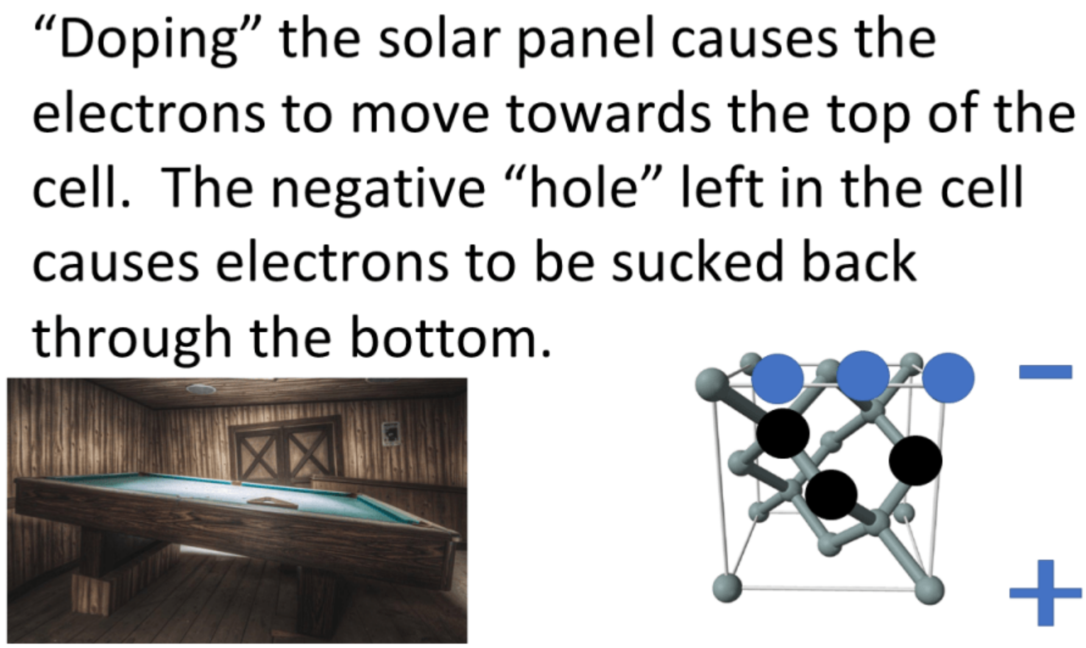


Figure 30 - Doping the Cell

So, to continue the analogy, take that pool table and pick one end up and all the balls fall into the side and go into the pocket. So, the way manufacturers get all the electrons to fall into the holes is, they dope opposite sides of the silicon cell in two dissimilar elements which create a disparity between the top of the cell and the bottom of the cell that nudges the electrons towards one side. So, the electrons bouncing through the cell have a tendency to be sucked up to the top of the cell and be repelled from the bottom, like a slanted pool table. And so, most of the electrons stack up on the top side of the cell where there's no electrons, with not as many electrons on the bottom side of the cell.

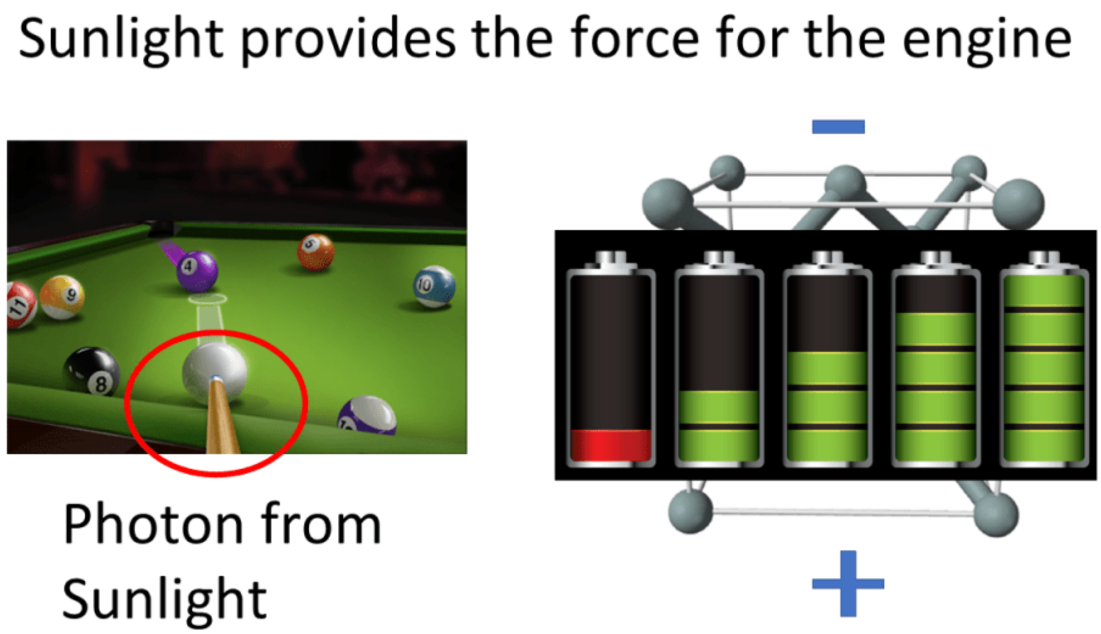


Figure 31 – Solar Panel Charge

The resulting difference creates a **voltage potential** just like you have on a battery with a positive and negative side. The solar cell, once that cue ball breaks the rack and keeping in mind you're playing on a slanted table, now has a positive and negative side to the cell just like a battery, except it's only on when those cue balls are hitting the surface of the cell and energizing the array. When you have sun, you get a big positive and a big negative voltage. A little bit of sun, a little bit of voltage, no sun, no voltage and at that point it's just a matter of connecting the positive and negative ends to a load and the electrons will flow from the positive end and back into the negative end. In this case the load is your house or more specifically, the load is the inverter that takes that DC circuit and converts those moving electrons to AC electricity.

Now when we were talking earlier about year one degradation, what happens is sometimes the electrons leap out of the cell and they don't come all the way back and they will leak out of the inverter ground.

It used to be that with inverters, you would take the negative side and you would ground it, but nowadays we have floating inverters where neither the negative nor the positive are grounded and that reduces this what's called **PID degradation**. Now with PID degradation, the electrons can also leak out of the frame so a frameless module has less degradation than a framed module although it's not worth losing the frame over. The frame is very useful. Manufacturers have started to space the cells a little bit further away from the frame and they have less PID degradation.

“PID” potential induced degradation
= electron leaves the table permanently
(leaking out various ground paths)

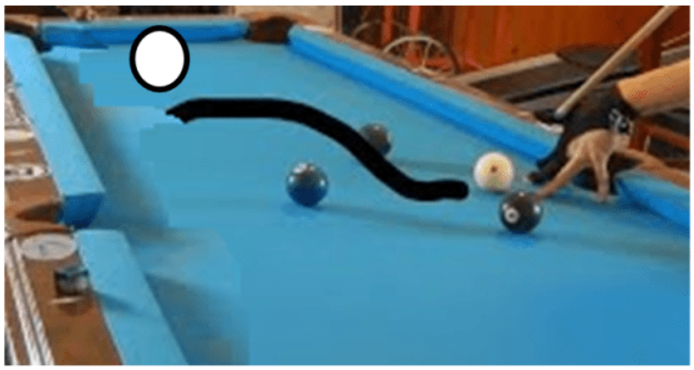


Figure 32 - PID Degradation

That’s like when you hit the billiard ball and the ball jumps off the table, so there’s build quality issues and system design issues that have been explored to reduce the PID degradation. This will happen mostly in hotter more humid climates, so it’s a particular concern on commercial flat roofs in the south where you get a lot of rain water just pooling right underneath the array.

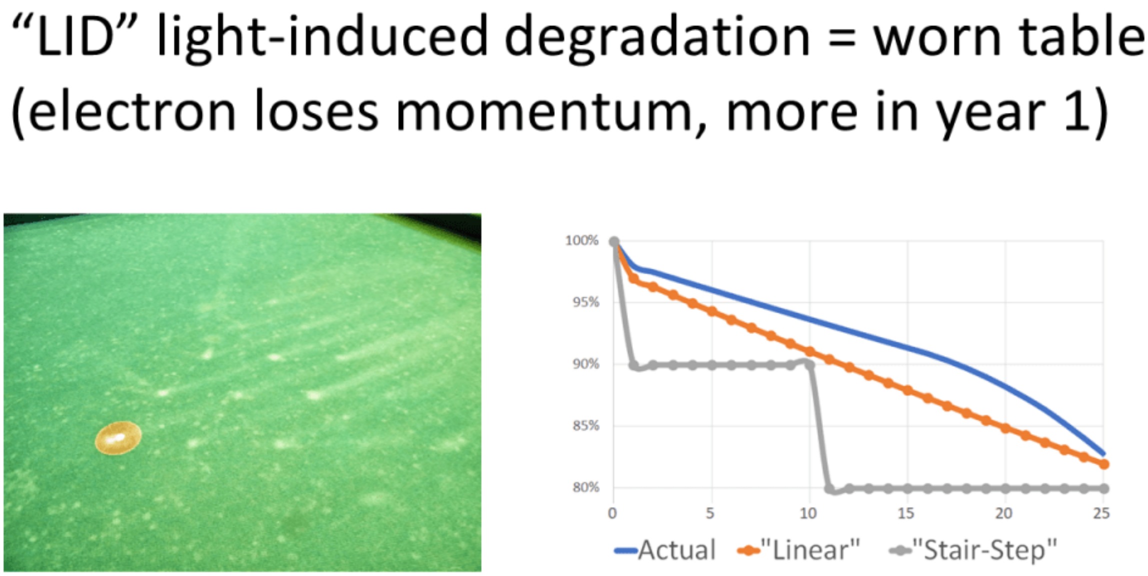


Figure 33 - LID Degradation

The other degradation is called **light-induced degradation** and that is like the felt surface of a worn pool table and so the billiard balls careen around the table. Eventually, for purposes of this example, they etch little gutters into the felt. Well, then the electrons careening around the cell will fall into those gutters and lose a little bit of momentum. That's why a brand-new solar array is going to have a little bit more punch than an aging one, because those gutters have not been etched into the cell yet.

So, in general you're going a first year a step down in array performance. That's warrantied by the way under most circumstances to be no more than 3% in the first then from that point on you have about .5% degradation per year. That .5% degradation is just from weather, such as humidity and water getting into the seal of the solar panel and then being vaporized and leaving little blotches that make the electrons not flow as well.

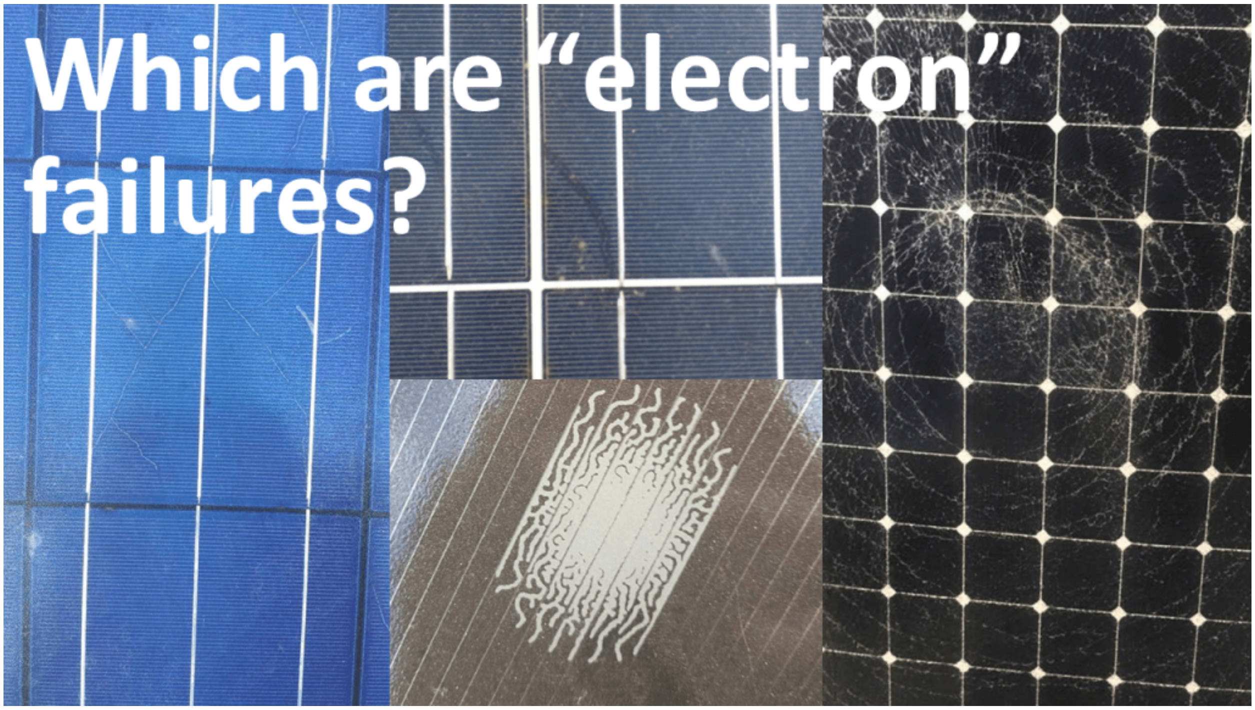


Figure 34 - Module End-of-Life Failures

So now we're getting into an advanced which are called **snail trails.** They've look like a slug just crawled across the solar array, but underneath the module glass. These are breaches in the cell where electrons have started to short-circuit within the cell themselves and the cell structure starts to rip apart and so these snail trails to some extent are inevitable at the end of a solar panel life, but can occur early in the module I fall resulting in almost no impact on a ray performance, depending on where they appear on the solar module. The electrons can still make it to the pathways unless they get so out of control that the electrons get trapped but even so the snail trails might only block one portion of the solar module, for an incomplete failure which might be further mitigated by inverter component selections discussed later. So, this is something that will naturally occur on solar panels even when there is no measured solar panel failure.

This is a thin film snail trail with it which is a little bit more dramatic than a traditional silicon snail trail. Whereas the solar panel failure on the right got hit with a large tree branch in a heavy storm hit the array like a battering ram.

Figure 35 - Rainwater Considerations

On the topic of water, with limited exceptions, you don't want your solar panels to be flat. You want to give them at least a 10° tilt, and I even think more than that. Rainwater will clean the solar panel, but that effect is greater at steeper angles because at shallow angles the grime gets caught in the lip of the solar panel, and so on a perfectly flat array you're going to get lots of dust and accumulation from rainwater evaporating and leaving behind even more grime on the solar panel.

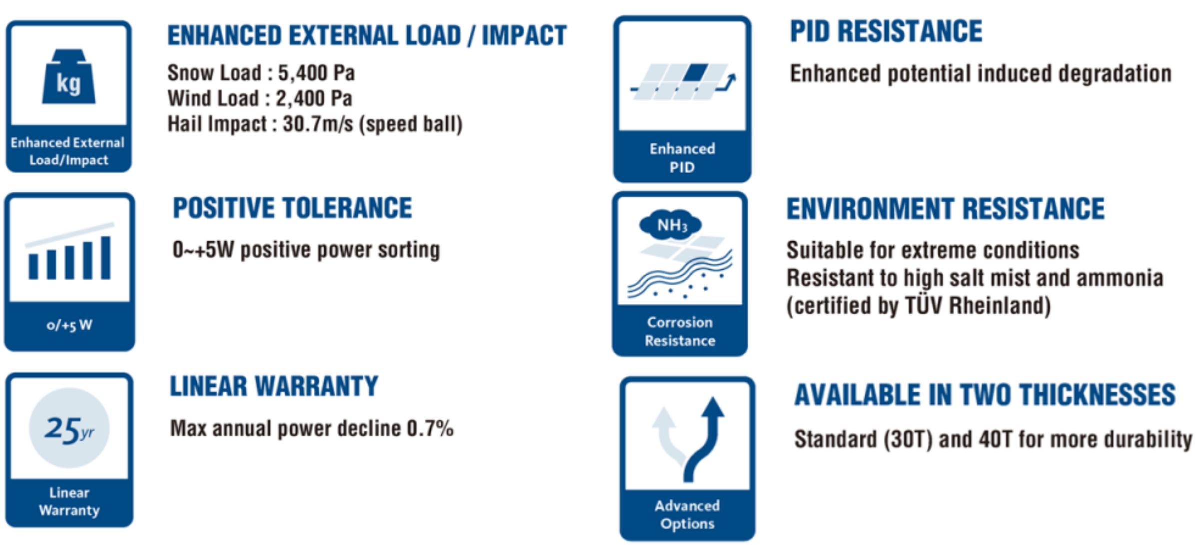


Figure 36 - Common Specification Sheet Items

On our module spec sheet, we see the module is rated for a snow load, wind load, and hail impact. The module frame is available in different thicknesses which can change how much wind load it can take, so there is stronger solar module better suited for hurricane winds. We see the positive power tolerance that we now understand that comes from the manufacturing process. We see a maximum power decline of 0.7% a year and we expect it to be actually be around .5%.

Mechanical Characteristics

Solar Cells	Monocrystalline 156 x 156mm (6 inches)
Number of Cells	60 Cells, 6 x 10matrix
Dimensions	1,650 x 990 x 30mm (30T)
Weight	17kg (37.48 lbs)
Front Glass	High-Transmittance Low Iron Tempered Glass
Frame	Anodized Aluminum Frame (Silver / Black)
Output Cables	PV Wire (PV1-F), 12AWG (4mm^2), Cable Length : 1,000mm
Connectors	MC4 Connectable

Figure 37 - Mechanical Characteristics

We get the module dimensions and can see the size difference between 60 cell and 72 cell modules, the weight of the panel, even things like the length of the cable coming out the back of the junction box.

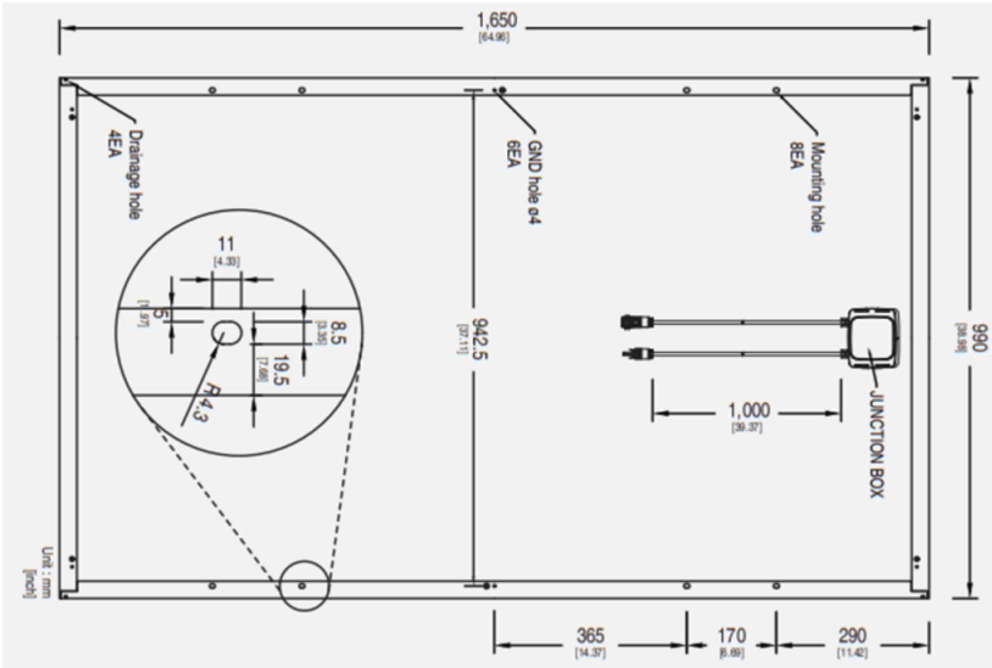


Figure 38 - Solar Module Dimensions

Even this data is useful as knowing these cables are going to be long enough so that the modules can be wired in either landscape or portrait is vital to design. Managing these cables gets messy and so every installer has their favorite cable management techniques and when these cables are longer you can do even fancier things with your cable management than when they're shorter. For example, we will often use metal clips to run these cables along the inside of the solar panel frame, with just a little bit of cable length peeking out where it's supposed to connect to the next module on the circuit. that makes it easy for the installer to plug in the module, and eliminates the slack in the cable run that would otherwise droop down onto the roof surface. Most solar modules have cable whips long enough for the module to be mounted in either portrait or landscape.

Warranty

Product Warranty	**10-year Limited Product Warranty**
Performance Warranty	**Minimum Power Output for Year 1 : 97%**
	Maximum Power Decline from Year 2 to 24 : 0.7%
	Power Output at year 25 : 80.2%

Figure 39 - Solar Module Warranty

Finally, on the module spec sheet we get to a warranty. There's a 10-year product warranty and a 25-year performance warranty and that's pretty common of your mid-range solar panels. High end panels often get a 25-year product AND a 25-year performance warranty. Well what's the difference? What it really means is a 10-year warranty is on the build quality of the panel itself whereas the performance warranty is more like a limit on the maximum amount of LID & PID degradation over 25 years and so we see that there's a year one warranty for 97%.

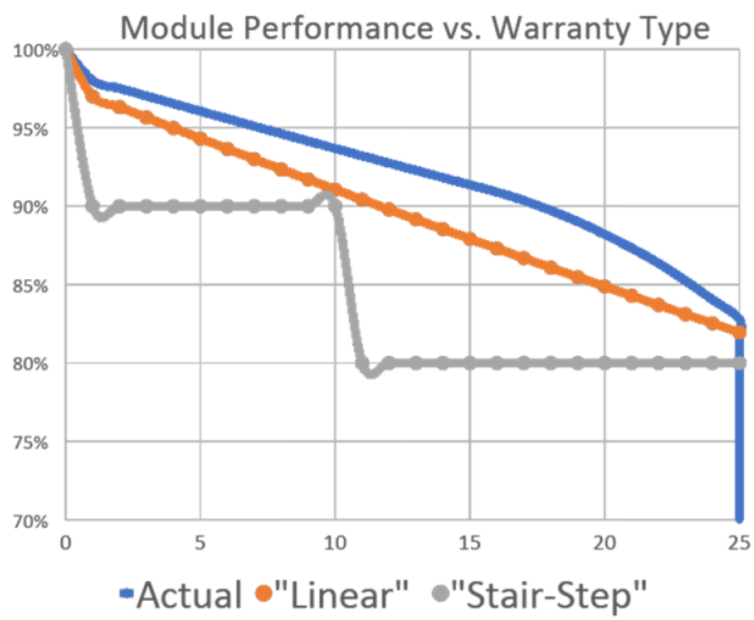


Figure 40 - Performance Degradation over Time

Well, now we understand why Year One light and potential induced degradation is greater than it is in subsequent years (because of those electrons etching those gutters on the pool felt) and we see that process reflected in year-over-year module performance warranties.

However, workmanship warranties should not be ignored either, as this is typically what you are purchasing when you go with a higher-end solar panel. Workmanship warranty address build quality, such as if the module frames started to come apart due to long exposure to the elements near the end of its life cycle. the standard workmanship warranty on a solar panel is only 10 years, what higher-end manufacturers greatly extending the length of this warranty to 25 years or even more.

Even the best warranty may not be a full model replacement, but rather compensation for lost electrical production. The manufacturer could go insolvent, although there are third-party holders of warranties. And even if you had a basic warranty, most warrantable module issues occur within the first few years of operation, and would reduce the performance of a module well below its performance warranty.

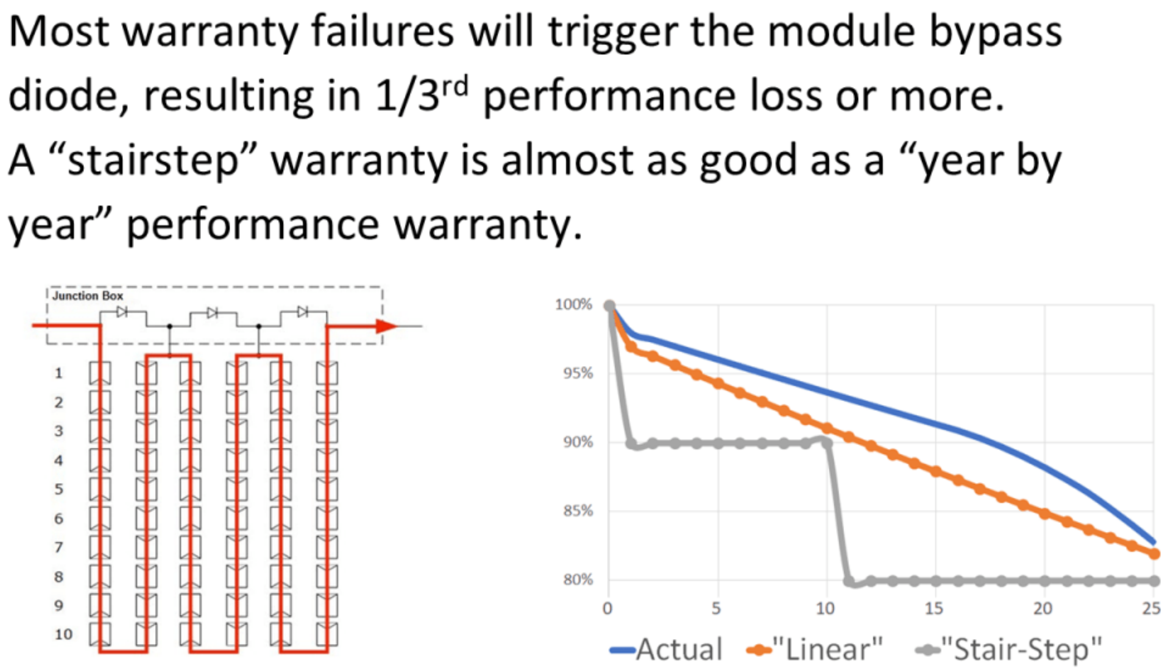


Figure 41 - Bypass Diodes

When a solar panel fails what is most common is that some little soldered connection from one cell to the next pops. What that's going to do is it's going to put a blockage in the circuit and your solar panels have **bypass circuits** so that if part of the panel becomes shaded, the rest of the panel remains on. That *cannot* necessarily be a huge benefit because just like one cell failing in the panel having impacts on the rest of the panel. One panel failing in the circuit can have impacts on the other panels in the circuit and so one part of the module being shaded will take the whole circuit down by one third and generally shading is going to occur on the whole panel and not just one little part of it.

But I guess what I'm trying to say by this is if you do have a little solder point pop and it takes out a third of the panel, well that's going to trigger your warranty regardless of if it's a stair-step warranty or a year over year warranty. And so, whether it's a 90% for 10 years than 80% three-year 25 or 97% year 1 96% year to 95% year 3, either way you're going to be covered. If a solar panel arrives on site defective because it's not just a half percent that's going to be defective it's going to be a third of the panel or so. The panel's producing 2X the voltage of what it should be and that's going to be covered under your warranty whether it's the most aggressive warranty or the most conservative warranty.

My general preferences to go bargain-hunting for solar panels, because I feel the difference in price is greater than the difference in value. However, in hard-to-reach installations, as many rooftops can be, spending more money on a higher-end warranty could be worthwhile.

Further exploring the specification sheet, Designing projects by the pallet or container can be more economic than a custom design.

Packing Configuration

	30T	40T
Container	40' DRY	40' H/C
Modules Per Pallet	25pcs	25pcs
Pallets Per Container	26pallets	26pallets
Modules Per Container	650pcs	650pcs

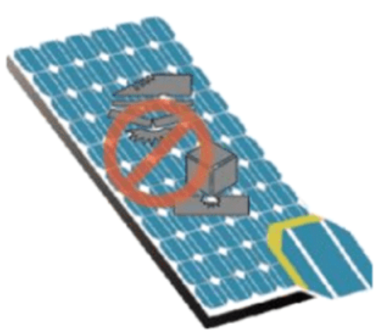
Figure 42 - Packing Configurations

I find this to be really useful: how many modules are in a pallet? When I do designs, I try designing an array that both pleasingly fits the rooftop, but also uses a full pallet of solar panels. Not all installers do this. Again, this is something I do to cut costs. So, my customers usually get a 1 pallet or 2 pallet option or 3 pallet option and that might be a $25,000 project, $32,000 project, or a $38,000 project. Because I can go to a solar liquidator and buy a pallet but not an individual piece. Sometimes, I can go to a mainstream distributor buy by the panel rather than by the pallet, but it costs more, sometimes 50% more! And shipping by the pallet is easier.

INSTALLATION MANUAL

PV Module Installation

SN Model Version 1.0 / 2015



[Caution]

Do not place heavy objects on the module.
Stepping on or allowing objects to fall on the module may damage certain parts of the product and slow down the performance significantly, or causes risks to the whole system.

Figure 43 - Common Handling Error

A common audience question is, “Is the performance affected by workers stepping on the panels during installation?” The answer is yes. That’s the danger of the installer getting too comfortable with the solar panel, as these failures can occur at the microscopic level so you’re going to have a solder point pop and you really can’t identify it with the naked eye. You could use a thermal imaging scanner to see a hot spot on the panel that would reflect open circuit voltage which would it reflect a popped soldered connection, but you wouldn’t be able to just look at the panel and see a wire that’s not connected in there.

On ground mounts the same thing can happen. You can get the ground mount built and then your workers might be leaning or sitting on the solar panel and think there’s nothing wrong because the panel itself is strong enough to withstand hail. But there could be a crack in the cell and sometimes the cracks in the cells don’t matter, like the snail trails earlier and the panel will keep working. Other times, it’ll result in the connection being completely destroyed and that results typically in one third of the voltage dropping out on the panel. Always try and put the weight on the actual frame and not on the surface of the glass!!

But what’s more likely to happen is that the installers on the ground get a little too lazy handling the panels, lean them up against the wall and a big gust of wind comes over and blows them over and they smack onto the ground and shatter the glass. Or, you’re unpacking them out of the box and then putting them onto a lift to lift them up onto the roof and you jerk the lift and the panels bounce up and down and how if they’re loosely stacked then yes, they can break. I’ve seen a bolt get underneath a panel frame and shattered the glass. Usually it’s going to be something like that, rather than putting weight on the surface itself, but it is somewhat common and this is another reason why I like ordering by the pallet, because they shipped to sight in a more organized fashion than when shipped loose. Loose solar panels might be stacked and shrink-wrapped and then the shipper may put additional boxes on top of the panel surface itself, resulting in damage during shipping.

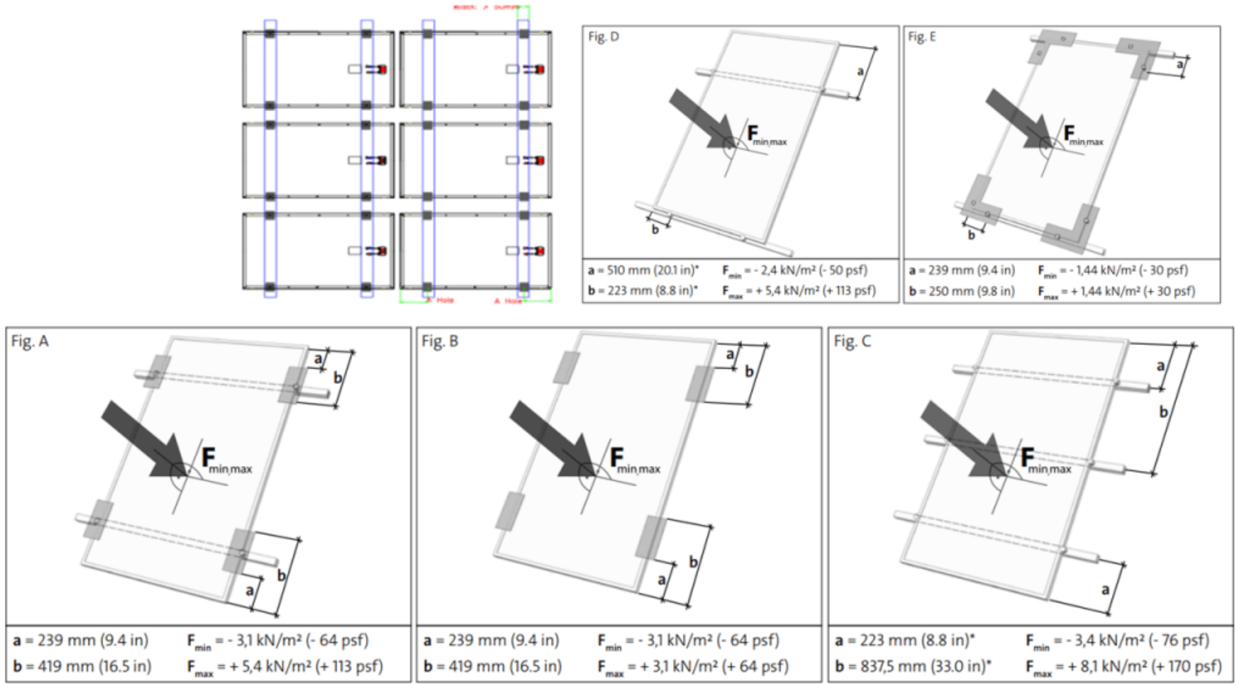


Figure 44 - Window Load and Clamp Zones

So, the module spec sheet will give you a force load rating for the panels and likewise you're racking manufacturer can give you different load ratings on the panel based on how the racking is used. If you need more strength, such as in a heavy snow or hurricane prone area, you may be able to add additional reinforcement, or find that a traditional rail mounted solar array is not even necessary for your roof. You may be interested in these figures if you want to mount the array a certain way to achieve a particular aesthetic.

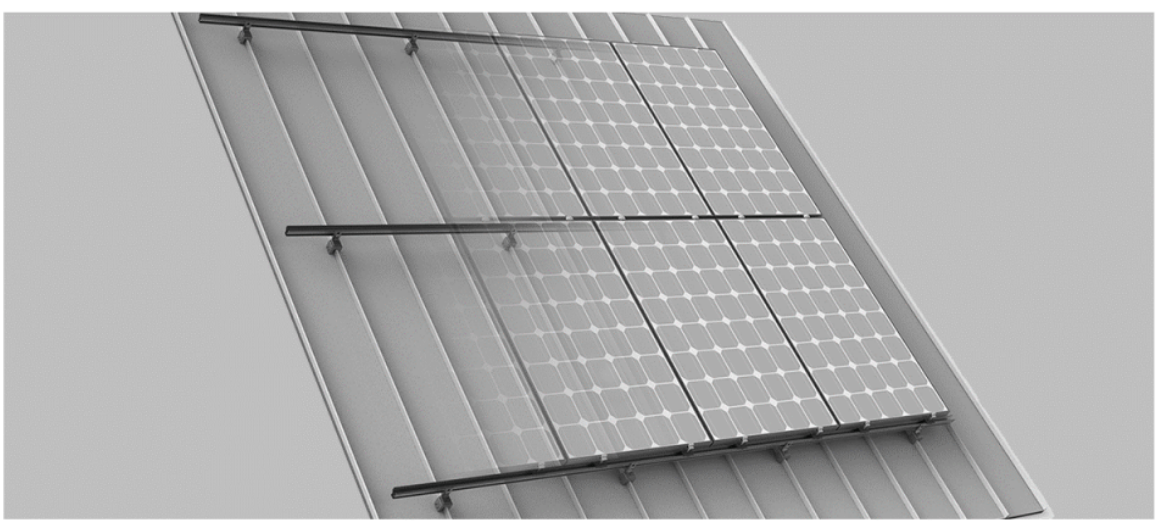


Figure 45 - Shared Rail Configuration

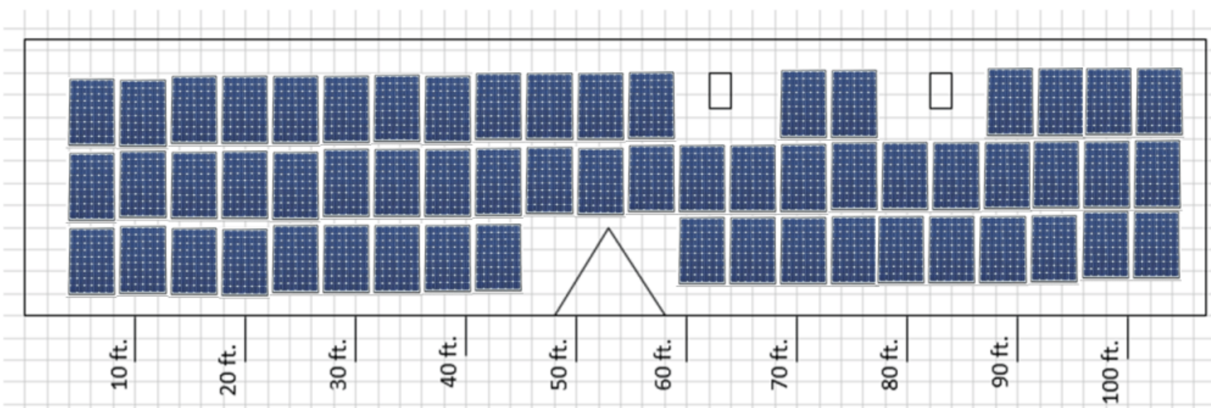
One advanced racking type is called a **shared rail racking** system where normally you're going to have two rails per module and they're going to be about one foot in on each side. With a shared rail system, you get rid of one of the rails, so that might mean fewer attachment points onto the rooftop and you save the cost of the rail, although the increase in labor cost is often greater than the material cost savings of a shared rail system. One of the more frustratingly difficult aspects of solar installation is keeping perfectly straight rectangles and perfectly straight lines on top of a wavy roof.

Now when I look at shared rails I think they're neat in the sense that normally there is an air gap between your modules on top of rack and so rainwater can fall into that gap and get underneath the array, but if you use a shared rail system at least for this gap, you can collect the water inside the rail and gutter it down to the bottom of the top. Worth enough forethought put into flashing and flashing tape, a watertight solar array can be integrated into the roof of a building, perhaps using bifacial solar panels to increase the aesthetic. I don't know any installers who are doing this. I'm waiting for my first client who will let me do it with their garage rather than their house. Shared rail is harder to install. You have to be very, very precise for it to line up correctly.

Figure 46 - Rail-less Racking Example

Another unconventional racking system is a **rail-less racking system,** where you just put supports down onto the roof rather than the rail itself. Most residential installers are not fans of the railess system because you have to be more precise. Most rooftops are wavy. So, rail is helpful because if you get the rail square, then the panels will go on square. But it so happens that on a standing seam metal roof top, railess is better structurally for load distribution. There aren't real cost savings involved because you are buying and installing more attachment points to the roof. These attachments let you clips onto the roof instead of penetrating into a structural support member. Rail-less is something that you should do when your rooftop is unconventional, rather than as a standard design practice on a slanted roof.

Array Layout



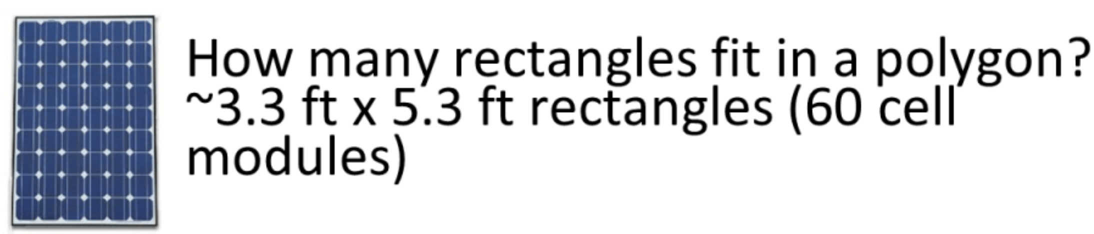


Figure 47 - Array Layout

So, let's talk about racking design. Now a very high-level solar design is how many rectangles can you fit into the larger polygon, (laughter) so that's not too mathematically challenging, particularly for an engineer. There is some **shade analysis** although many rooftops are not shaded. I generally do shade analysis with 3D modeling using **design software.** It's not always available in rural areas but Google Earth does its 3D buildings and trees and stuff, so you can, from the comfort of your desk, do a site evaluation with regard to shade.

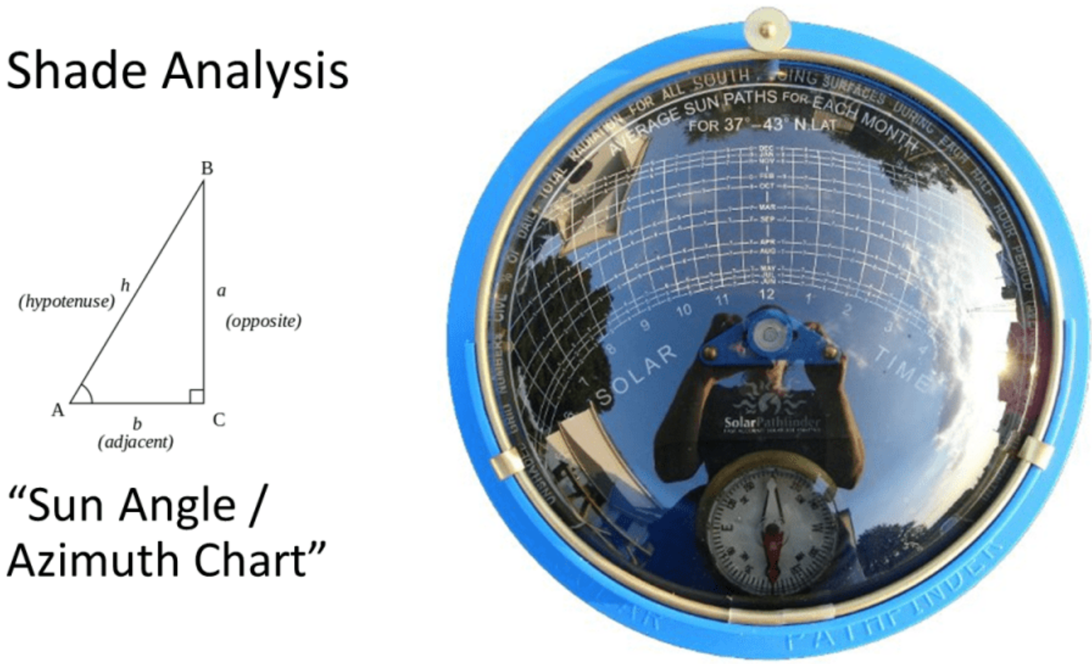


Figure 48 - Shade Analysis

The analog way to do it is to this device called a **Solar Pathfinder** and use its chart and a reflective dome. the x-axis has hours of the day and the y axis has months of the year, and where these shadows fall on to the chart will tell you what hours of the day and what months of the year you get shadows exactly where you're standing on site. And so, what we can see is this in June and July, because of this tree, the solar array might normally come on at 7 a.m. although with spring forward that might actually be closer to 8 AM and then in December the solar array may not be turning on until 9 AM. Shade from this nearby house is not as big of a deal breaker as it seems. Generally, what you're trying for sunlight at least from 9:00 AM to 3:00 PM as the best solar window every day. The solar window is narrower in winter and wider in summer so maybe a better one would be from 9:00 to 3:00 in the winter and then from 8:00 to 4:00 in the summer. This is a fairly unshaded spot, but once the Sun gets into those branches there, it'll turn off the array even though the tree will lose its leaves, the branches will still diffuse the sunlight.

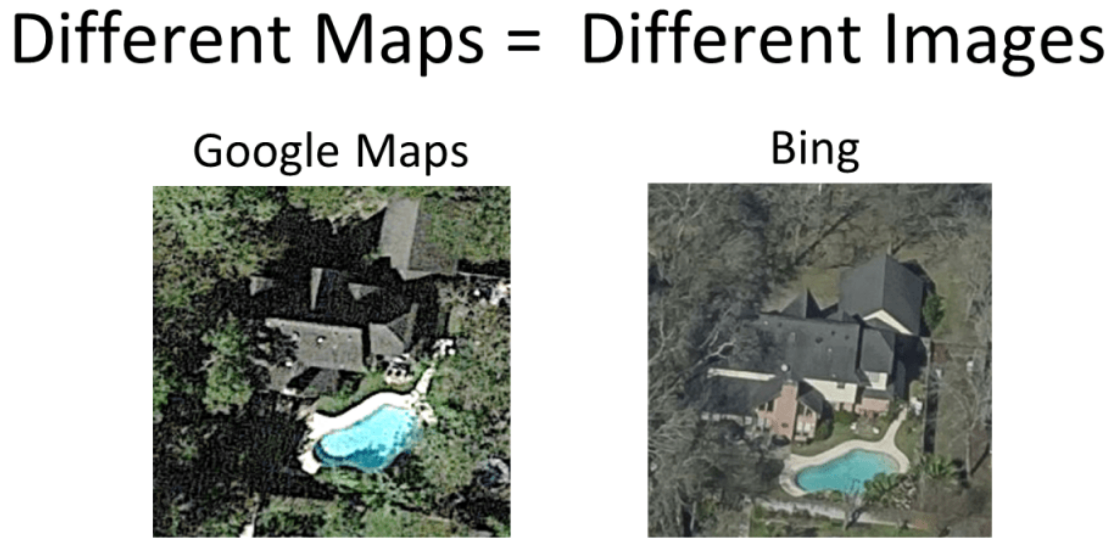


Figure 49 - Overhead Site Images

You can also use good old-fashioned trigonometry for shade analysis. A few things: one is Microsoft has a map software search engine and it will often have more clearly defined pictures than what Google Maps or Google Earth will have.

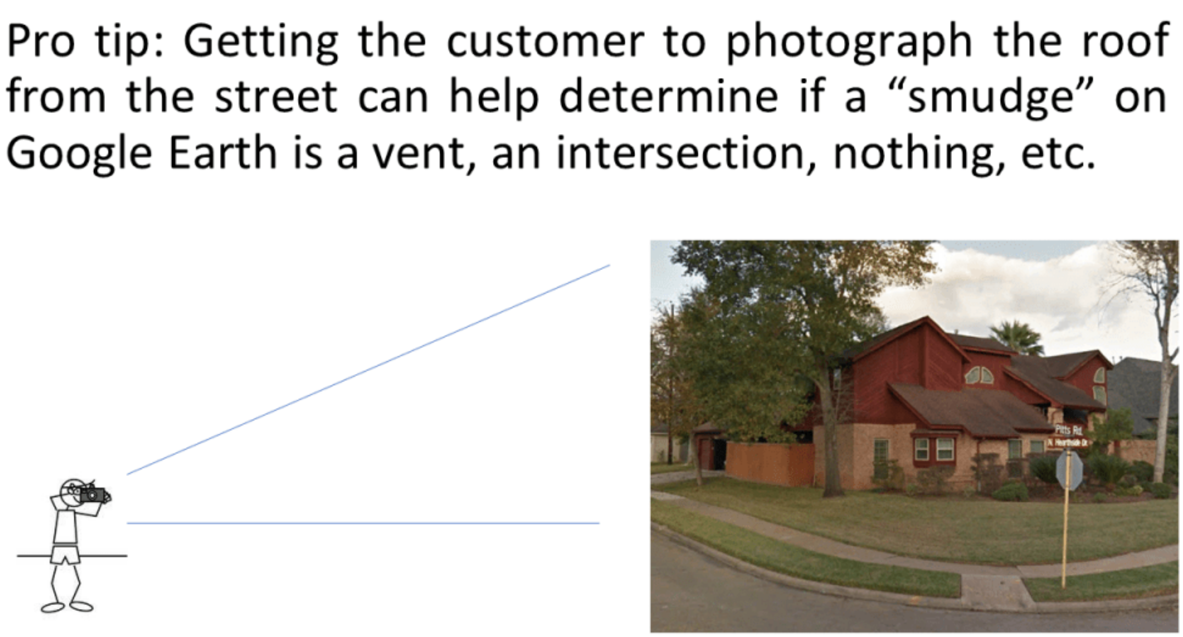


Figure 50 - Street View Resolution

Also, it’s always useful just to tell the client to take a few steps away from their house and turn around and take a picture of the roofline. Good on-site photography will tell you what’s going on.

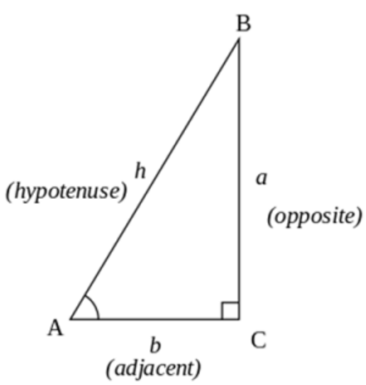
Using Google Earth, you can determine

1) Length of a shadow,
2) Compass orientation (azimuth)
3) Date of photo

Figure 51 - Identifying Tree Height

I have a Google Earth trick I use frequently. If I’m looking at Google Earth and I see a tree, then I want to know the height of the tree. Commercial solar software has LIDAR data in it, but we can use trigonometry to start figuring things out like building or tree height.

It is even possible to determine tree height remotely!



USNO

“Sun Angle Azimuth Chart”

Figure 52 - Solar Trigonometry

You can find online charts that are called Sun Angle Azimuth charts. The US Naval Office puts out a really good one. So here we are on Google Earth. We put in our address and if I want to find out what the height of this of this tree is, I can use the Google Earth ruler tool to measure the length of this shadow which Google Earth is telling me is an 80-foot shadow.

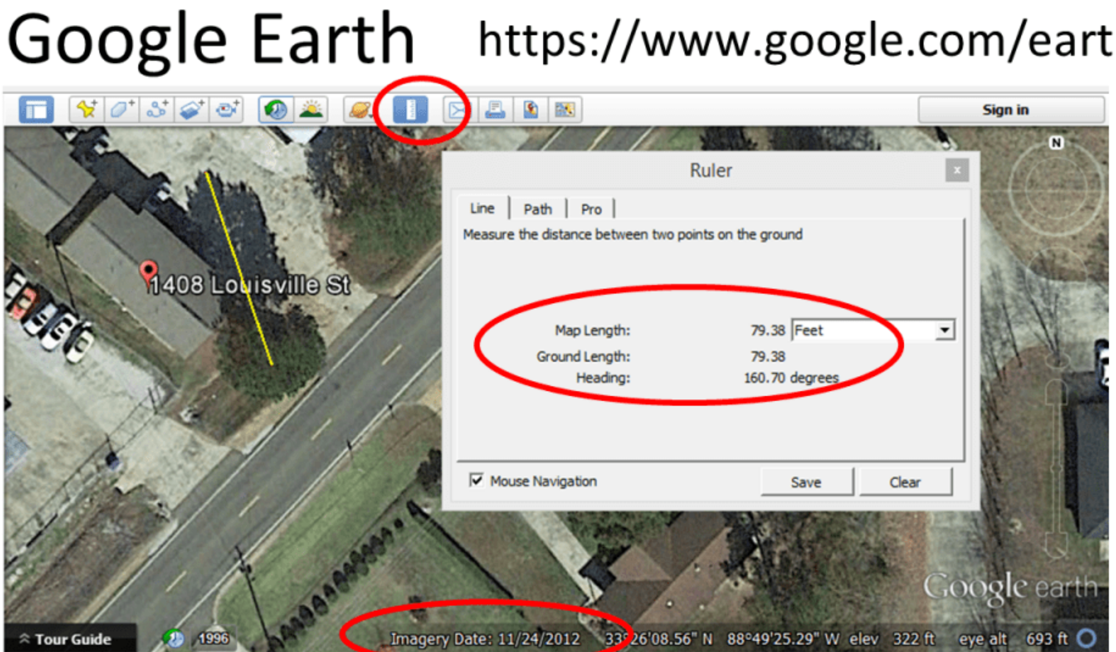


Figure 53 - Google Earth Information

The Google Earth ruler tool will also tell me the heading of the shadow or the azimuth of the shadow so it's going to add a 160° with 180° being due south. Then Google Earth will also tell me, circled in red at the bottom of the picture, the date the image was taken. So, this shadow of this tree was taken on November 24th 2012, when the Sun was at 180° and the shadow was measured to be 80 feet long. Next, google Navy Sun angle azimuth chart. Here we are using the chart and I'm putting the date the picture was taken.

Put the date stamp into a "Sun Angle Azimuth" chart

http://aa.usno.navy.mil/data/docs/AltAz.php

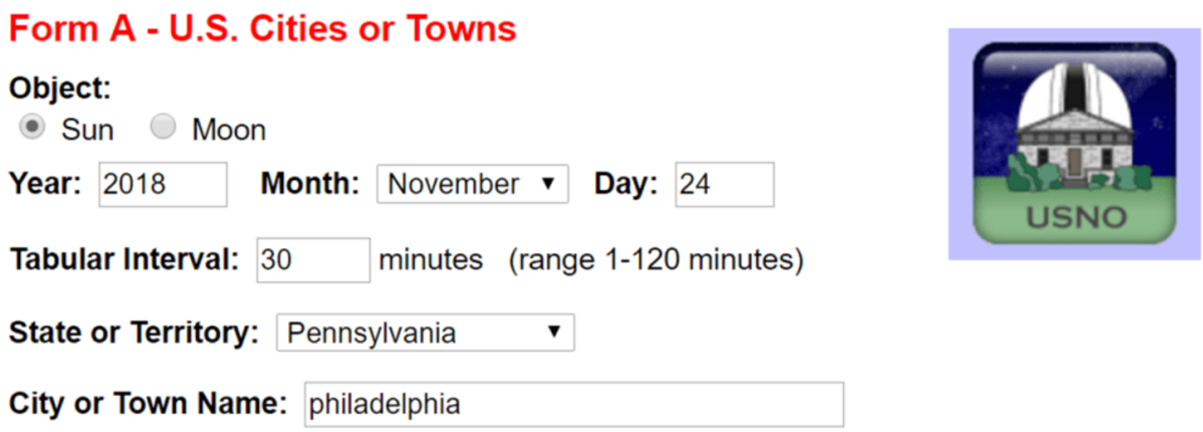


Figure 54 - Sun Angle/Azimuth Chart

Let's say Google Earth told us the photo was taken November 24 2012 in in Philadelphia, Pennsylvania and remember the bearing of the shadow was at 160°. We can now find the altitude of the sun as and so what the altitude and azimuth of the Sun.

PHILADELPHIA, PENNSYLVANIA
W 75° 09', N40° 00'

Altitude and Azimuth of the Sun
Nov 24, 2018

By combining the data from Google Earth with a sun angle/azimuth chart, we know the sun was at 27 degrees when the photo was taken.

h m	o	o
09:30	21.5	145.5
10:00	24.5	152.4
10:30	26.8	159.7
11:00	28.4	167.4
11:30	29.3	175.4
12:00	29.3	183.4
12:30	28.6	191.4
13:00	27.1	199.1

Figure 55 - Determining Sun Angle of Elevation

The chart shows that when the sun was at a 160° bearing, it was 27° up in the sky. So, although Google Earth won’t tell me what time of day the photo was taken, still I can determine the elevation of the Sun. So, if I know the elevation of the Sun and the length of the shadow, I can use trigonometry to calculate the height of the tree.

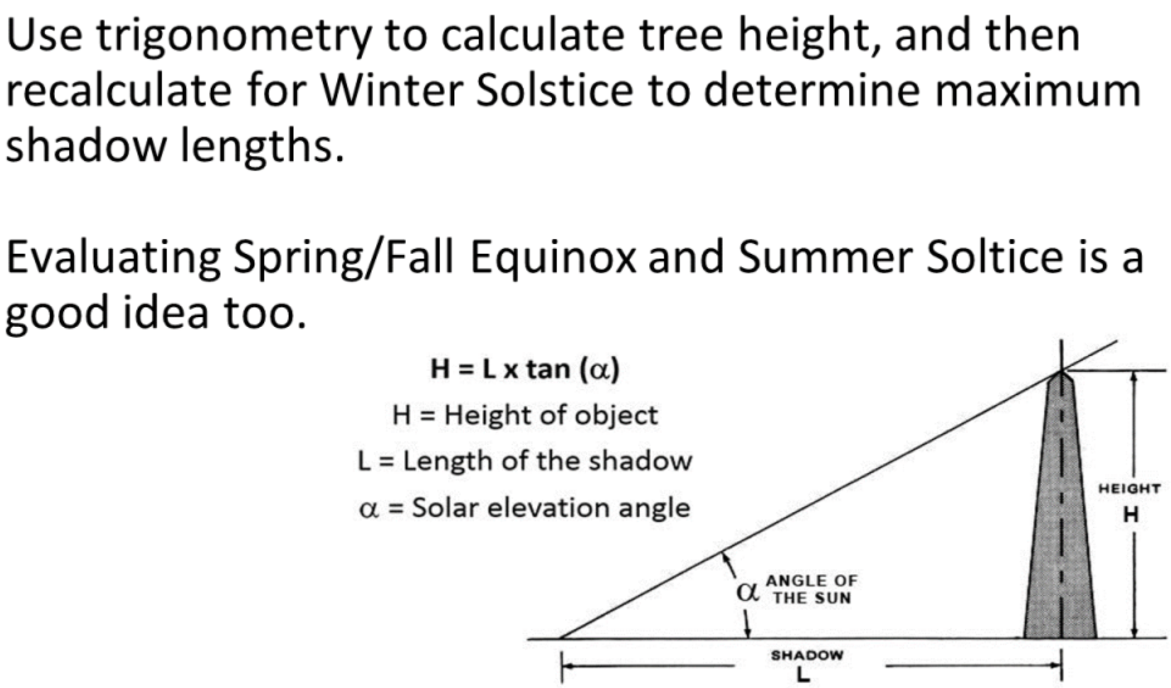


Figure 56 - Determining Shadow Length

I can use the same technique to the height of the house. Don’t forget to subtract the height of the house from the height of the tree.

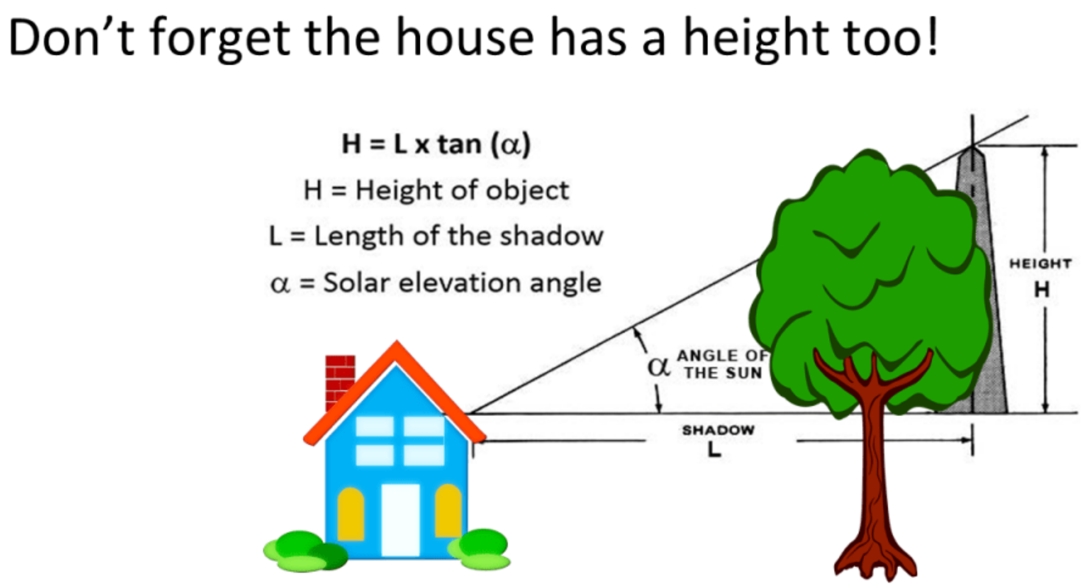


Figure 57 - Roof Height

So, if you don't have access to fancy solar design software you can get an idea your tree heights and shading before getting out to the job site. Oregon has a good guide for converting shade objects into PVWatts loss… But if there is also of potential shade, I think it's best to use commercial design software for your shade model. Helioscope, for example, gives a free trial.

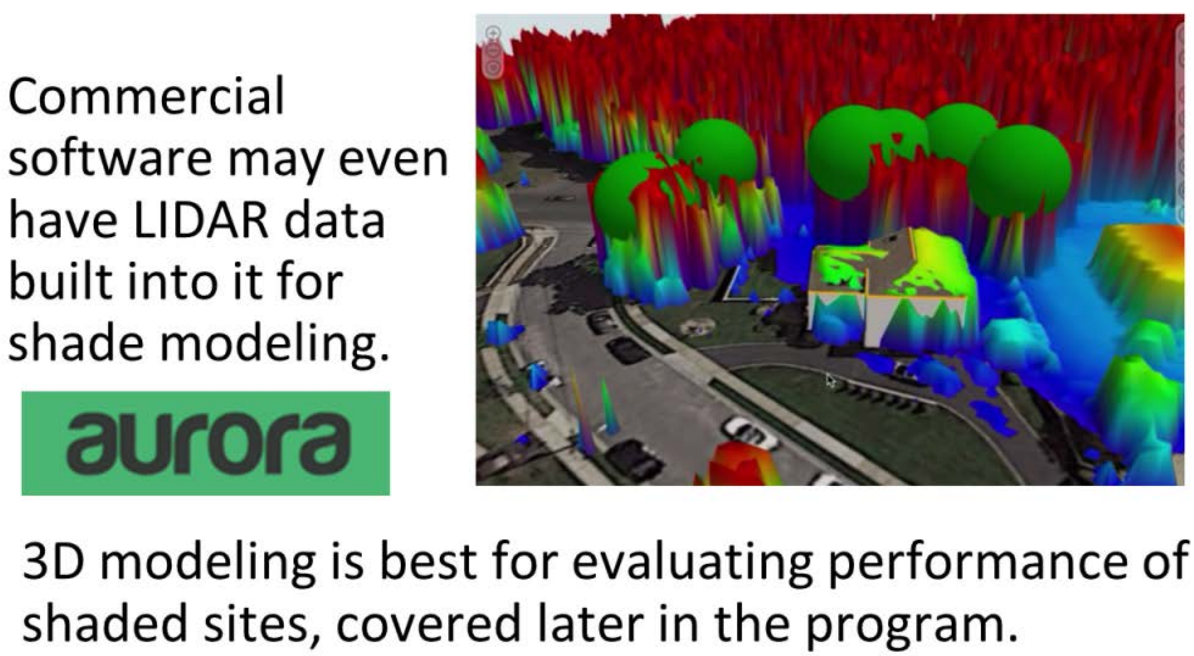


Figure 58 - LIDAR data

Then again accuracy is a relative term because trees grow, so you might not have to be as accurate in your shade analysis. What you need to do is overestimate your shade analysis because the trees will grow over time.

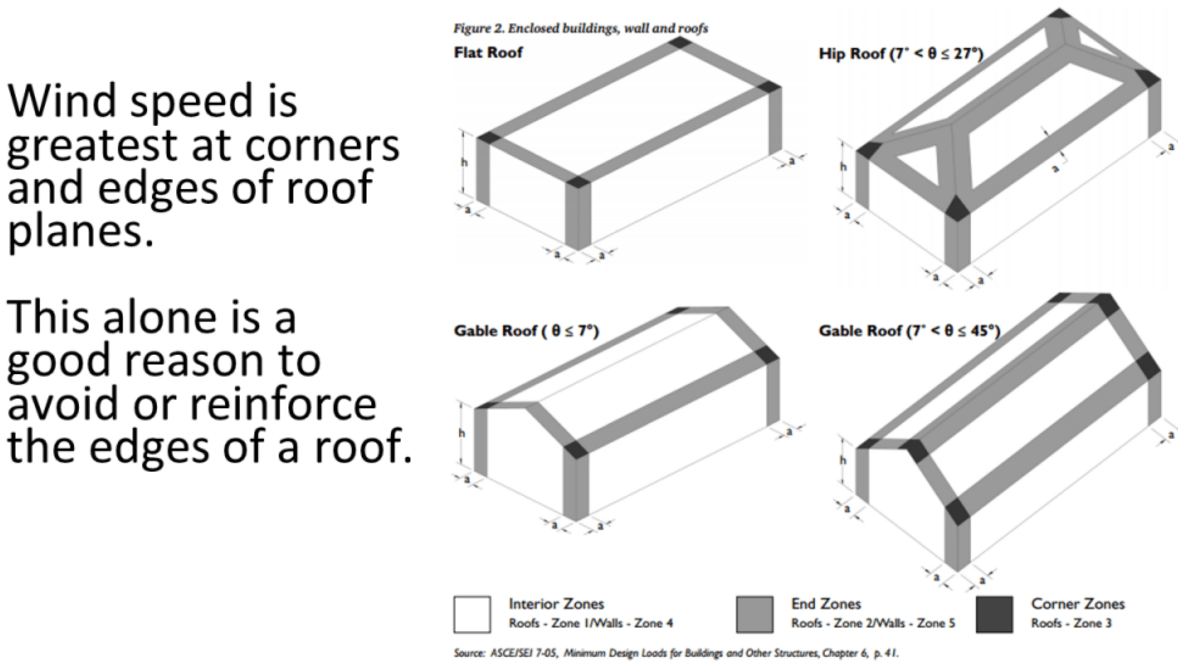


Figure 59 - Roofing Zones

Wind speed is greater at the corners and the edges of the roof rather than in the middle of the roof and some local fire code will require you to stay off the edges of the roof. There are ways around it, like forced air side vents in the Attic. But the bare-bones, most basic way to get the smoke out of a house on fire tis to get to the top of the roof and cut a hole in it. If there’s a solar array covering the roof, the concern is they can’t do that and so that’s been incorporated into residential code to say you have to stay 3’off the sides and 3’off the top of the roof at minimum.

Many fire departments require roof access as part of local or international building code.

Figure 60 - Fire Access

To some extent, it is wise to leave an offset from the edge of the roof to the top and sides anyway. There is less wind load, and the extra space is welcome when servicing the array of every needed. If your roof overhangs the side of the exterior wall by three feet, that's going to be a weaker area to penetrate anyway and so why not just leave it for the fireman so they can cut their hole in the roof? And remember it's 3′ off from on both sides and the top because the fireman needs two ways to access the same roof plane. They don't know what's on the other side of the roof. They need to be able to go up one side, get across and then come back down a different way.

The result is a common rule to stay 3' off the sides and top of the roof. There are exceptions, but this is a good starting point.

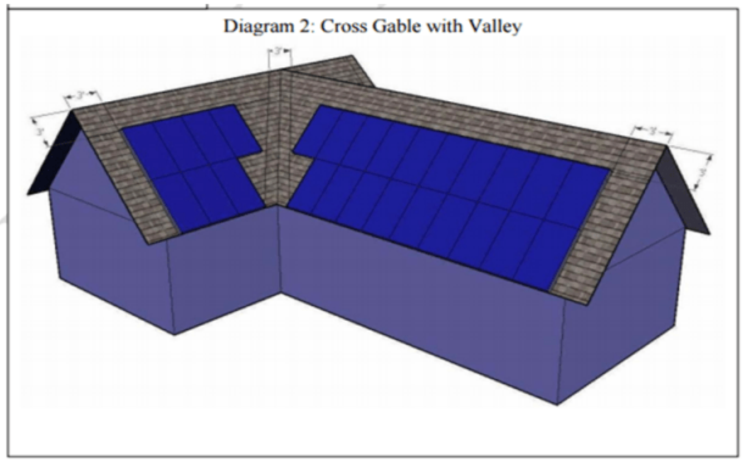


Figure 61 - International Residential Code

Fire code is a little more flexible than that, though. On a hip roof rather than a gable roof you can go all the way to one side without an offset, because on a hot roof, unlike a gable roof, you only have one hard edge with the other being a 45° step to the next roof surface rather than falling off entirely. But even in a roof valley, where you only need three feet offset rather than six, having a little extra space can be useful.

You don't really want your solar array to be inaccessible in case there is a maintenance task you have to perform when you're up there, Now, hopefully there's not going to be too much maintenance to do up there. If there are trees around your house and you get squirrels up there, yes there are squirrel guards. I'll show you in a little bit but at the same time you can't plan around everything. For one thing, code is encouraging the use of little electronic boxes behind every solar panel on the rooftop. That can help with de-energizing the array during the fire but also puts a failure point on the roof. Being able to get up on the roof and service that for one solar panel is not absolutely required but often useful. Otherwise, you would just start at the bottom, remove a few panels and then work your way up.

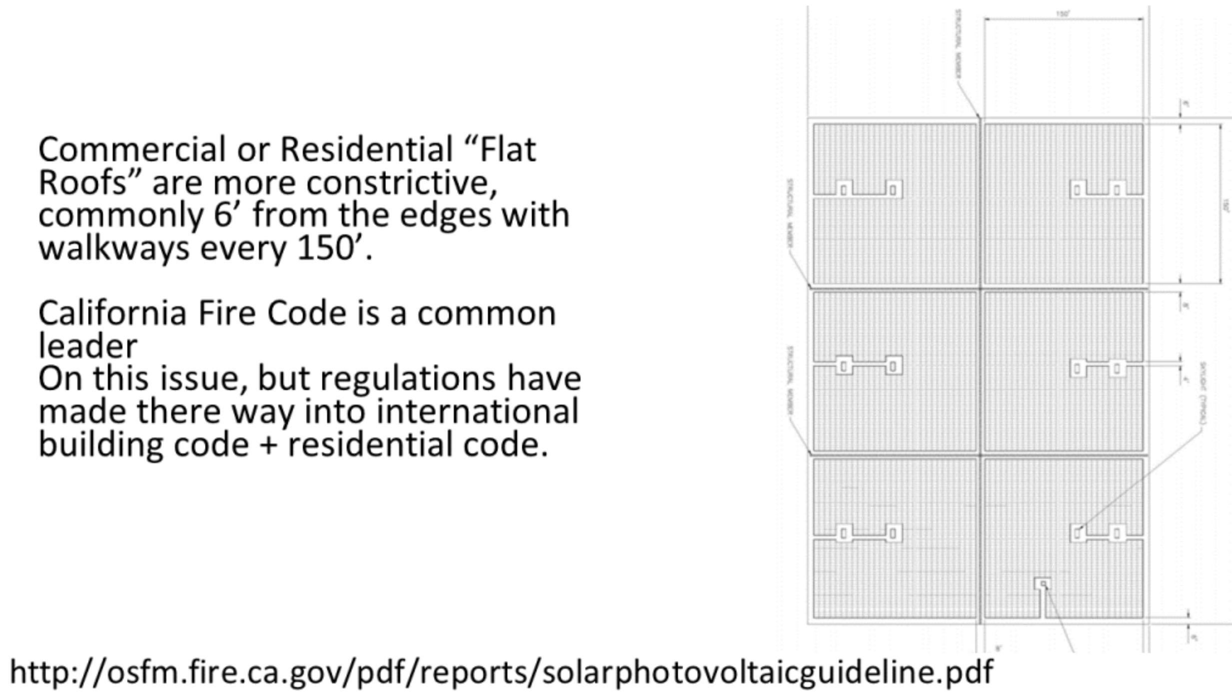


Figure 62 - Flat Roof Clearances

Commercial buildings have offset requirements too, and that makes a lot more sense as well, because there's work done on a flat commercial rooftop. There are air conditioner units that need to be serviced that you can't box in. Water drains that should be worked around rather than over. You need 4' pathway requirements to get to your air auditioning units. Every 150', you need a walkway. The standard walkway is 8' but it can be 4' as long as you're putting little cutouts for the firemen every 20'. You have to be 6' from the edges, rather than 3′ from the edges in residential, because you expect more walking around on this flat roof on a regular slanted roof.

Some safety codes seem a little excessive but there's actually been a few solar fires that have burned down some commercial buildings. One big one was the Dietz and Watson 11 alarm fire in New Jersey in 2013 or the Bakersfield Target solar roof fire in 2009.

These fires occurred for a few reasons. What most solar installers know is that you have a combiner box where all the circuits come into before going down to the inverter and the old style inverter had a ground fault circuit in them that was grounded to negative, and what would happen under a very rare circumstance is one circuit on the rooftop ground faulting to ground would the ground fault detection system to fail. Then all of a sudden you get all of the circuits of the array feeding into that ground fault without a good means of disconnection and it start a fire that burns the building down. So, most inverters are no longer negatively grounded and instead are floating, with the ground fault detection isolated from ground.

The ground fault detection blind spot fire in older commercial inverters allowed the fire to spread, but it began with the very hot *metal conduit* the rooftop home run cables were run through. The cables inside the conduit would expand at a different rate than the EMT conduit itself. This EMT conduit worked its way out of it's fitting and cut into the cable. Thermal expansion is a consideration at 120′ or greater.

So, these walkways are not just for access but also to ensure that you have broken up your metal so that thermal expansion doesn't rip your homerun circuits apart.

After excluding heavily shaded areas, remove 3' off the top "ridge" and side "rakes" of the roof. It is nice, but not mandatory, to have leave access to the bottom gutter of the roof. Other roof mounting equipment, skylights, and vents should also be accessible for maintenance.

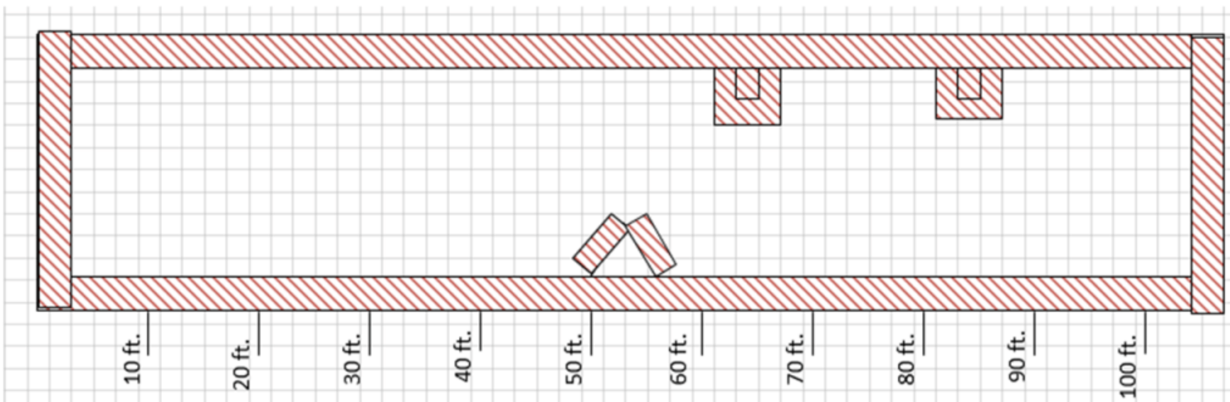


Figure 63 - Determining Array Area

If your commercial building has a slanted roof, it might qualify as a residential type roof, so we'd stay 3′ off the sides and 3′ off the edges. If using commercial clearance requirements, we would have stayed 6′ off the sides (which is also OSHA friendly) and then also stay at least 4' around the skylights, to produce an array like so. And since I had a little bit of space left over, I shift the whole array slightly over to center this panel right above the doorway to make the array look a little squarer from the ground.

From that point, the game is "how many rectangles fit into your remaining roof area"?

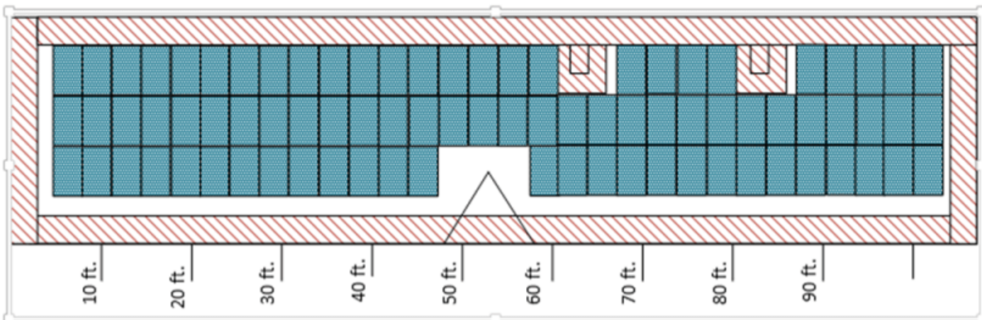


Figure 64 - Determining Array Layout

The general contractor should be able to figure out the starting point of the array. On particularly long or difficult array layouts, some installers will start in the middle of the roof and work outwards to ensure they are on center, but what's more traditional is just to start on one side and work your way down in order to preserve that square-like appearance. Now one of the problems I ran into with this design is even though you stay away from the skylights all of a sudden these clearances around the skylights become walkways and so it's not just you don't have to just think about if the attachment through the roof is going to cause a leak. What is much more likely, because that solar installer is making that attachment and we're assuming they're good at their job they're doing what they should be, it's a brand-new attachment generally what leaks is the pre-existing stuff on the roof. This is because a roof is not designed to be a jobsite.

Figure 65 – Finished Array

When you get a team of workers tromping around on this rooftop around existing penetrations, that can be bad for the roof and so what I incorporated into my design was actually removing the skylights, and then we put more solar panels there and it was probably for the best that we did that. But, even walking around on a shingle roof can be bad for the roof.

The shingles protect the roof and when you walk on those shingles it gets grit off them, so that's one reason to cover the whole roof, is that you're then shielding the shingles with your solar panels instead of leaving them exposed to sunlight. What I try and do now is instead of assembling the whole thing on the rooftop, we'll do is as much on the ground pre-assembly as possible. So we'll build our rails and mount our electronics at attachment points all onto our rails as much as we can, depending on what lift equipment we have, we'll do it all in one piece or into maybe three pieces but do as much on the ground pre-assembly as possible to reduce the time spent on the roof itself.

	Retail Rate	Net Excess Generation Rate
January	$ 0.09	$ 0.03
February	$ 0.09	$ 0.03
March	$ 0.09	$ 0.03
April	$ 0.09	$ 0.03
May	$ 0.12	$ 0.05
June	$ 0.12	$ 0.05
July	$ 0.12	$ 0.05
August	$ 0.12	$ 0.05
September	$ 0.12	$ 0.05
October	$ 0.12	$ 0.05
November	$ 0.09	$ 0.03
December	$ 0.09	$ 0.03

Figure 66 - Seasonal Electric Rates

Electricity pricing varies by season. South-facing gives you the most production, but the value depends on your solar buyback rate, a function of your net-metering policy. To find your policy, there is a website called the DSIRE database at dsireusa.org worth checking out.

As an example, I chose Illinois, and here's a list of all of Illinois' green energy policies, as well as the federal. So, you can find out information unlike the US tax credit stuff. I won't spend too much time sorting through here, but I just type **net metering**. The federal government does not regulate the price of electricity. That's left to the states. So here we have Illinois's net metering policy, and it applies to a variety of on-site generators up to two megawatts in size. There are some limits and net metering is a controversial policy. This has to do with what generation is pushed onto the grid by the solar array.

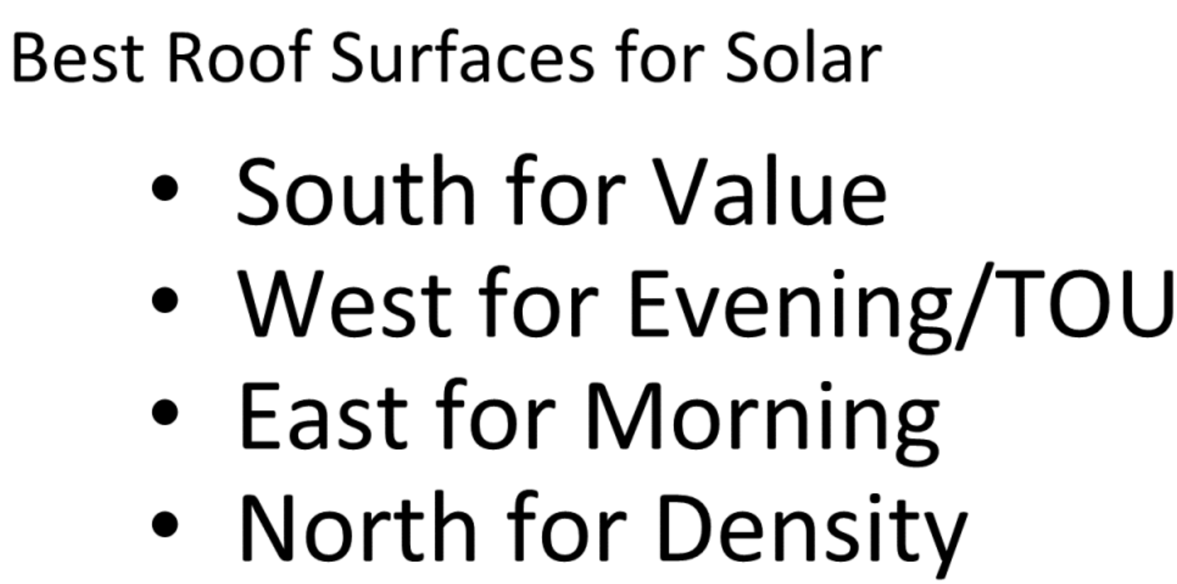


Figure 67 - Rooftop Reasoning

If you're if you're trying to offset 100% of your electric bill, but the solar array is only on for 1/3 of the day then de-facto 2/3 of the solar production is going to be pushed on to the grid. So, how you're compensated for that 2/3 of the production becomes a controversial issue. You can view net metering as a consumer protection law that entitles the solar owner to better than default compensation. So, with an Illinois net metering policy, they say if you are in a monopoly, you're credited at retail up through 12 months. If you are on a non-monopoly, if you're on a deregulated market where you can choose your electric provider. It's credited at **avoided cost** at the end of the month. Now in Mississippi, the net metering policy is defined as no net metering, and we're credited at avoided cost not at the end of the month but rather instantly.

So, the instant we're out-flowing onto the grid we get avoided cost as compensation whereas in this policy for Illinois, customers are credited at avoided cost at the end of the month. They subtract what you put onto the grid versus what you bought back, and any surplus is credited at avoided cost and so only a small fraction is credited at avoided cost and not the whole amount of outflow. If you're in a monopoly they say because you're in a monopoly, you get more rights than in a non-monopoly and so you get credit at retail rate throughout the year until the end of the year.

This gets complicated because: what's defined as the end of the year? They could define the end of the year as the end of spring or the end of fall instead of the end of December. So, even when you have a net metering policy that entitles you to outflow there's more to the story. That's why I'm love doing work with batteries and off-grid, because we don't have to involve ourselves with that whole debate on whether it is right for the power company to charge you $.09 cents but only buy back at $.03 cents or to charge you at $.12 cents but only buy back at $.05. Someone's going to be unhappy either way. Whether you have net metering or not I believe if you're in a monopoly you should have net metering, and if you are not a monopoly then I can see why you would not have net metering.

Where it's playing out is in Houston, Texas, where they don't have any net metering laws but they have a deregulated grid. You get better deals for your outflow onto the grid than in Mississippi, where there is a monopoly but no net metering at all. There's a clear example of deregulation benefiting the customer, so if you're going to have a monopoly you should protect or entitle your customers to more rights than what they get the open competition. It's more nuance, but if you do have a good net-metering policy then south-facing will be the most economic array orientation.

If you don't get retailed compensation for your outflow, if you only get what the cost of the unrefined electricity is to the power plant, the cost of coal, the cost of the natural gas, before it goes into the power plant. That's the **federal minimum buy back**. The avoided cost of operation is what the federal government requires the power company to buy back your electricity. Then your net metering policy is a state policy that might entitle you to a higher compensation rate. If you don't have a net metering policy, south-facing may not be the best deal. A west facing array or an east facing array may be preferable when you have higher loads. You're getting up in the morning and running the air conditioner. At high noon there may be no one inside the house, and so an east facing array or a west facing array may produce less energy but will coincide better with your load and therefore produce less outflow.

Even though east or west may be producing 15% less, if the compensation for that outflow is 70% below retail, then that's not going to do you any good to produce more, and so I would I would caution solar designers in states that have net metering. Most states do, and net metering has changed solar design. In a similar way that any subsidy impacts the unsubsidized business model, the **30% solar tax credit** encourages solar installers to go for the top shelf. If I'm getting 30% off a Nissan or 30% off a Mercedes, I might go for the higher end product because I get that discount.

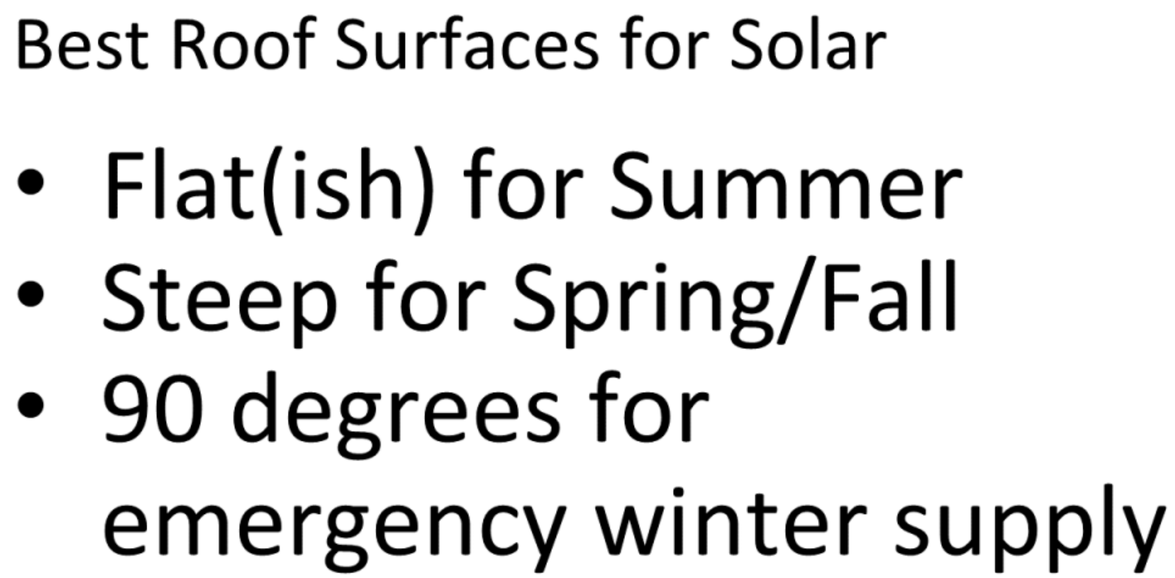
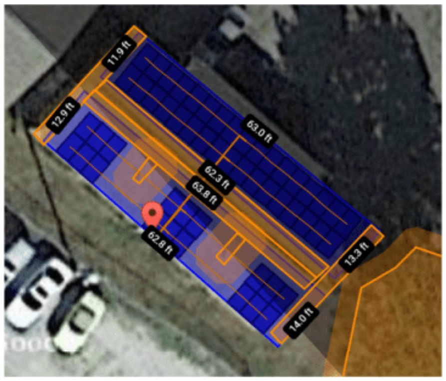


Figure 68 - Additional Reasoning

Similarly, if I'm getting paid retail price for all of my outflow, I'm going to design my array around what produces the most amount of energy, regardless of whether or not it's in sync with the consumer load, for better or worse. Now, that makes net metering sound pretty bad. Actually, it might be one of the best energy policies we could have as a society, so there's more nuance in that argument, but what I would say is don't just think about your solar design has to be south-facing There's more to the equation, particularly if your outflow rate is less than your inflow rate. For that matter, if you're doing an off-grid design it might be that you need the most amount of energy possible, and so you're just covering the whole roof. We made these arguments earlier on in the program but thinking about it even more unconventionally, if I'm doing an off-grid house, my most critical power may be in the winter.

I may just put the solar panels down the side of the building rather than up on the rooftop, or if I'm in New York City and I have electrical equipment covering the roof and I don't have any surface area on my roof but I'm in a tall skyscraper, the side of the building might be the best fit. So, all you have to do to confirm non-traditional design ideas is just do a PVWatts calculation, and say I'm producing 1.5 kilowatt hours. Let me let me go with New York City, and so, here I am in New York City. I'm during the 1-kilowatt array at a 10° tilt angle on a commercial flat roof facing south.

My solar array produces 1.24 kilowatt hours per watt per year. If I go with a 90° tilt and run it down the side of the building, I'm producing 938 kilowatt hours a year. While that's certainly it's less but we're talking it's 25% less not 70% less. So for that matter, New York City electricity pricing being over double what it is in Mississippi, if the solar arrays were installed at the same price (which I admit is a stretch for New York City compared to Mississippi) but if they were installed at the same price, a solar array going down the side of the building in New York City would be more cost-effective than one installed in Mississippi.



South 4.6 kW:
$4.50/W x 70% / [1.36 kwh/W/yr x $0.11/kwh]
21 Year Simple Payback

Total Roof: 13.3 kW:
$2.75/W x 70% / [1.19 kwh/W/yr x $0.12/kwh]
13.5 Year Simple Payback

Figure 69 - Economies-of-Scale

Don't be afraid of being creative with your array layouts! Let's put some numbers to these **economies of scale.** Let's just compare, doing three little small array sections on the south side of the building versus covering the whole roof with solar. So, we would be looking at a 4.5-kilowatt array. That's a small solar array. There's a minimum amount of money that you have to make to get up onto a roof and put solar panels on it. I might charge $2.75 per watt for a 13 kilowatt or $4.50 per watt for a 4.6 kilowatts and so if I do this small solar array at a substantially higher price, even though it produces more energy, it's going to have a longer payback than if I do the larger array at a lower price. Even though it produces less energy per watt, the larger array is more cost-effective because of the discount that I've achieved due to economies of scale.

So, the basic way that solar is attached to the roof is through this system of solar rail and brackets that are called L-feet. Ten years ago, integrated L-feet with flashing did not exist, but today the standard way to do it is to get an L foot bracket and mount it to some flashing that slides underneath the shingle. Now it is not a perfect process. If you are doing new construction with shingles get the solar installer out there to put these flashing in as their shingling the roof because otherwise you have to get up underneath the shingle with a pry bar and pry out roofing nails.

Racking and Structural

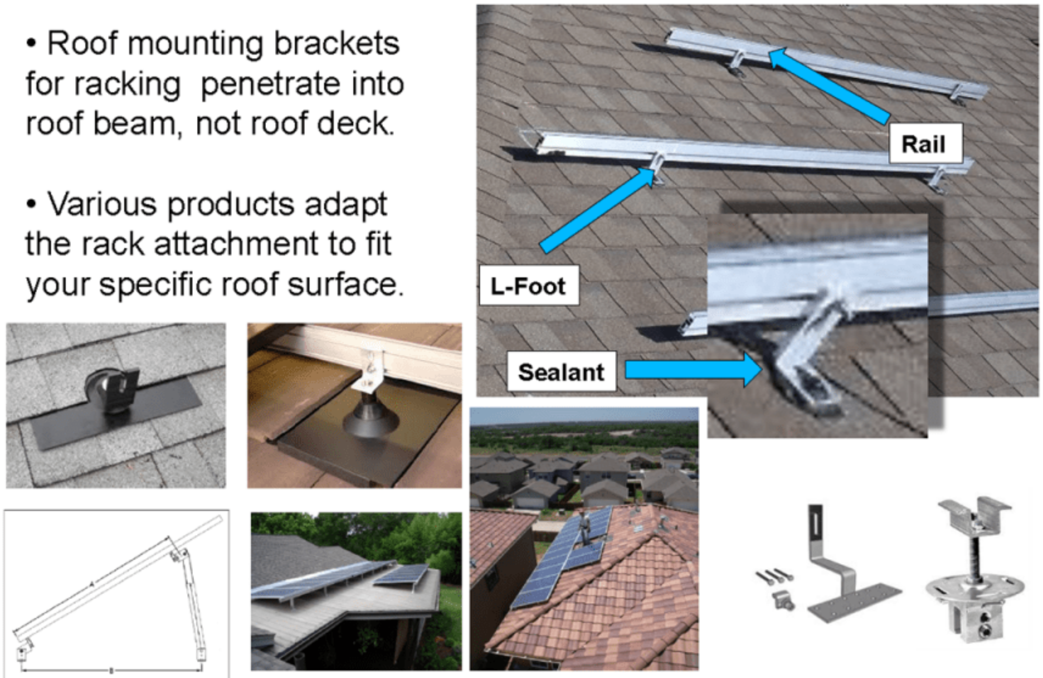


Figure 70 - Racking Basics

Particularly if the roofer is trying to do a good quality job and puts in a lot of roofing nails rather than standard, it becomes a nightmare for the solar installer. There are **above the shingle mounting systems** that some installers are using but this flash pad, it doesn't just go back to here, it goes all the way under this next course of shingles. That's a good distance to get that water away from the penetration. So, using flashed attachments as standard on a tile roof, you get a tile to replace your tile. They used to sell hooks that snake underneath the tile but that design has been phased out by the industry.

Instead they are using true tile replacements. There are manufacturers who specialize in making the tile replacements to fit the form factor of the tile you're using. On the bottom right, we see a clip that clips to standing seam metal roofing. Out of all metal roofs, standing seam metal is my least favorite to work with. We'll get into a reason why, but above the attachments you have the flushing, you got the elf foot, and then you have your rail. Regardless of the manufacturer you get clips that hook into this rail channel and they all do it a little bit differently.

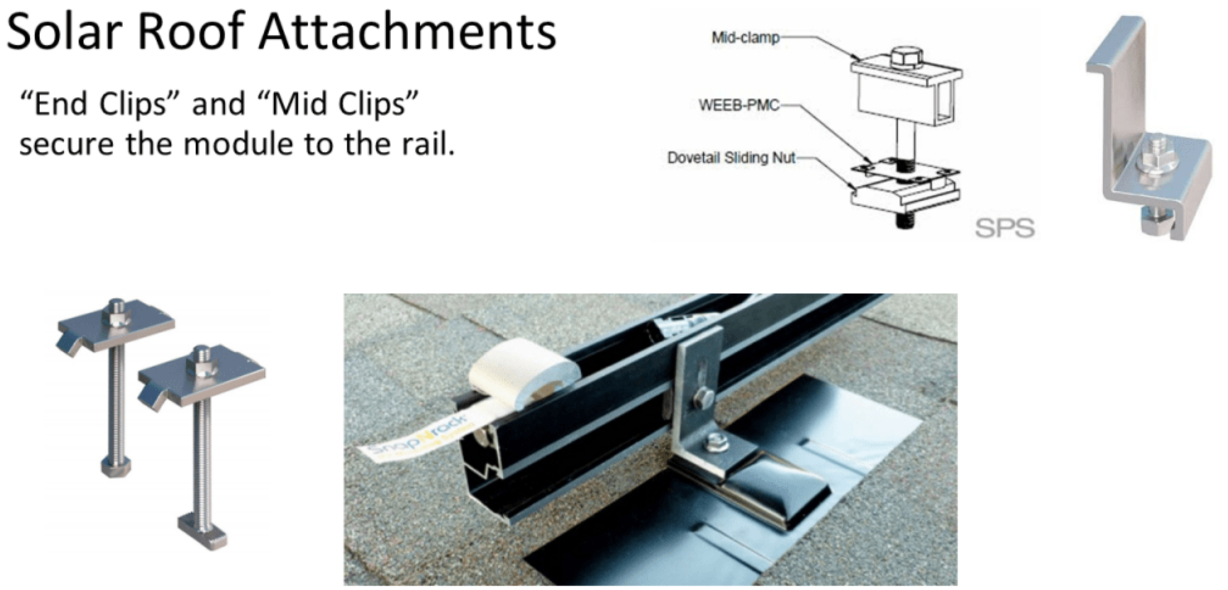


Figure 71 - Racking Clips and Attachments

I am partial to certain racking companies over others but the whole system is pretty much the same. You put a bolt into this channel, and then you have mid clips that space and clamp down the solar panel onto the rail between two panels and then you have end clips that go on the very end just for one panel and the clips have a grounding washer that grounds the panels to the rail. Then you ground the rail to your equipment ground conductor, and that gets run with your cables.

Figure 72 - Staggered Attachments

Pro installers are going to mount to every single rafter as they go across the roof and so the way that they do that without making Swiss cheese out of your rooftop is that they stagger the attachments. So, here's a rafter, and here's a rafter, and there's a 4' spacing between their attachments.

Sometimes in the interior of the array where there's less wind load, that spacing can be stretched out to 6' instead of 4', but this is a very good standard. You're not going to make any mistakes with this layout if you keep your attachments 4' on center and then stagger them so that you're hitting every single rafter. Now, not all rafters are 24" on center.   A 16" on-center rafter is common as well.

So during the site evaluation what I do is I get in there and I measure the rafter spacing and then in AutoCAD, I locate every single attachment position to make sure that if I have if you have two rows of solar panels and your 4' on-center, it really doesn't matter about the spacing of your rafters. Instead of going every other, every other, you can go 1,2,3,1, and hit every rafter as you go across, so that you evenly distribute the load over the truss of the roof.

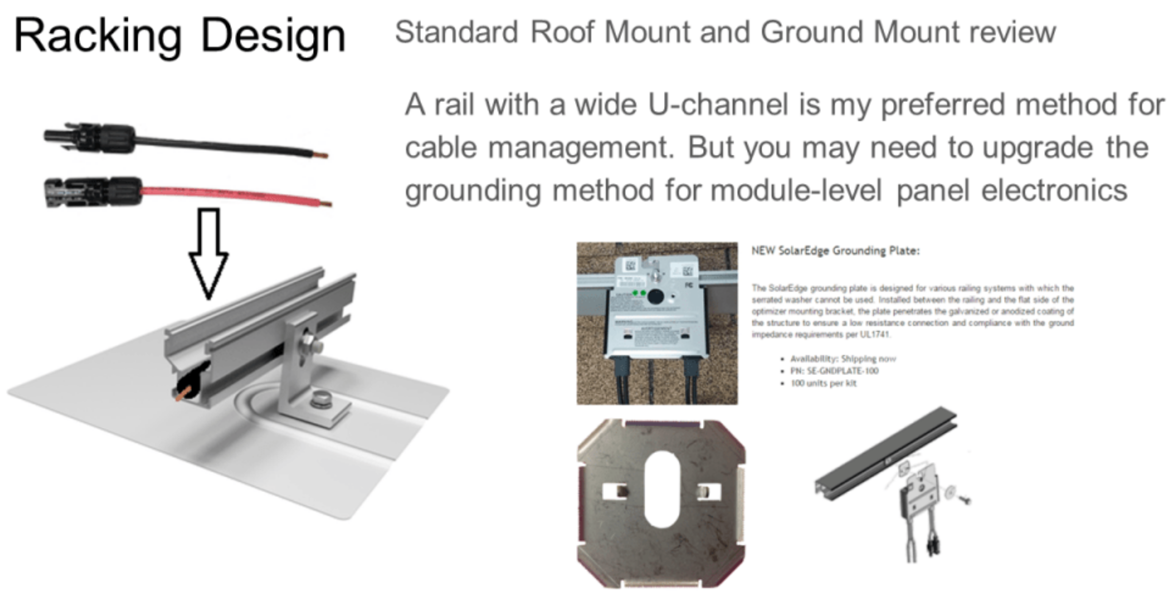


Figure 73 - Wire Management Planning

I like using rail that has a little bit wider of a channel, where you're using a lock nut that goes into here, rather than a bolt. The reason is, I like using the wide channel rail for **cable management**. It keeps my cable up on my roof secured and protected, and it doesn't drip down onto the roof.

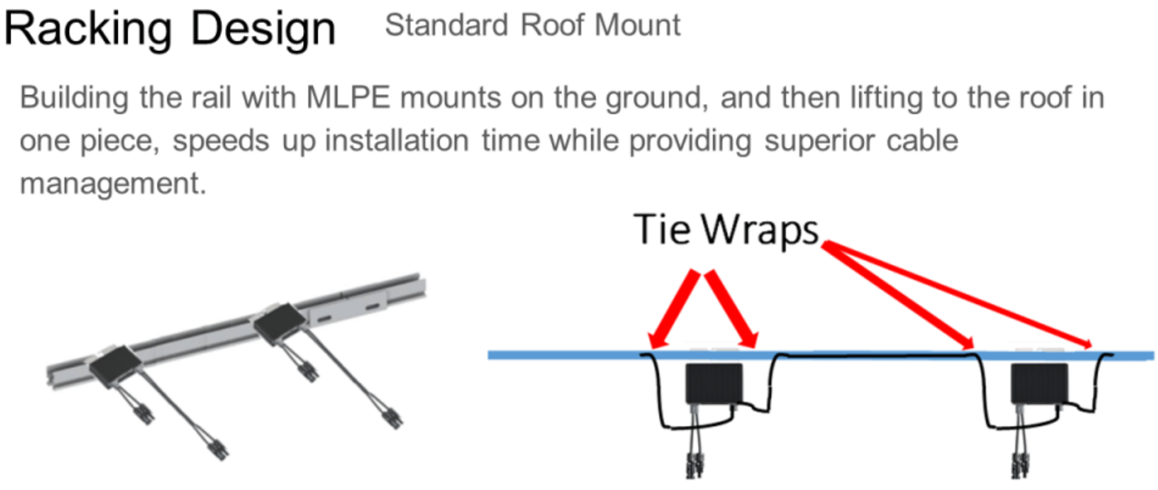


Figure 74 - Mounting Module-Level Panel Electronics

So, what I do is, I take my electronics and cables and I build my rail down on the ground. I throw my cable into the top channel and *share* it with tie wraps and then when it comes time to put the panel onto the rail, the module frame itself holds the cable into the rail.

Figure 75 - Wire Management

You can use **tie wraps,** you also get **cable clips**, but they serve different purposes. The tie wraps can get messy. They look cheap. People are concerned about them failing over the long run, but the cable clips though the module cable can actually pull out of the clip so it's not a perfect solution either. I look at the cable clips as being a helping hand to pre-position the cable but neither zip ties nor cable clips are perfect. What I think is perfect is when the modules get clamped onto the rail. If you have your cable inside the rail then it's permanently secured by the edge of the module frame. There's no way that thing is ever going to come out of there and so the sign of a good installer is able to look underneath the solar array and be able to see all the way through it.

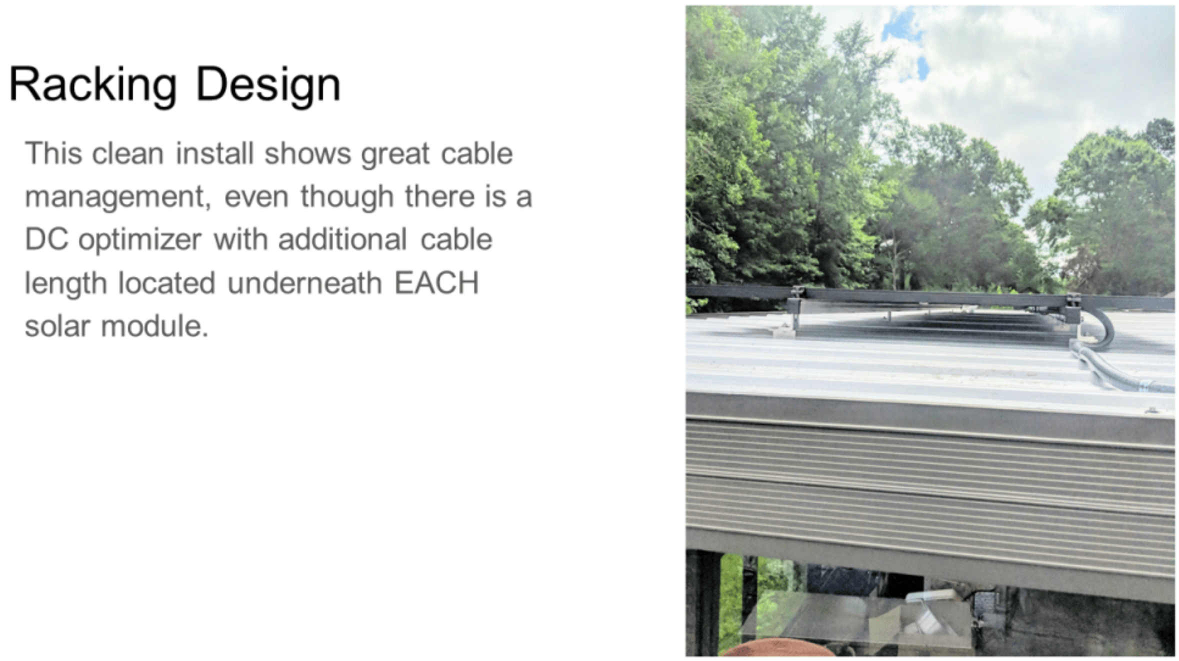


Figure 76 - Clean Undercarriage

Even though we have little electrical boxes and droopy cable whips at every single panel, the end result is you can look underneath the array and can hardly see. You see the little boxes and cables right here and that cable then is going right into this rail, so no squirrel is going to get up under there and start chewing things up as you would if you had a rat's nest of cable underneath.

Figure 77 - Snow Guard and Array Skirt

A couple of finer tips: now this is called an **array skirt** or **squirrel guard.** How good are they? I have my doubts. They do restrict air flow. You definitely would want to use them if you have nearby trees and squirrels on the rooftop. Otherwise I think through good racking selection you get most of it done.

These are interesting. These are called **snow guards** and what they're there for is to catch the snow so that it doesn't slide off the roof all at once. So, in areas of heavy snow, that could be important to prevent avalanches that can rip the gutters off the side of your roof, depending on how good your gutter guy is.

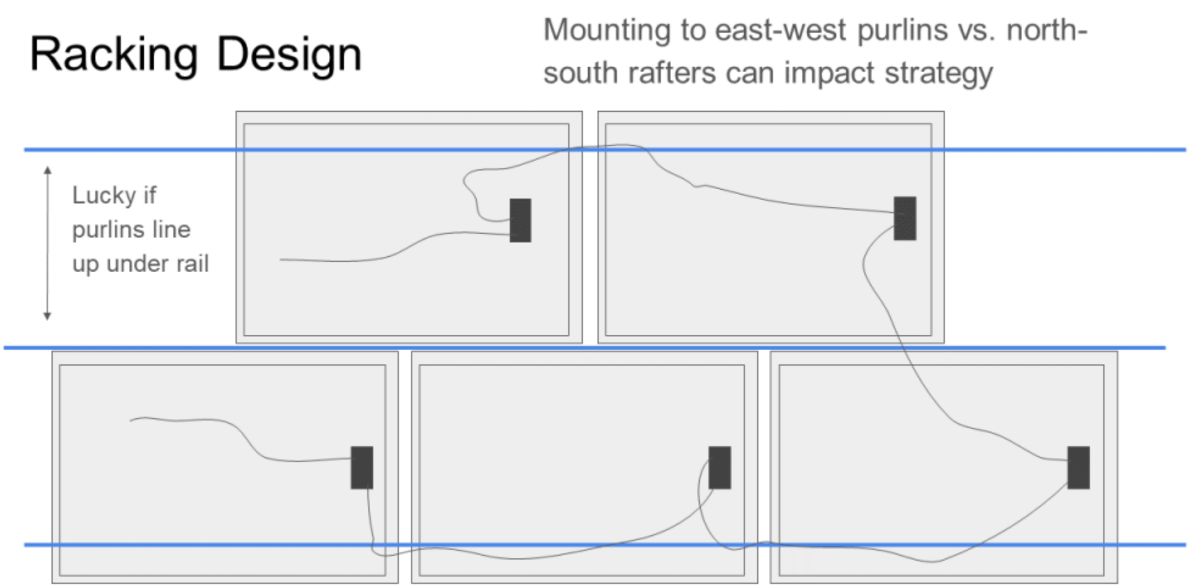


Figure 78 - Landscape Modules on Purlins

If you're mounting the **purlins** instead of rafters, it can be a little bit trickier to get them to line up correctly. You might end up going with a landscape configuration instead of a portrait configuration.

Running the rail up the roof rather than east-west is possible, but it's not preferred. It's a more difficult install because you get up on the roof and either using a $600 stud finder. Not a $50 stud finder! It's still tricky. You need a flat piece of cardboard and you use your stud finder through the cardboard, and then through the roof, rather than on the textured surface of the roof. The old-fashioned way is to take a rubber mallet and bang the roof and feel where the rafters are with the aid of someone inside the attic measuring it out. So, what I do is I'll go across the roof and I'll bang the roof and I'll take a whiteout marker and I'll just dab the roof wherever I think there's a rafter.

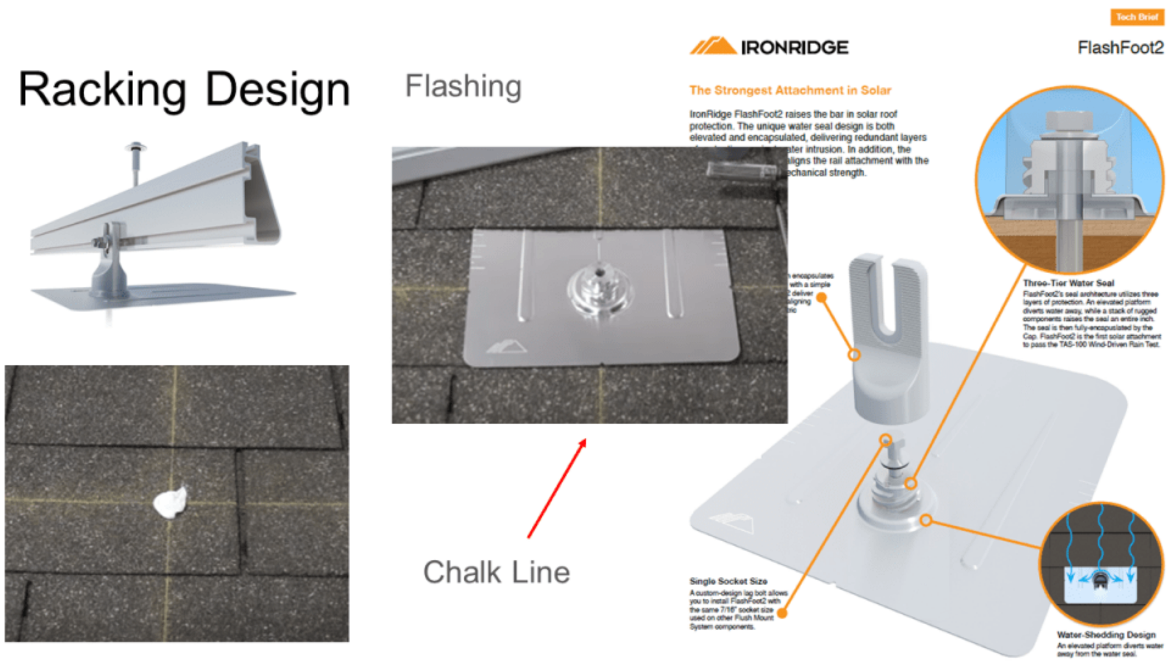


Figure 79 - Positive Attachments

I'll start at the top and do it in three different spots: at the top, in the middle, and at the bottom. Then look at my spots and see if from one *road t*o the next if they're lined up or not and once you get going with it it falls into place. So, once you've identified your rafters, you put a chalk line to keep them straight, and drill a pilot hole. Once you drill your pilot hole, you're going to know if you hit the rafter or not. If you missed it you can stick a wire down there give it a twist and see how close you are and then hopefully you don't miss too often. But that's what the flushing is there for. So, you call up and your guy misses and then you're flush around it.

Now the reason why I don't like **standing seam** is because it becomes a weakness of the standing scene panel itself because instead of lag screwing into the rafter, you're now clipping onto the seam and relying on the strength of the standing seam panel. It is then attached to the roof which is nowhere near as strong as a lag screw into the rafter. The advice from the standing seam manufacturers is to clip to every single standing seem to get the best load distribution across the standing seam roof. Most installers don't want to do that because you're spending more money on your clipping system.

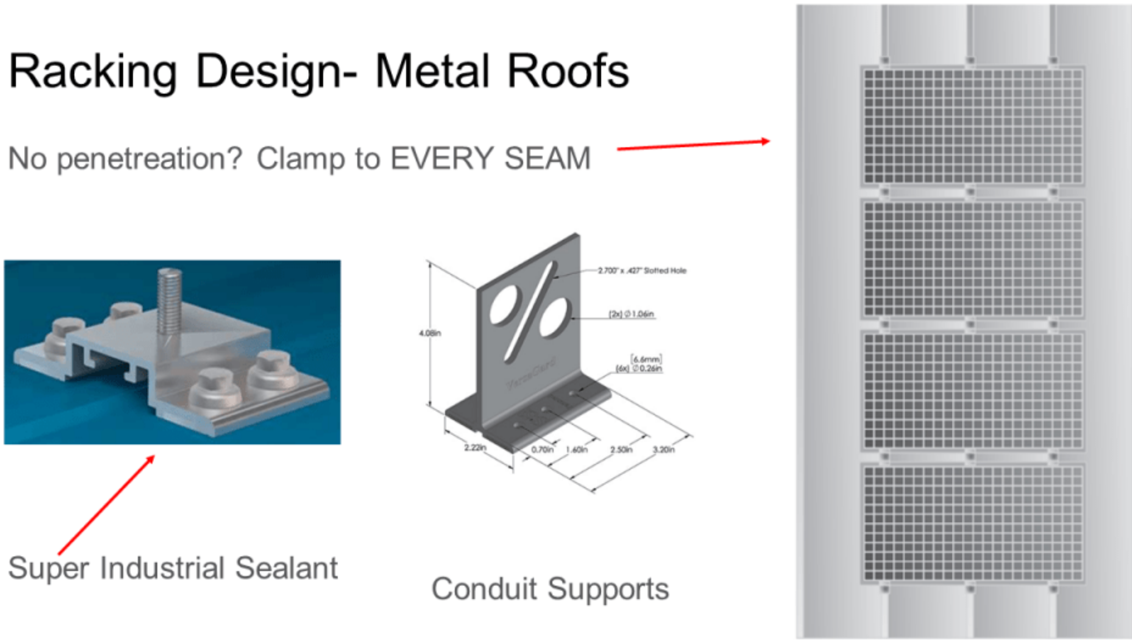


Figure 80 - Metal Roofs

There's little advantage to a **rail-less system**. It is harder to install than a rail-based system and you're not saving any money because you're buying so many more attachment points and you're covering up the roof anyway. I know standing seam is considered to be higher end than rolled metal but rolled metal is actually better for solar because your lag screwing into and through the roof, which terrifies the homeowner. But as an installer, I can tell you that the standing seam metal roofing products have an industrial butyl tape that goes underneath. You can see it here.

That goes underneath and so lag screwing through that butyl tape, which is very well sealed, and it's a very strong attachment that you can be confident in.

Here's another thing that I wish I had known on this previous project. There's now **conduit supports** for standing seam or metal roofing systems that can help you keep that conduit up off of the roof. So that's worthy of note.

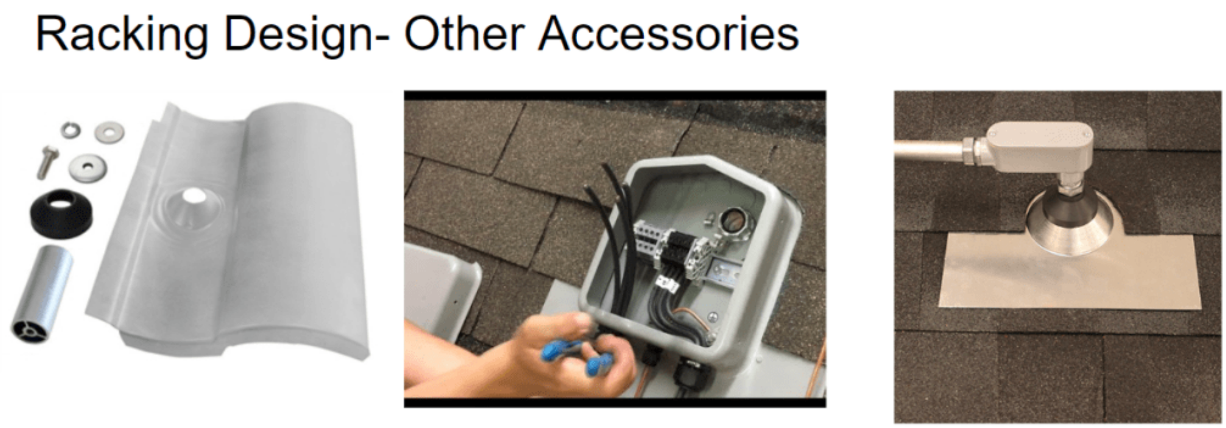


Figure 81 - Into the Roof

Here is a picture of a Spanish tile stand-off that replaces a tile on the rooftop in order to transition the cable through the roof. I am a big fan of **internal conduit runs**, and consider them to be best practice, as compared to leaving the conduit to run across the roof outside the building in most circumstances**.** The way to prevent obsolescence in a solar array is to make sure it looks good. The best way to make a solar array look ugly is to muck up the rooftop with visible conduit that out the side of the array, across the roof, and down the wall.

In the northern hemisphere, solar arrays are commonly found on the south-facing side of a rooftop. Aside from the solar panels themselves, when locating the electronics of the system outside, you don't want to expose them to direct sunlight. These electronics get hot during normal operation, and adding additional operating temperature to them is asking for trouble. So, on the ground the inverters are commonly mounted to the north side of the building.

So, the array here is on the south side of the building, with the inverter and point of interconnection on the north side of the building. An internal conduit run will not really impact the project budget here. The route through the attic is a shorter than the roof gymnastics required which would be required for an exterior conduit run. So, the question becomes how do you actually land the cables coming off the array in order to go into the attic?

High-quality solar installers are comfortable drilling a hole through your roof. I like to make the transition at the last solar panel in an accessible corner of the array. I will hide the transition box underneath a solar panel, to protect it from rain as well as improve the aesthetic look of the installation. This is a specialized solar transition box called a **Soladeck.** It has integrated flashing to get up underneath the shingles. The cables come out from the attic to both land on this **terminal block,** meeting up with the solar cables from the roof which enter through a cable gland. Of course, this is a specialized box which costs about $100 just for the near empty shell. Generally speaking, using higher-end components will add quality to the job without substantial price increase. It just requires more knowledge and planning. However, there are inexpensive, code-compliant ways to make the transition into the roof in a workmanlike fashion.

For example, you could get a flashed pipe boot at the local hardware store. Your electrical conduit could then be stubbed up through the pipe boot for the cable to transition between the roof to the attic. One caveat on trying to make the rooftop transition work elegantly with generic, off-the-shelf components is that you only have about 4” of clearance between the roof deck and the top of solar panel itself. So, if you want to hide the box underneath the solar array, by the time you add the height of the pipe boot and the height of the box, it is easy to be past the height of the solar panel off the roof. The specialized, solar-specific rooftop transition boxes make it easy to maintain the good look, whereas a generic box bought at the hardware store might be 6” deep and not fit at all. When using generic off-the-shelf components, I will commonly skip the box on the roof, simply by transitioning the cables through the conduit via a cable gland and then landing a box in the attic, accessible and just underneath the array. In short, you can achieve a quality installation with off-the-shelf generic parts, but it too requires knowledge and planning.

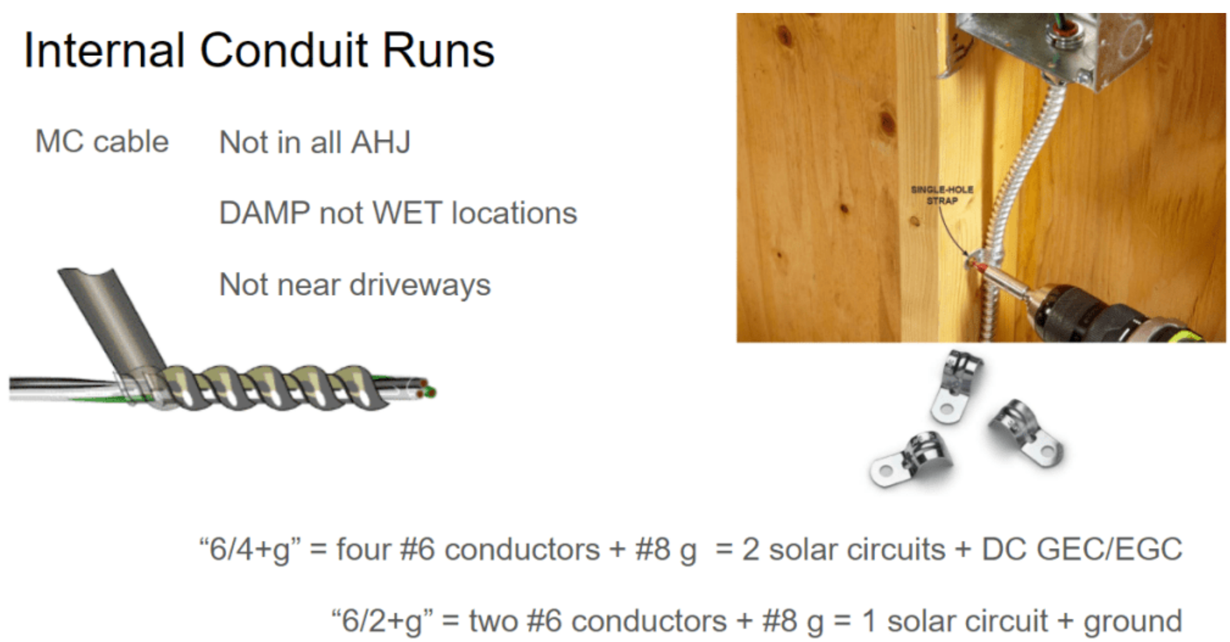


Figure 82 - MC Cable

DC conductors when inside the building, are required by code to be protected by metal conduit. It’s confusing as metal conduit is commonly associated with a ground path, but in this case, it is **not** for grounding, but instead for physical protection. A rodent is less likely to chew up a wire if contained in metal conduit. A nail or screw is less likely to puncture a power cable if the cable is contained in metal conduit. The physical protection requirement is DC discrimination, as there is no similar requirement for feeder cables supplying AC to be contained inside metal in a building. Some installers will select an inverter system to go on the roof, leaving you with AC output at the array specifically to avoid the metal requirement, running the home run cables in AC-rated Romex. Running metal conduit as a retrofit through an attic can be a difficult task.

I prefer DC systems with one inverter down on the ground, which requires a metal-enclosed home run circuit from the array to the inverter. So, what I do is buy a bundled cable product called MC cable, which stands for **metal clad cable.** The conductors are already bundled together, in a metal wrapping that encloses them fully. This is expensive stuff – one DC circuit of MC cable will contain two full-sized cables plus a ground, and costs just under $3/foot. I will often get four full-sized cables plus a ground at about $3.50/ft, which would give me two circuits total with two positives and two negatives plus a ground. It is expensive, but can be quickly routed through an attic while meeting the DC metal requirements, making the code-compliant installation go very quickly. I'll typically stub it up into the Soladeck box, and run it through the attic to come out the soffit on the underside of the roof eave on the north-side of the building where the inverter is located.

However, when using MC cable, you must be aware that it is only rated for damp rather than wet conditions – which makes sense as the metal wrapping isn't nearly as weather-resistant as a complete metal tube. Yet outside of a building is considered a wet condition, unless the outdoor area is sheltered, such as a covered parking area, an awning, or a porch. In other words, a damp-condition outdoor area is one not exposed to sprinkler systems or rain. Additionally, many local jurisdictions will determine MC cable not to provide enough mechanical protection of the cable if installed in areas subject to extreme damage, such as a driveway where a car could crash into the conduit run.

So, the MC cable run transition to the inverter can be accomplished in two ways. One, you can stub up some EMT through the soffit and land on a junction box in the attic. This can be complicated by the slope of the roof and the attic layout, as accessing the soffit from inside the attic can become so narrow as to be difficult. It's easier to pull the MC Cable from the outside of the building, through the soffit into the attic, and then up to the rooftop transition box. Then leave roughly 12 inches of MC cable hanging out of the soffit on the outside of the building, transitioning to EMT before finally landing on the inverter. You might simply strip back the MC Cable for the final run, using a conduit fitting to transition to EMT for a nice clean look. Or you might install a junction box to make the MC-cable to EMT transition.

Figure 83 - Cable Glands

For this homerun, most installers will size the cable to be #8 or #10. I usually go for $6MC cable, because the MC Cable comes with an undersized ground. Separately, the minimum AC or DC grounding electrode conductor size for more 200A residential solar services is #8, so I select a #6 MC cable to take advantage of the #8 ground wire included in the cable bundle. I will then land that ground on the solar racking up on the roof, completing my grounding run from the inverter on the side of the building to the solar array on the roof. The solar inverter is then tied into the building ground.

Therefore, the easiest code-compliant way to bring two solar circuits from the rooftop down to the inverter is to use "#6/4 plus undersized ground" MC cable or #6/2+g where there's only one solar circuit (so that you only need a two conductors for your positive and negative run). In other words, 6/4 will give you two solar circuits and #6/2 will give you one solar circuit, in addition to your ground. So yes, MC cable is expensive but it makes the array look really nice and installs quickly. Plus, costs are kept under control by having a much more direct route to where the inverter is going to land, by going straight through the attic rather than around the building with your homerun. By keeping all of your cable inside and tucked up under the array you achieve a very pleasant aesthetic effect where the solar array looks like it's magically hovering above the rooftop.

This is the name of the solar game, finding the right electrical balance of system components to make the cable transitions easier. There are many kinds of electrical fittings you can find at a local electrical distributor that you can't get at the hardware store, and there are additional kinds of electrical parts the distributor might need to order from their supply house. If the idea of having a junction box underneath the array up on the roof sounds worse than putting the box inside an accessible attic underneath the array, it's possible with the right knowledge and planning. It can pay off to budget some money for preliminary and even final design stages before moving forward with the build.

I had the opportunity to do a string of very similar residential projects, and discovered that with the right racking selection, there's a lot of on-the-ground pre-assembly you can do. So, in addition to buying pre-bundled cable, we also make up rail sections and mount module-level panel electronics to the rail before lifting up to the roof. Essentially, any reduction in time spent on the roof is worthwhile, not only for project safety but also for the durability of the existing roof itself. That roof surface is usually not intended to be the site of a major construction job. A shingle roof deteriorates primarily due to direct exposure to sunlight – shading it would improve its over life, except that does not consider a construction worker scraping their foot across a shingle, which might even be worse in the access areas. Rooftops can be dimpled. Things can fall off of them. In any event, considering how the module whips coming out of the solar panels, to any module level-electronics they are plugged into, to the **home run conductors** from the array to the inverters will be managed is critical to spending the least amount of time on the roof possible. We will revisit this later, but let's continue spending time on our cable discussion.

Sometimes it's necessary to build what's called a **jumper cable** between two sections of a solar array. Jumper cables might be kept up on a roof or sometimes run in the attic. For example, I might install another soladeck box and run a single circuit MC cable between two sub-arrays, that same metal clad cable we discussed earlier.

Outside of conduit, up on the roof, the solar industry uses a different cable, a more robust cable literally called **pave cable** or **pv wire**. The jacket is very thick, about as thick as any cable you've scene as it is commonly rated for 1500V as well as direct exposure to light. It has to be thick so it doesn't deteriorate. It is common for solar installers to order PV cable by the 500' spool – or even greater! Well if you know the distance between the end of the array where the home run conductor begins, and the end where it terminates within the Soladeck rooftop transition box, you can pre-cut and terminate these cables on the ground, and potentially lay them into their rail sections before a lightweight lift to the roof.

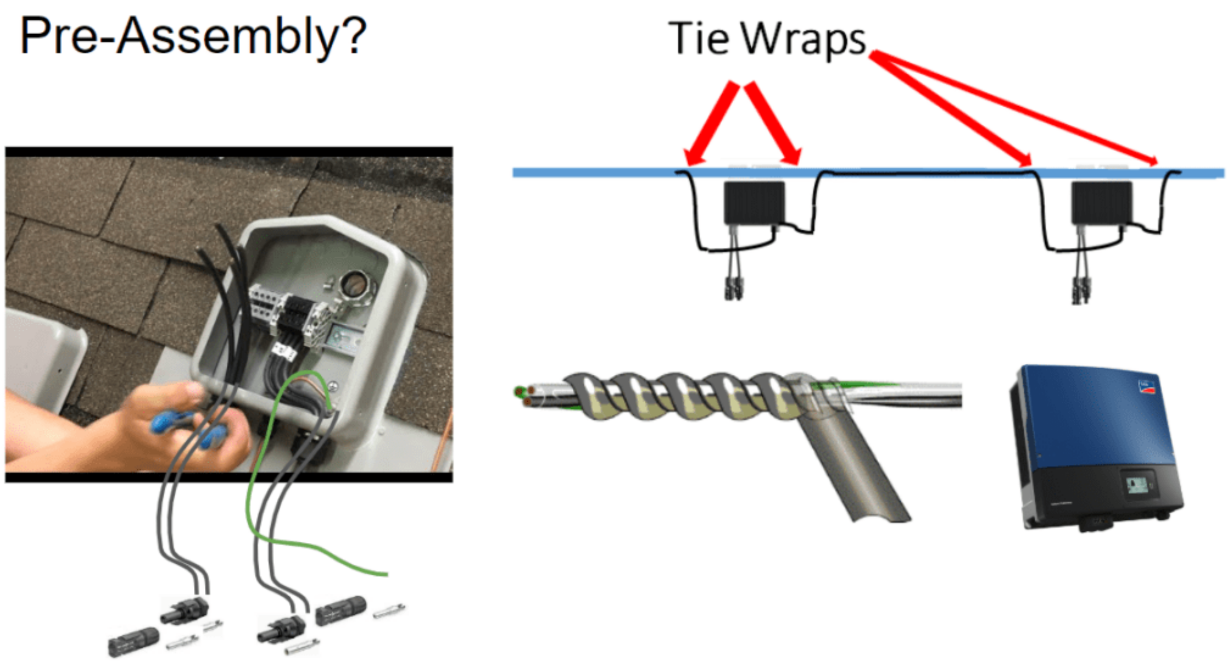


Figure 84 - Project Planning

The thick cable jacket helps when you are tugging the solar cable through the racking system. The home run cables are long and might drag across along module and racking metal edges. It is not a good installation practice to have solar cable touching sharp metal edge, but nonetheless, these items are in close proximity to each other on a solar project. The extra thickness should be appreciated. Keep that in mind if considering swapping with other high-voltage, high temperature, wet-rated, outside of conduit cable – all else being equal, a 600V rated cable will have a thinner cable jacket than a 1500V cable. In any event, pv cable is particularly robust.

One of the more specialized tasks in solar is using this **MC4 crimping tool** to add solar connectors which plug into the modules. Strip off the end of the wire, stick it into a metal insert held in place by the crimp tool, crimp it, and make up the plastic housing that protects it. You can get MC4 crimp tools for around $30 on Amazon that get a single job done, but there are more expensive MC4 crimp tools that are quite expensive and do a little bit more in terms of cutting the cable and stripping the cable, resulting in a faster and more professional connection. MC4 is a manufacturer who created the end termination standard, but there are a variety of MC4 connector makers on the market.

Figure 85 - MC4 Connectors

The MC4 connector deserves special attention for being one of the more dangerous connections on a jobsite. The connectors from module-to-module are plugged together as the array is installed. But he connectors from the array to the home run connectors are usually installed before the solar array, but connected after the modules are mounted (such as to prevent electricity from flowing through the home run cables if still the terminations at the other end of the cable). These open-ended MC4 termination should be protected against rain falling into the connector, as water can wick into the wire and damage the solar panel or electronics the cable is connected to. Likewise, MC4 connectors should not sit in water, which can easily happen on a flat commercial roof. Remember the cable gland around the MC4 connector should also be made up tight. Some MC4 connectors might require stripping 3/8ths of an inch

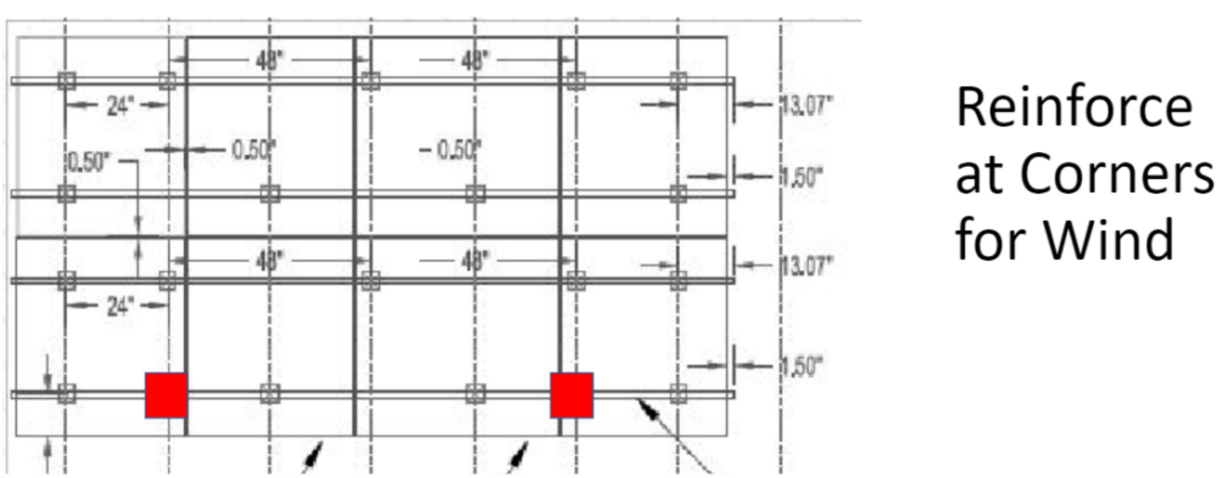


Figure 86 - Wind Reinforcement

As the positive attachment connecting the rail to the roof are typically staggered 4’ on center, staggered to hit every rafter as the rail goes cross the roof, the next step is to add additional positive attachments to take care of specific instances where improved racking strength is important. The corners of the array are subject to higher wind speed, so it’s a good idea at the corners of the array to attach to less than 4’ on center spacing before going to a wider spacing in the array interior. If I’m doing multiple rows of modules, I may transition to 6’ attachment spacing, provided I am still hitting each rafter and still reducing the spacing at the array edges and particularly the corners.

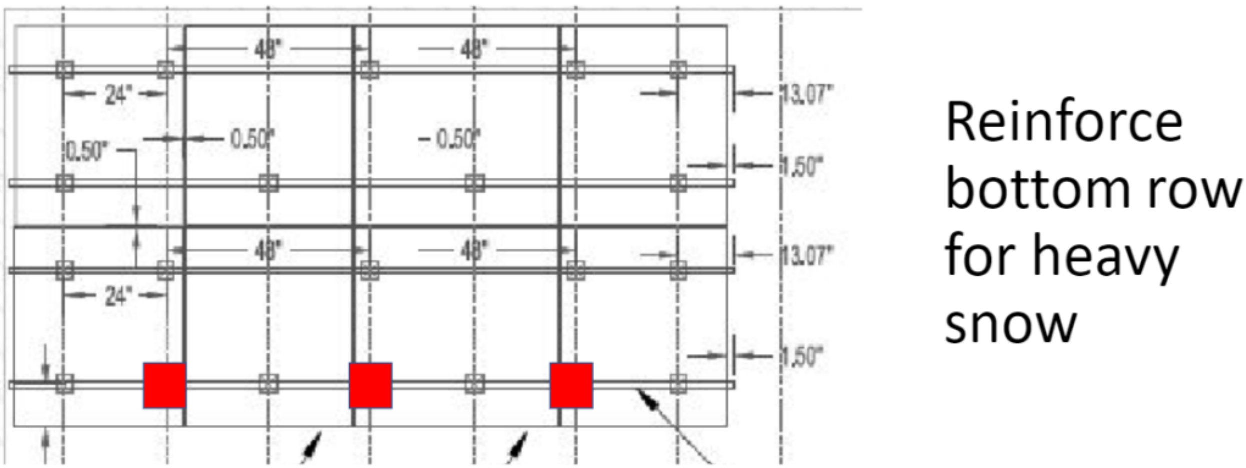


Figure 87 - Heavy Snow Reinforcement

In areas of heavy snow, such as 1 foot of snow on the roof each year, keep in mind is that the weight of the snow will distribute more at the bottom rail, which can crush the attachments through the roof deck. So, on the bottom rail you may go with a 2’ on center spacing to give it some additional load distribution. Because by doubling the number of attachments along that rail, obviously you’re going to have half the amount of force at each individual point load.

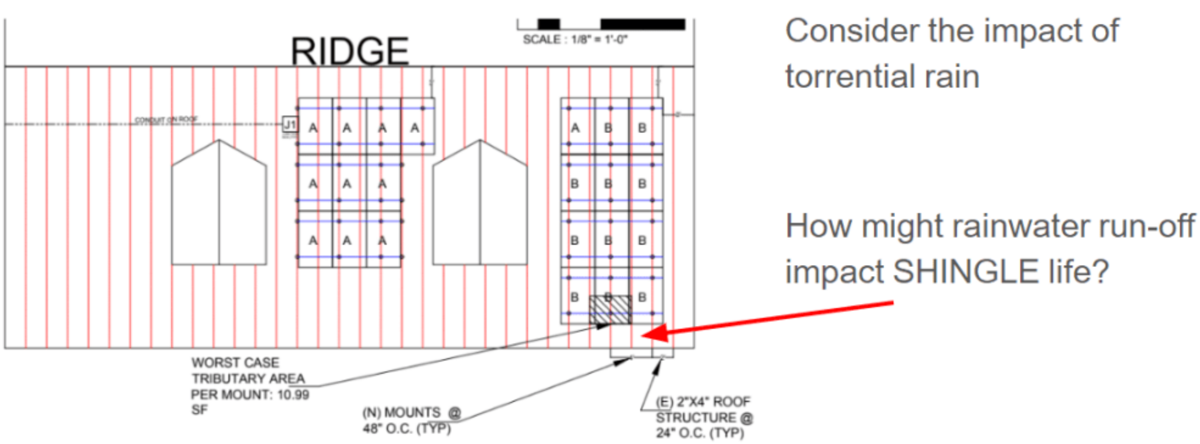


Figure 88 - Bad Array Layouts

When planning your layout, you definitely want to consider aesthetics. Here is a design that came to me from a developer. It is asymmetrical and discontinuous. As is, we would need two rooftop transition boxes, or some ugly rooftop conduit and jumper cables across the rooftop. And it doesn’t look very nice. Instead, I redesigned it for a more symmetrical array layout. Furthermore, only the lower portion of the roof was walkable, with an attic space underneath. The upper part of the roof had a steeper tilt and potentially exposed to the open cabin interior underneath, making me concerned about lag screws going straight through the roof through the ceiling of the room underneath! The redesign looks better, is on a better portion of the roof, and only requires one transition box.

Consider aesthetics and symmetry

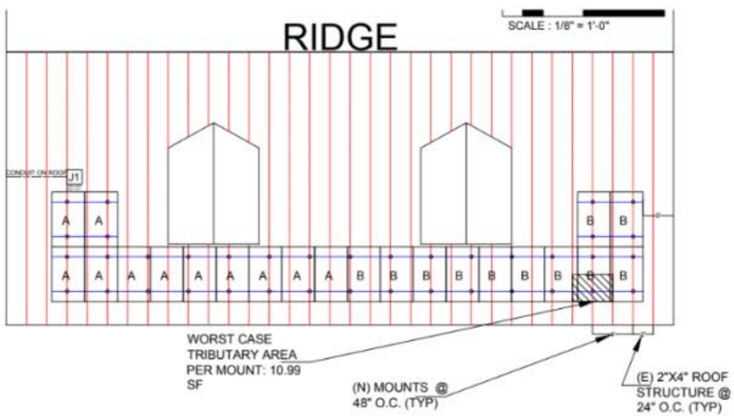


Figure 89 - Happy Array Layouts

This is another side note, but I found it interesting that this developer's designer had noted the worst-case tributary area for rain-water runoff. This is a metal roof, so rainwater run-off is not quite as important as shingle, but imagine all the rain which is supposed to hit the surface of the roof instead collecting together to all hit the same part of the roof in a single line. Might that erode the shingles or otherwise leave a water line? Yet also consider that putting the array at the very bottom of the roof along the gutter might cause torrential rainfall to overshoot the gutter and fall directly onto the foundation of the building wall which is not good for the structure, of course. What I do is sit the bottom of the array a couple inches off the lip of the roof right before the gutter, as well as appreciating that a wider, narrower array would not have the same run-off issues as a taller array spanning from the top-to-bottom of the roof. I say this because I haven't seen water erosion on a shingle roof become an industry issue, but at the same time, it's important to apply common sense design to solar, or even bring skills to the table. Being able to collect both water and heat from the surface of a photovoltaic solar array is an untapped market that might be more the purview of a roofer or plumber than a solar installer.

How are roofs maintained in the future with solar, especially roofs which might need replacement? My preference for covering the entire roof section with solar because the solar panels will now uniformly protect the surface underneath.

But if the roof is only halfway through its 25-year life, covering it up with a solar array could extend its life further. But you would still be left with dealing with the other portions of the roof not protected by solar. Would the solar owner then replace only one third of their roof? Roofers can repair roofs by weaving in shingles, which is an easier process when done from top to bottom. But to me the problem with solar and rooftops is that the degradation of the roof is no longer uniform.

If it's too hot, the shingles can be damaged. If it's rainy the grit comes off easier. I haven't seen examples of mismatched shingle life between the roof and the array. You are really face with the decision to replace the entire roof or to try and get more life out of the existing roof.

It would be better a new construction for shingles if you put the flash pads directly onto the decking with your lag screws and then shingle around them so that you could rip the shingles off and put a new course of shingles on if you're prying up the shingles and sliding your flushing into it at that point you're going to have to redo the whole roof when it comes time to do something substantial like that.

Anyway, here is the end result, using internal cable runs to avoid having conduit on the outside of the rooftop. Without the most expensive racking or solar panels, through good workmanship we can still achieve a long-lasting visual aesthetic. The ends of the rail have been cut with a bandsaw custom to fit, with the final attachments being on the inside of the array perimeter, within the racking specification for cantilevered rail ends (often the final rafter within the array perimeter). An all-black solar panel is selected. As they say in fashion, black never goes out of style, twenty years from now, the modules will not appear terribly obsolete so long as they are still generating electricity.

Utility-scale racking is commonly driven by piledriver although there are reasons why you might not want to use a pile driver – such as rocky or sensitive terrain or landfills. There are racking systems which fit on top of the surface, weighted down with concrete or even durable plastic for highly corrosive environments.

Add a frameless solar panel and there is very little to corrode.

Figure 90 - Above Ground Mounting

Here is a fixed in place tracking system where they're doing an above ground concrete pour with the pre-built forms for pouring the concrete into.

Floating solar is another utility scale trend. What's interesting about floating solar is that it has some additional benefits which can justify its existence. Obviously floating solar is a challenge to install, but it is especially beneficial on calmer bodies of water, such as wastewater treatment plants or stormwater facilities. For these locations, the real estate is not only free, but there is a heavy electrical load. The solar array is a cap for the pond, with less sunlight going into the pond for algae bloom. It discourages evaporation as well.

Here is this system is designed for landfills, which is very similar in design for commercial flat rooftops where the solar panels sit across trays weighted down with concrete blocks – a common method for flat roof mounting. These systems typically come in metal, but here is one made out of fiberglass instead.

Figure 91 - Non-metal Racking

I'm personally not a fan of low-end commercial solar racking. I'm not a fan of loose concrete blocks covering the roof of a building not originally designed for the weight. I'm not a fan of the large amount of water that can pool underneath a high voltage solar array sitting on a flat roof, with cables inherently dangling underneath. I very much like slightly more costly racking systems which elevate the solar array off the roof a little bit, with cable management carefully considered, and even a few positive attachments made by a roofing contractor.

In a fire, I don't think the loose concrete blocks on top of the building are a good idea – even when the fire is not the solar array's fault. An easy way to reduce or eliminate the costly concrete is to poke a hole in the flat commercial roof, but there are plenty of things that poke holes in a flat commercial roof. On a solar jobsite, you need to be prepared for the event that you might need to patch a roof if something goes wrong. But with commercial rooftops, plenty of things already have poke holes in the roof, such as drains, air conditioning units, and other roof-mounted equipment. But with just a scant number of penetrations, (often just anchoring the corners of the array is sufficient, with the remaining array ballasted by just the weight of the rack, modules, and ballasted stand-offs. In other words, just a few anchor points are enough to keep the array in place, while substantially reducing if not eliminating the concrete. Remove as much dead load on the roof that wasn't designed there to begin with and eliminate the safety hazard of the loose blocks.

- Most penetrating commercial roof systems are “minimally” penetrating
- Non-penetrating systems are heavy, maintenance issues

Figure 92 - Poke a Hole in a Flat Roof

Here is an elevated racking structure that keeps the commercial solar array up off of the flat roof so water can pool without much wiring concern, like you inherently get when the solar module sits inches from the roof deck. This was a product made by Unirac, but they discontinued the product line because it wouldn’t sell. But the conventional method is to use these concrete ballast blocks.

Everyone wanted this stuff which comes from the satellite dish mounting industry. The design philosophy goes no further than deciding to put a satellite dish on a roof using a bracket anchored down by concrete blocks. That’s all well and good but then the same philosophy is applied to weighing down an entire solar array spanning across the entire roof. Instead in this picture we’re just anchoring the corners of the array and most of the array is up on pipe blocks pipe supports that are used to support conduit. The array has nowhere near the number of penetrations as a residential array. The weight of the array is enough for uplift force, it’s really the tangential force that needs to be countered so that gust of wind doesn’t start pushing it around on the rooftop. Getting rid of the concrete is earthquake friendly as well.

The way that we seal this penetration is pictured here. We cut a hole in the roof and bolt into the metal beams underneath. The **TPO membrane** is tamped down with a special flashed pipe boot for TPO the roofing contractor melts with a heat gun (think: hair-dryer) to melt the roof back together. It is very apparent that this is a good seal, and the reward is eliminating the concrete.

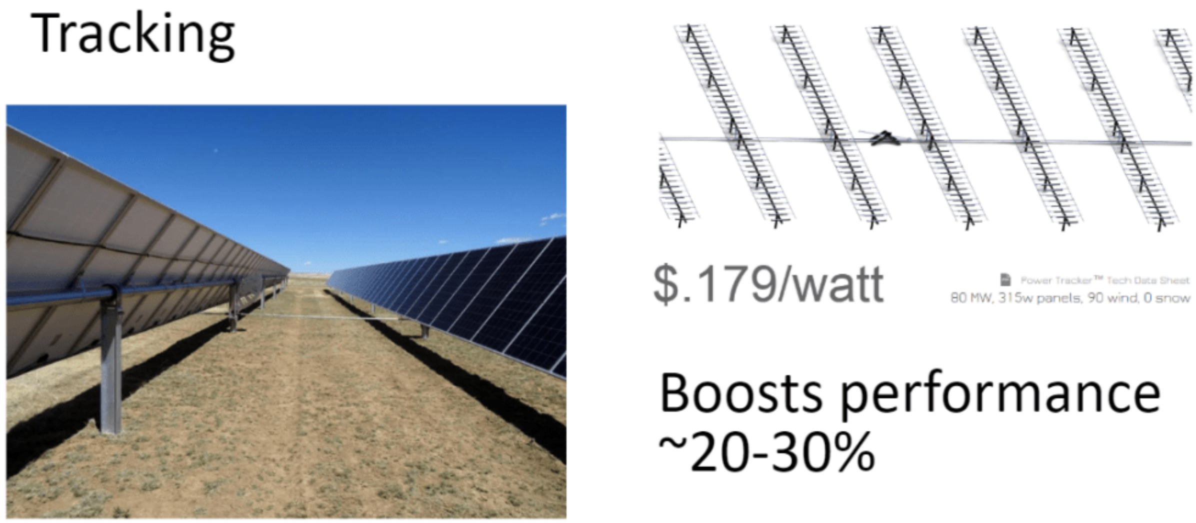


Figure 93 - Single Axis Tracking

The majority of utility-scale projects are on **single axis trackers,** which track the sun from east to west rather than north-to-south. Solar theory might posit that east-west tracking is better for the equator and north-south tracking is better for the poles. But morning and evening load are particularly valuable times of day for power generation, so the vast majority of these trackers move east-to-west. Double axis tracking is less popular, as it is more complex and so far, requires more real estate due to shading. This market has the potential to shift, as it has already shifted away from fixed-axis to single-axis tracking within the past ten years.

Single-axis tracking is simple and popular for utility-scale projects, so why not use it for residential? If tracking increases your project cost by 10% and boosts production by 20%, it's generally cost-effective, but the utility market is different than the residential market. I suspect the primary reason why single-axis tracking is not a thing residentially is the lack of manufacturing support. Most of the residential tracking companies have abandoned the market to pursue the utility-space.

I've built a residential single axis tracker but the customer preferred to keep it manually adjustable as the project was cost restrained and the actuator, shock absorbers, and control circuit would add roughly $3500 in cost to the project. It's very simple to do a fixed-in-place ground mount and they are the most popular residential system.

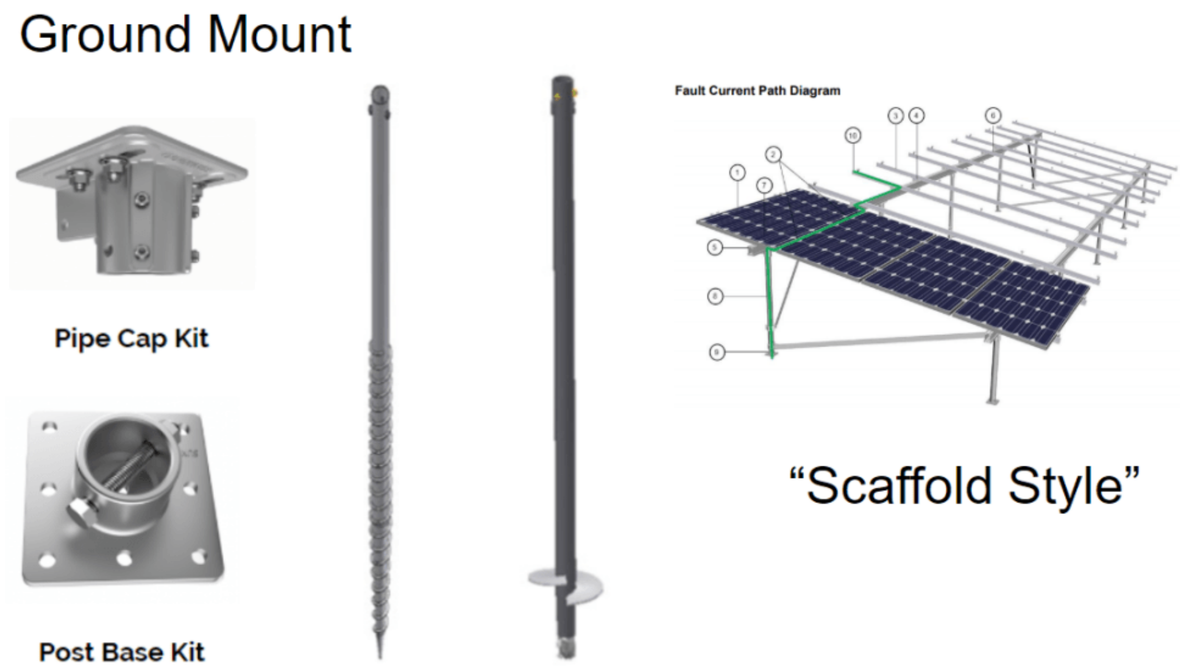


Figure 94 - Concrete-Free Ground Mounts

Post-based foundations require substantial depth, unless you use a lot of posts. Here are helical piles which have enough stability to replace concrete. I've used them before and they can be precisely driven with an upgraded bobcat, laser level, and experienced crew. Here is a variation on the same theme, a ground screw used for rocky soils. Of course, your ground is solid rock you may need to settle for an above-the-ground concrete pour.

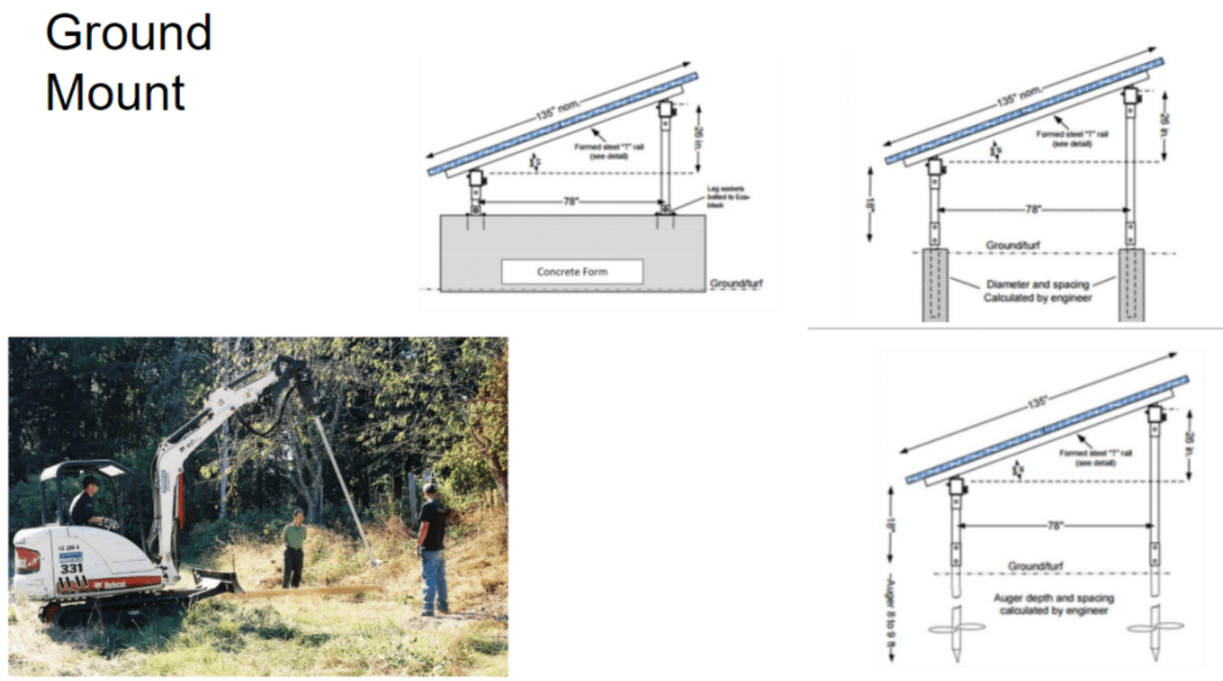


Figure 95 - Ground Mount Options

This picture shows a Bobcat driving the helical post and suggests leveling them off with a bandsaw. I've found a laser level to be effective as well as it takes a lot of time to cut into steel.

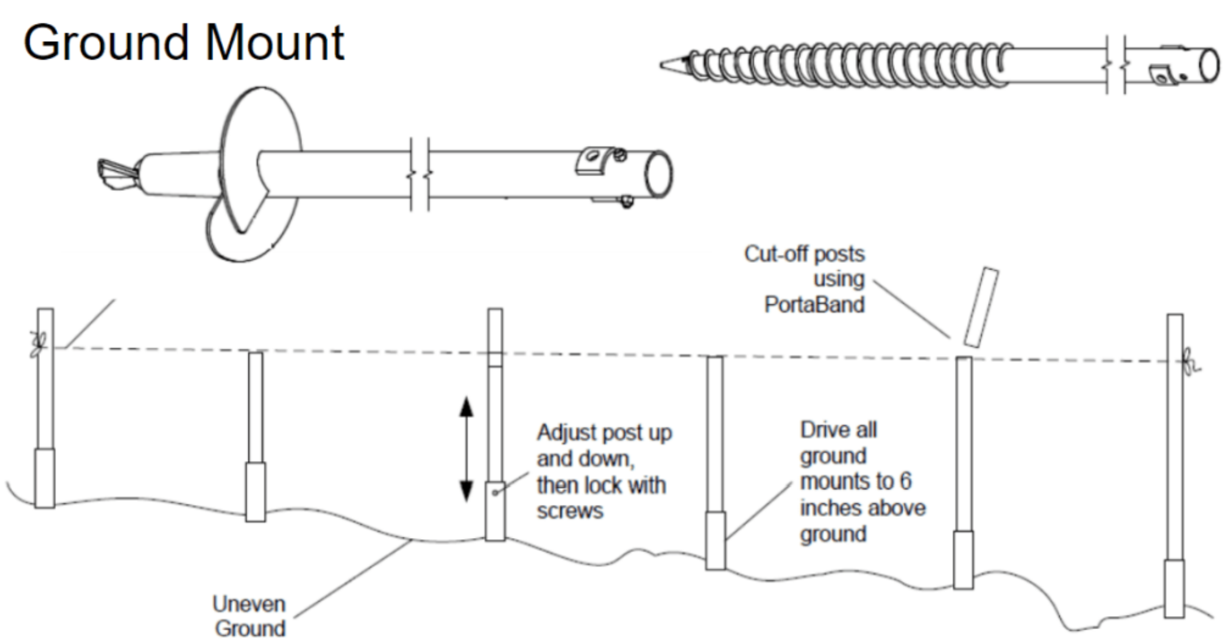


Figure 96 - Leveling Uneven Terrain

The helical posts are about the same in cost as compared to the all-in cost of concrete systems. But if your site is located in an area where concrete delivery is difficult, it can be easier than transporting and mixing your own concrete. At the very least, a pile driver for a residential ground mount is hard to find, and could be expensive for a project so small.

Easier ground maintenance

Fewer Foundations =

Deeper Foundations

(post or pile driver)

Figure 97 - Single Post Racking

Single-post systems for that matter often require 7' deep foundation which is a little beyond the capabilities of a bobcat with the attachments, raising costs further. But not all bobcats are strong enough to drive the helical posts. So, the common residential solution is to use racking systems supported by two rows of posts instead of one, reducing the foundation requirement but increasing the number of foundations (which can complicate grass maintenance underneath).

Dominant in utility-scale

BUT

ALMOST non-existent at the residential level

(expensive due to lack of manufacturer support, not because of technical viability)

Figure 98 - Utility-scale Tracking

The design of single-axis trackers arrays gives it a functional advantage. The underside of the array is accessible, consisting of a single row of posts, but the foundations are shallower than typical single-post systems, as single-axis trackers are typically one module tall (about 6 feet) deep whereas non-tracking single-post systems commonly hold twice as many panels per foundation post. I think it makes a decent fence to define a property line, so long as there are no trees around. Single-axis takes advantage of the module frame in its design, using the module frame itself to support the canti-level instead of adding additional rails. This reduces the total amount of material required to be purchased.

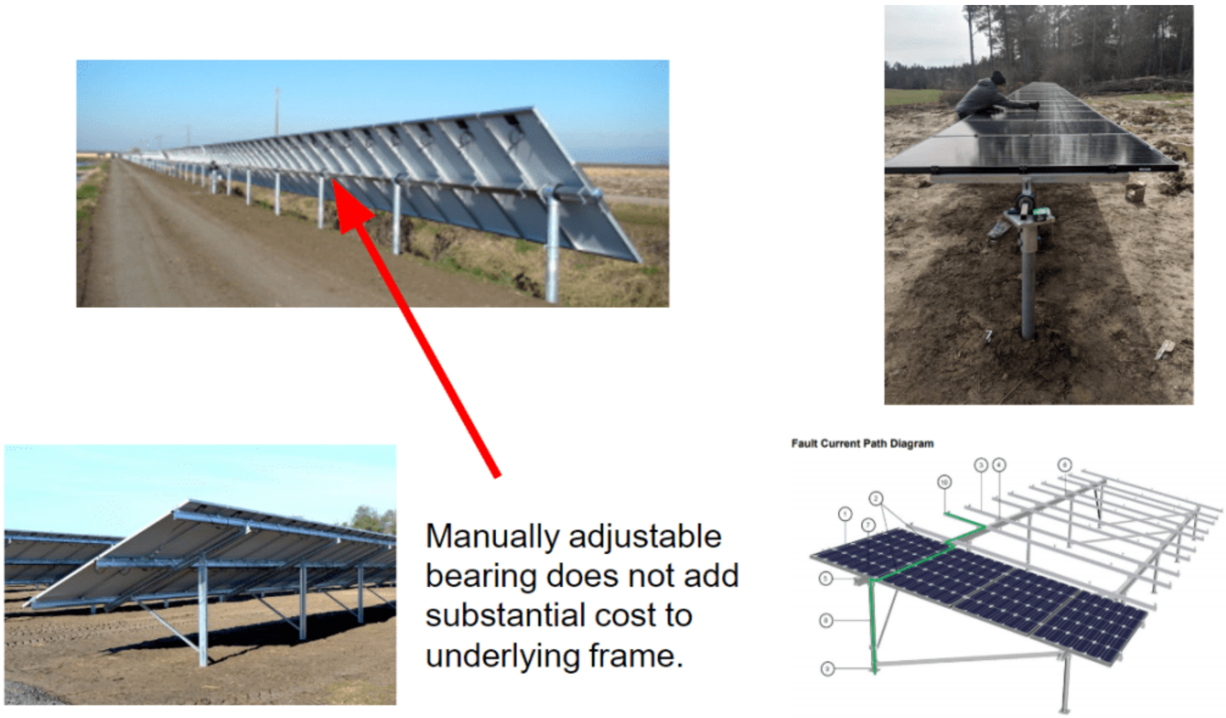


Figure 99 - Tracking Additional Parts

As we stated earlier, the only real added cost is the cost of the motor and control gear. The single axis-tracker market seems to not exist due to a lack of sufficient market size to attract manufacturer support, rather than fundamental economics.

This discussion of cost-optimization reminds me of a more important point. Yesterday in class we discussed the difference between a 60 cell and 72 cell modules. On a ground mount system, using those taller 72 cell modules might squeeze a few more watts onto your mounting frame for very little additional cost (upgraded bolts and brackets, but no change in foundation) resulting in a little more bang for your buck.

Similar aesthetics to a satellite dish?

Figure 100 - Double Axis Tracking

There is a USA manufacturer focused on residential **double axis tracking,** and is well-reviewed by system owners. really like them. There is a lot more foundation work involved, and I have not found it to be cost-effective, but it would be a good fit in a sunny but limited yard space. I personally think they look like giant satellite dishes, an aesthetic that did not age well. My opinion is that single axis tracking solar looks better.

Utility-scale trackers have a benefit of selling every kilowatt hour they generate back to the grid. When too much solar is installed, it creates a mid-day hump, increasing the value of electricity particularly during the shoulder transition periods. Morning-to-evening single-axis trackers which provide this critical shoulder production can be rewarded. But this production may not be so valued to residential customers. For example, if you are living off-grid, you commonly oversize your solar array to increase its output on cloudy days. Good off-grid design is already based around filling its batteries back up to the top each sunny day, with wasted, surplus over production to spare. This would reduce the need for a residential tracking array as well. Anyway, most residential ground mounts are fixed in place, but you might find yourself wanting to design your own ground mount foundation to achieve a better form or function than what is currently out there.

Inspecting the attic can benefit the design process. Rafter spacing can allow you to plan out the location of each attachment before getting back on site. Knowing the location of the attachments, and other exact dimensions, can allow you to place your optimizers ahead of installation, allowing you to install a substantial amount of your hardware into larger pieces on the ground, before lifting up to the roof.

Figure 101 - Architectural Drawings

Here is a project where the drawings indicated the roof was 29-gauge steel sitting directly on top of horizontal purlins. Purlins can complicate attachment spacing.

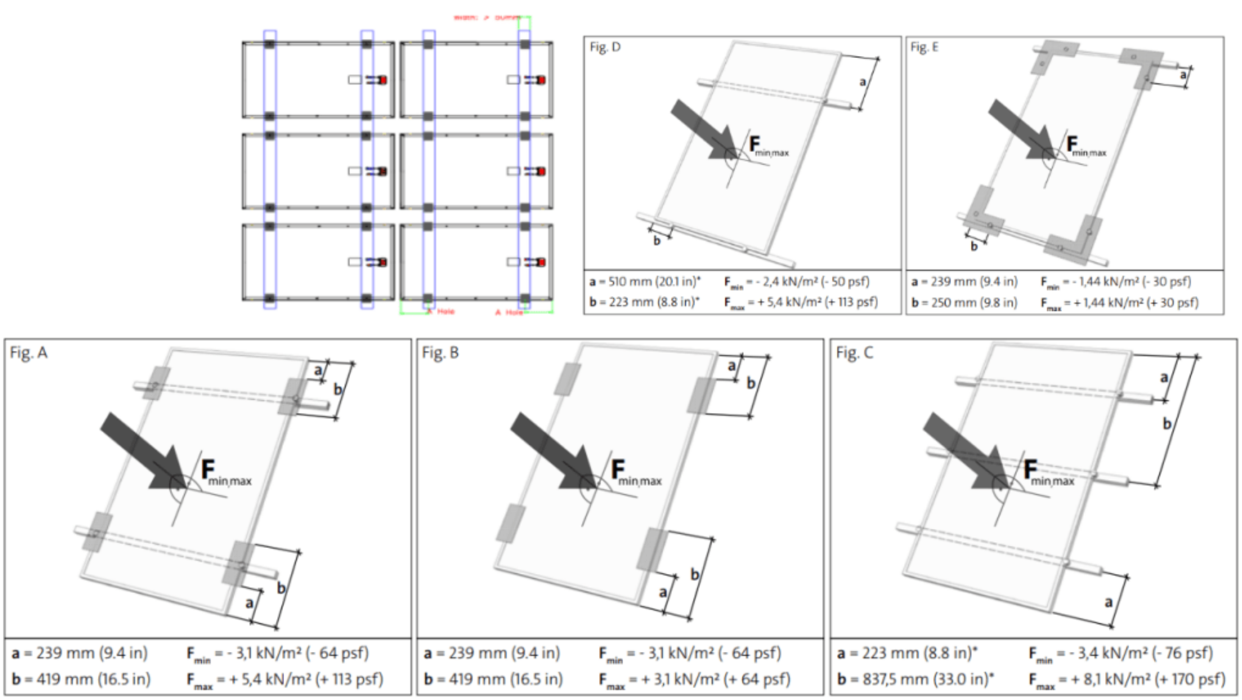
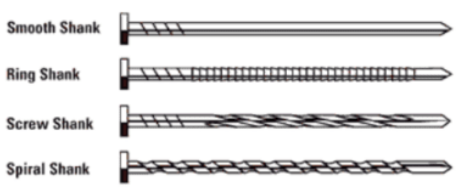


Figure 102 - Clamp Zones Revisited

Racking systems have dimensional **clamp zones** dictating the spacing requirements between the module edge and clamps which secure the module to the rail underneath. These zones are not complicated for the standard residential solar array, which places the modules in portrait and runs the rail east-west across the roof, attaching to the rafter's underneath. But these clamp zones, determined by the module manufacturer, may not allow you to run the rail both horizontally or vertically across the roof, and may additionally disallow modules mounting in portrait or landscape depending on the racking configuration. Some manufacturer clamp zones are very simple, and others are more complicated. Typically, you get less of a clamp zone if you have a weaker module frame. But that is only one attribute of module build quality. For example, I was reading the SolarWorld module manual after realizing they had hollowed out a section of their solar panel frame, and the clamp zones indeed were more conservative than older, more expensive solar panels I had been used to installing. At the same time, the manual stated the SolarWorld warranty would still apply to the solar panel if the actual roof were built out of solar panels itself (except in the instance of animal stables). In short, the solar panel was still of acceptable quality, but cost-cutting decisions limited its racking structure ever so slightly, which might only become a design issue on a purlin roof.

Whereas rafters are usually spaced less than 2' apart, providing many attachment points across the roof, purlins have a much wider spacing, which can complicate the array due to how the wider purlin spacing interacts with the clamp zones. Furthermore, how the purlin is attached to the rafter becomes an engineering point. The screw strength of the purlin-to-rafter attachment might need reinforcement given the heavier weight of the roof. In any event, a photograph of the attic confirms the building drawings, in that in fact there is an air gap between the roof and the rafter. The mounts will run along east-west purlins instead of north-south rafters. So even if the solar array is designed remotely, having the client photograph the jobsite, noting critical locations can provide valuable insight for planning.

With the attention spent on how the solar array attaches to the roof, it is easy to overlook how the roof is attached to the house. Racking companies will provide a strong enough system to attach to the roof in a very solid manner so the question becomes how is the cladding connected to the rafters (particularly important in a standing-seam roof) as well as how are the rafters connected to the load-bearing wall? Identifying the use of hurricane clips in the attic is an important site evaluation item.



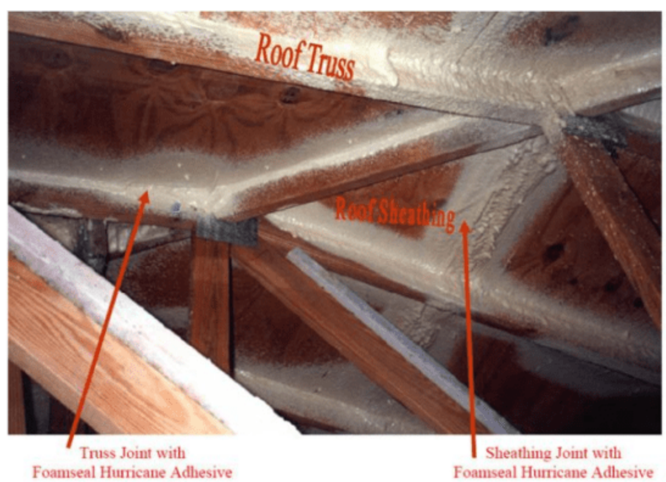


Figure 103 - Oceanside Reinforcement

If the rafters are weak, irregularly spaced, or to make the installer's job easier, adding additional wood blocks under the roof, called daughtering or sistering, can provide solid anchor points without screwing a lag screw into the actual rafter.

Structural Engineering

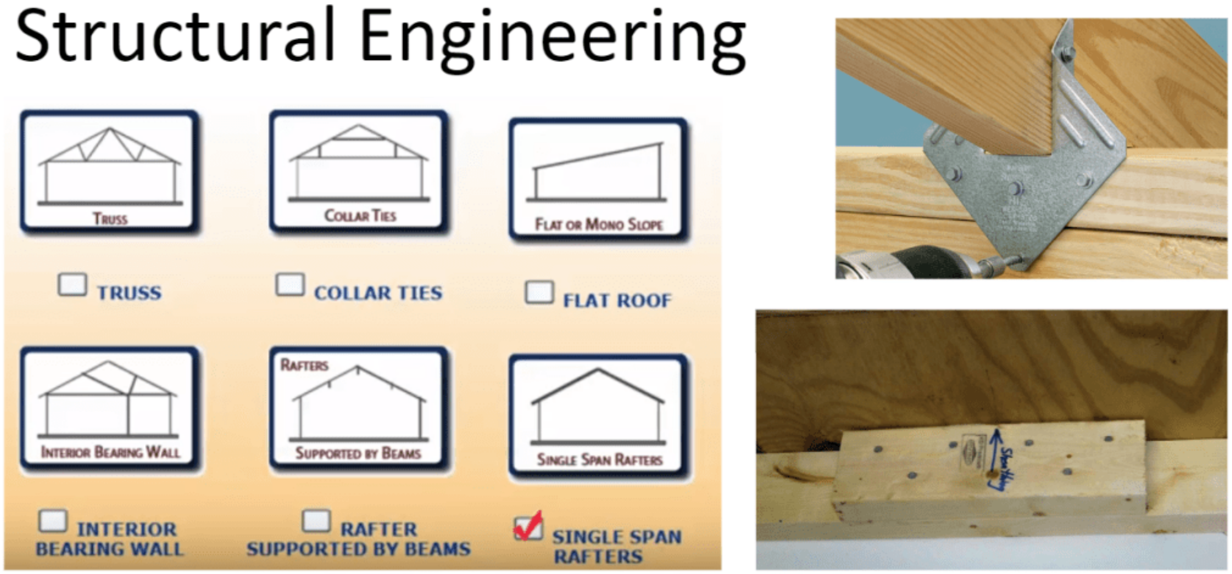


Figure 104 - Structural Engineering

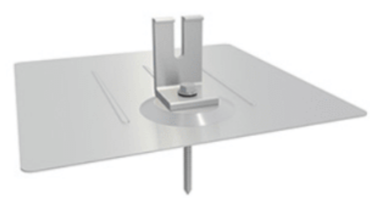
There are even online structural engineering companies specializing in analyzing the roof truss for issues. Keep that in mind when you encounter an unconventional roofing system or weaker roofing system that needs a closer look.

Pull Strength

VersaBracket-47™ - Normal to Seam

Units: SAE Metric | Safety Factor: 3 Reset Test Results

Substrate	Material	Number of Fasteners	Ultimate (lbs)	Failure Mode	Safety Factor	Allowable (lbs)
Wood Deck	1/2" OSB	3[2]	532 lbs	A	3	177.3 lbs
Steel Purlin	16ga Steel	2[1]	887 lbs	A	3	295.7 lbs
Wood Purlin / Rafter	2x4 Timber (2" Vertical)	2[2]	1,317 lbs	A/B	3	439.0 lbs
Wood Purlin / Rafter	2x4 Timber (4" Horizontal)	3[2]	1,886 lbs	A/B	3	628.7 lbs



VersaBracket-47™ - Parallel to Seam

Units: SAE Metric | Safety Factor: 2 Reset Test Results

Substrate	Material	Number of Fasteners	Ultimate (lbs)	Failure Mode	Safety Factor	Allowable (lbs)
Wood Deck	1/2" OSB	3[2]	576 lbs	A/B	2	288.0 lbs
Wood Purlin / Rafter	2x4 Timber (2" Vertical)	2[2]	985 lbs	A/B	2	492.5 lbs
Steel Purlin	16ga Steel	2[1]	1,282 lbs	A/B	2	641.0 lbs

Figure 105 - Pull Strength

Racking manufacturers will often provide an online design tool which provides the loading the solar array will put on to the roof. This manufacturer specializes in attachments for various metal rooftops, showing the load capabilities of the attachment. They make a very popular standing seam clamp, but they also make a very quality lag screw attachments for corrugated metal. The engineering data provided details strengths for different kinds of roofing material. Here is one for vertical rafters when using only two fasteners. With a safety factor of three applied, the attachment provides a 440-pound pull strength. The strength varies depending on the orientation of the attachment. I find it particularly interesting they provide the pull strength for decking, implying the attachments can be placed anywhere on the roof with the right decking underneath.

Residential solar installers today prefer rafter-based lag screws. Decking-based systems are not as strong and solar is very long term. But fewer attachments come with their own problems. Aside from ruckus caused during construction, what causes a roof leak over the long term is the force on these attachment points wiggling back and forth. More attachments mean less force on each attachment. More attachments often mean you can get rid of the rail, reducing the wind load of the array.

So, decking-based racking systems do have some merits even though they are not the preferred option. They could be a valid choice for putting solar on a trailer home where the attic space between the roof and the ceiling of the interior is filled in making rafter identification difficult. Furthermore, the decking-based systems tend to go on top of the shingles rather than under the shingles. A professional solar installer with experience flashing shingles will vouch for the quality of the flashing process, but I think it is the hardest part of the job. A do-it-yourselfer may have better luck with attachments which stay on top of the shingles.

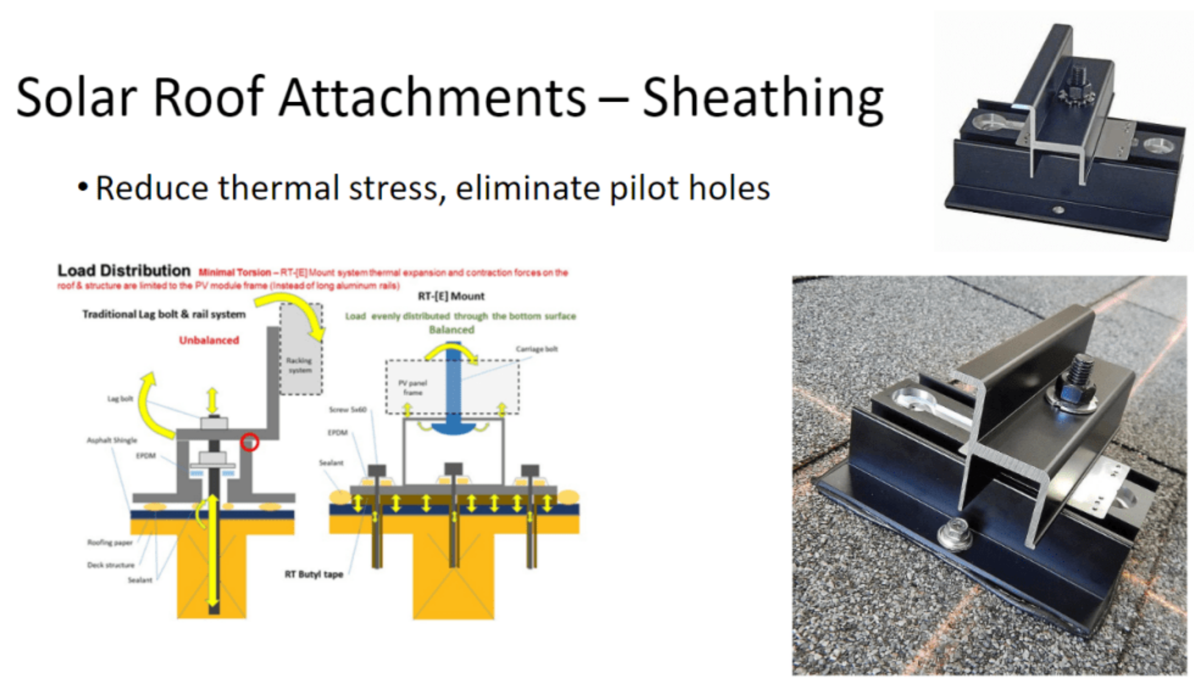
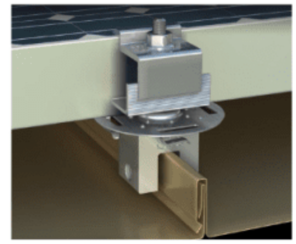


Figure 106 - Rail-less Racking Revisited

Here's an example of a decking based solution made by company *RTE.* Waterproofing butyl tape is placed all around the attachment point.

Solar installers may be dubious of decking-based racking systems, and installing on rail-less systems is more difficult than rail-based systems, especially with regard to cable management. But residential installers use a decking-based racking system all the time, perhaps without realizing it. Standing seam metal roofs are clipped onto the seam, rather than penetrating into any rafters.

Solar Roof Attachments – Metal Roofs



LOAD-SPAN TABLE FOR 12" WIDE STAND'N SEAM® PANELS

		WIND ULPIFT LOAD (psf)											
	SUBSTRATE	1.00'	1.25'	1.50'	1.75'	2.00'	2.25'	2.50'	3.00'	3.50'	4.00'	4.50'	5.00'
24 GA STEEL	16 ga. purlins(CEGS)[1]	319	255	213	182	160	142	128	116	99	87	77	70
	22 ga. deck[2]	214	172	143	123	107	95	86	71	61	54	48	43
	¾" plywood[3]	125	100	84	72	63	56	50	42	36	31	28	25
	½" plywood[3]	79	63	53	45	40	35	32	26	23	20	NR	NR
.040" ALUM	16 ga. purlins(CEGS)[1]	273	218	182	156	136	121	110	105	98	86	76	68
	22 ga. deck[2]	214	172	143	123	107	95	86	71	61	54	48	43
	¾" plywood[3]	125	100	84	72	63	56	50	42	36	31	28	25
	½" plywood[3]	79	63	53	45	40	35	32	26	23	20	NR	NR
.032" ALUM	16 ga. purlins(CEGS)[1]	223	178	149	127	111	99	89	84	79	74	69	64
	22 ga. deck[2]	214	172	143	123	107	95	86	71	61	54	48	43
	¾" plywood[3]	125	100	84	72	63	56	50	42	36	31	28	25
	½" plywood[3]	79	63	53	45	40	35	32	26	23	20	NR	NR

Figure 107 - Standing Seam Uplift Limitations

Here's a load span table for standing seam metal roofs based off the width of the standing seam panel which are usually about 16" so we're looking between 1.25-1.5 feet per standing seam span. The uplift force from the solar array becomes excessive when the attachments get multiple spans apart, spacing I might specify when using a rail-based system attached to rafters. But similar spacing on a standing seam roof could pry the metal panels off the roof during high wind. Because of this, the racking manufacturer recommends attaching to every seam the module transverses, to achieve an even load distribution across the roof decking.

That gives us back to our previous discussion about reinforcing the corners. Perhaps within the interior of the roof you might start staggering your attachment clamps to still hit every seam while distributing out the load. But around the corner regions would want to hit every single point possible.

Of course, getting rid of the rail lowers the array closer to the roof, complicating wire management as well as making it all the more important. Structurally, I think it's important for standing seam, which already has a weak attachment between the metal roofing panel and the support roof underneath. But normally you want some clearance under the array to encourage airflow, and to give you a visual look underneath. Solar installers should aim to have ALL of the cables managed, nearly hidden from sight. It should be easy to tell if a critter is nesting underneath the array.

Clipping to the standing seam of a roof, despite the strength of the clamp, is not as strong as drilling through the roof. A corrugated metal roof with solar screwed into the rafters is stronger than a standing seam metal roof with the solar clipped onto it. But most homeowners doing standing seam metal roofs are paying for the assurance that the roof will not leak. So, they are not so willing to consider structural arguments, preferring the peace of mind of a non-leaky roof. From my experience as an installer, these butyl tape attachment points result in very solid connections. Roof leaks resulting after system installation have been other weak points not addressed during construction, such as skylight flashing near the array (which became a common walkway during construction). In any event, I would not discount the value of using a cheaper but adequate roofing system underneath a solar array during planning process. Thick decking, white rolled shingles, and bi-facial frameless solar panels could achieve maximum solar value, for the same cost as a basic solar array on top of a standing-seam metal roof.

Figure 108 - Metal Roof Attachments

Other kinds of metal roofs are commonly held on by metal roofing screws, bought at the hardware store, which have neoprene washers that provide more waterproofing than a standard roofing nail. Here is a trapezoidal form factor attachment. I suppose the thought is having less rainwater than when the attachment is located down in the valley. My preference is to have the screw bite into something solid, such as a rafter or purlin, even if it means locating a more conventional positive attachment in the valley.

Now that we have a better understanding of racking components, the challenge becomes to convert our array layout – our solar rectangles which now fill the interior of our roof – into a final racking bill of material. Solar racking manufacturers want to make this process as easy as possible on the designer. Essentially the array layout is replicated within the manufacturer-provided sizing tool, to generate not only the force loads on the solar array but also the final bill of material.

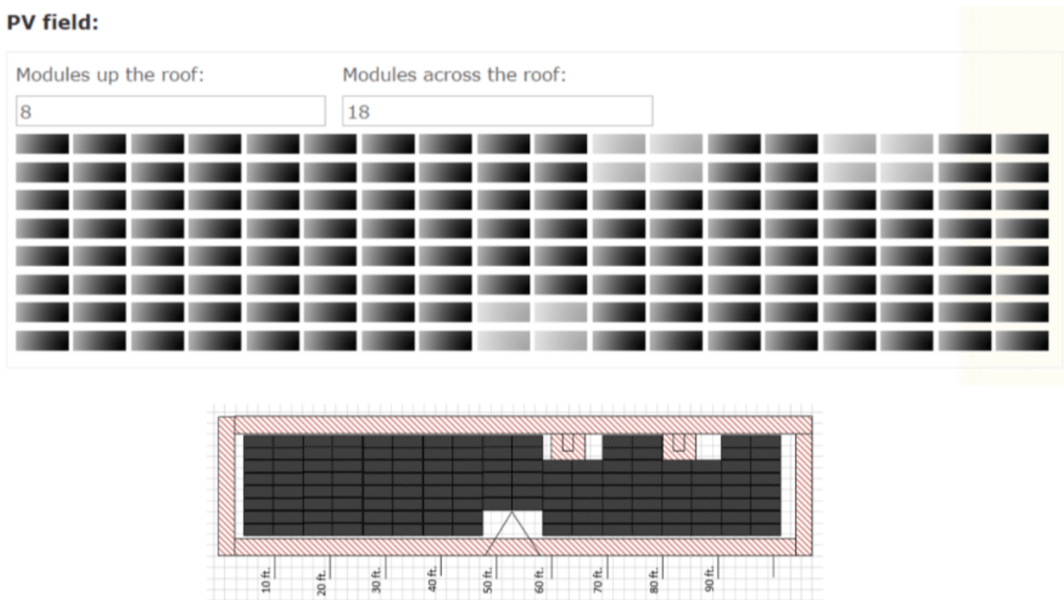


Figure 109 - Manufacturer Racking Sizing Software

Here is a commercial solar array in Wisconsin, an area of heavy snow load. To be a little different, we're modeling a CIGs solar panel, a non-silicon solar panel which comprises a very small portion of the solar market. A landscape layout is selected, and sometimes a landscape array can be a little larger than a portrait array, depending on the actual dimensions of the roof.

As we discussed earlier, on a rafter system, instead of purlins running across the roof, resulting in solar rails going up the roof, resulting in land-scape oriented modules. Rafters would rotate everything around another 90°, resulting in portrait-oriented modules. But in our area of heavy snow, our attachments needed to be 2' on center, so we ran across the purlins east-to-west, resulting in a portrait orientation. Having the rail run east-to-west is best for load distribution, and some solar companies will run east-to-west rail even when mounting in landscape – depending on the clamp zones of the module of course. This is despite the fact that it would require more rail and attachments to do so. And why not? It is possible for the solar array structure to strengthen, rather than weaken, the roof structure if designed correctly. Likewise, running the rails vertically up the roof can result in uneven load distribution, and is sometimes disallowed by the racking manufacturer. Regardless, these are decisions which must be made at this point in the design process and then inputted into the manufacturer racking software.

So, in this design software we're actually taking the array layout and then providing some building details. This software has a more visual layout.

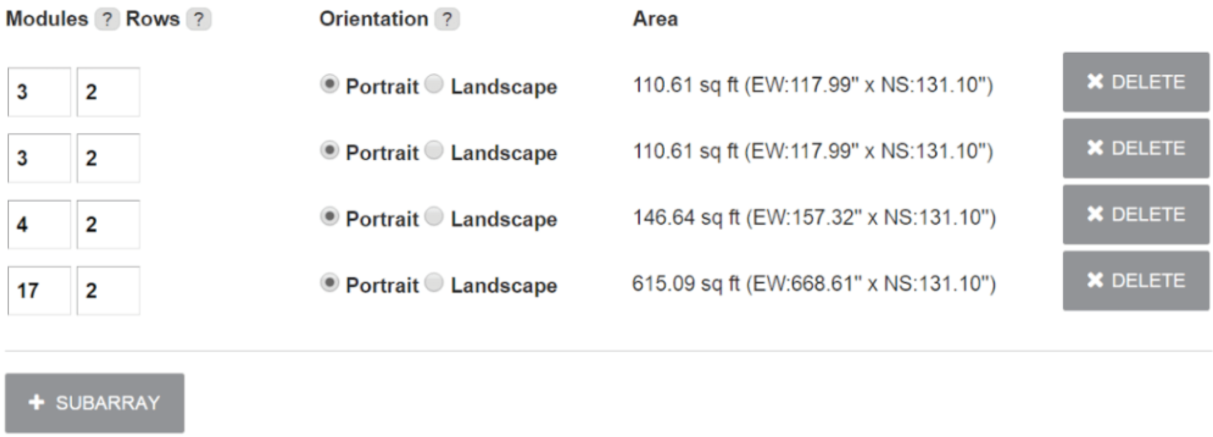


Figure 110 - Alternate Racking Sizing Software Example

Here is another example of inputting an array layout into a racking design software, where the number of rows and columns of array subsections are entered in separately. This section is three columns of modules for two rows. This other section is three modules for two rows. This section is four modules for two rows (the section around the skylights). The last section is 17 modules and two rows.

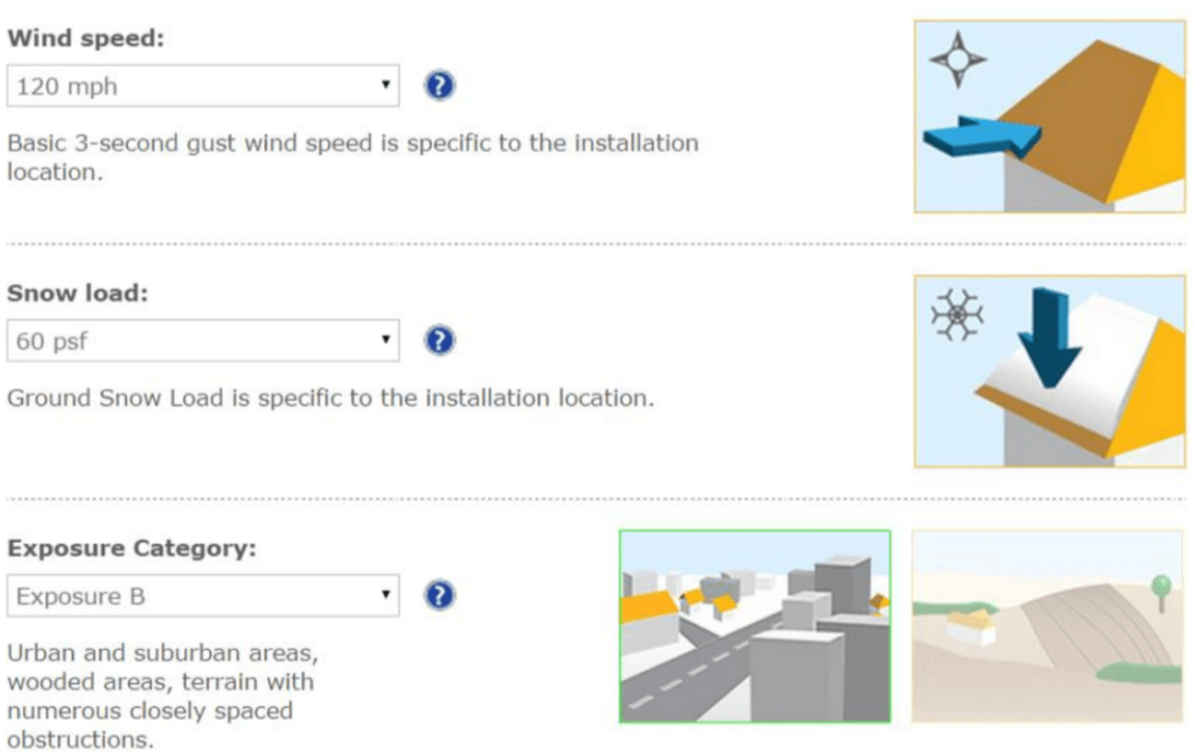


Figure 111 - Considering Wind Impact

The racking design software will ask about the environmental conditions: what's the local wind speed? what's the local snow load? what's the exposure category? Are you to open wind or are there objects around that are going to break up the wind?

Figure 112 - Racking Software Considerations

Then it asks for building details, such as if the array is mounting to north-south \or east-west rafters. Our discussion over purling spacing is not in vain – it's being asked for as an input on this form.

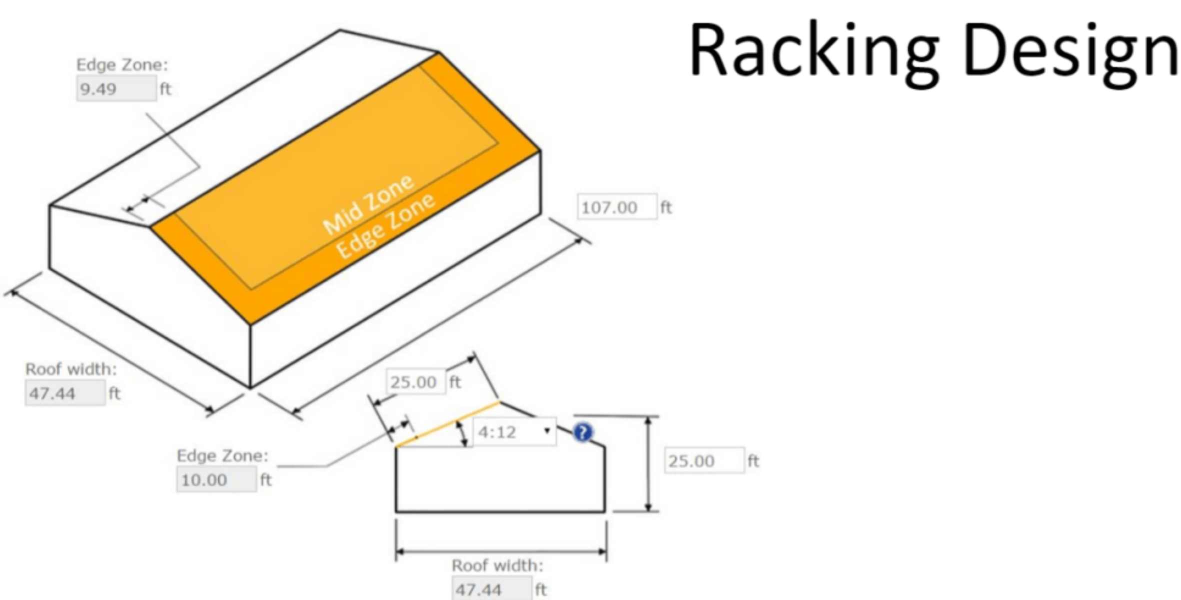


Figure 113 - Modeling Roof Zones

In this example, the racking sizing software is asking about proximity to the edge of the roof. At this point in class, you should understand this information is gathered to allow for sufficient supports exposed to higher wind conditions on the roof. It's nothing too complicated.

	XR10	XR100	XR1000
TOTAL PROJECT COST		$4,900	
MAX SPAN ? [portrait]			
Zone 1	5' 3"	7' 9"	10' 3"
Zone 2	5' 3"	7' 9"	10' 3"
Zone 3	4' 4"	6' 5"	8' 5"
MAX CANTILEVER ? [portrait]			
Zone 1	2' 1"	3' 1"	4' 1"
Zone 2	2' 1"	3' 1"	4' 1"
Zone 3	1' 9"	2' 7"	3' 4"

Figure 114 - Choosing a Rail Thickness

At the end, the array layout and building information is inputted, and it recommends different kinds of solar racking. Let's call them the XR10, XR100, and XR1000 which has a maximum span of 5' 3" except for zone 3, which has a smaller span as the edges of the roof experience higher wind speeds. The interior of the roof is zone 1, the roof cap and eaves are zone 2, with the corners being zone 3.

The XR10 has a lesser span the XR100. The XR1000 has the longest span. IS the longest span the most desirable? The longer the span, the fewer attachments needed to be installed.

Racking Design

ZONES (portrait)	DOWN ↓ (lbs) ?	UPLIFT ↑ (lbs) ?	LATERAL ↔ (lbs) ?
Zone 1	170.0	-103.0	39.0
Zone 2	170.0	-212.0	39.0
Zone 3	170.0	-335.0	39.0

WEIGHT

Total Weight: 2800 lbs.

Weight / Attachment: 28.0 lbs.

Distributed Weight: 2.8 psf

Figure 115 - Understanding Attachment Loads

While it is common for engineering to specify spans less than what the racking system is rated for, deferring to smaller spans for better load distribution across the roof truss. So, a solar array might not get much use out of the thickest rail gauges which could allow for longer spans. A strong and cost-effective may be to go with a cheaper rail and conservative attachment spacing.

A **cantilever span** is provided as well, important to achieve the hover-like effect where all the cable and racking are tucked underneath the array rather than sticking out the edges. The last attachment on the roof is placed within the cantilever span of the array perimeter, such that the last bit of solar rail will be cantilevered.

The L foot attachment supporting the rail is lag screwed into the rooftop, the rail that attaches to the raised side of the L foot, and the solar panel lands on the rail, with the last solar panel overhanging the final L-foot attachment. Because if it stuck outside the array, that would look ugly.

So, here's our cantilever for the last rail and the final module lands on it. This can be pre-cut down on the ground if you are good with your measurements or can be cut very carefully up on the rooftop with a portable bandsaw. The racking manufacturer probably has a plastic cap to cover the nub of cut rail, hiding any rough edges visually. Some more expensive racking systems will even plan for a (rather difficult to install) bolt for the array edge to be placed on the underside of the module frame, to get rid of the last little rail clamp that would barely stick out the side of the array – to achieve a very high end look. I don't think it's that big of a difference compared to what you can get with a quality but lower end racking system.

Moving along in the software, the array layout, location, and attachment spacings are defined. The numbers are crunched to provide the downward, uplift, and tangential forces on each attachment. In this example, there is a down force of 170 lbs and an uplift force of 100 lbs. The corners of the roof have forces three times that amount. This reinforces what we already know, which is that the corners of roof and the corners of the array will experience stronger wind load than the interior of the array. Moving the array in a few feet from the interior will reduce the load on the array, but even so the corners of the array will experience greater wind load than the interior.

Going back to previous course information, we can select particular S5 metal roof attachment because we now know that the clamp is rated for the local environmental forces, with a safety factor of three applied. But we also know to avoid the corners of the roof, which would actually fail if we were using a decking-based racking system. But we also know the interior of the roof could support a decking-based racking system (except this particularly jobsite does not have any decking, opting for purlins instead). In short, the racking manufacturing software can be a source of structural information.

Part No.	Description	Spares	Qty.	MSRP Ea	Price
XR-100-132A	XR100, Rail 132" (11 Feet) Clear	0 Edit	24	$58.00	$1,392.00
XR-100-168A	XR100, Rail 168" (14 Feet) Clear	0 Edit	8	$73.80	$590.40
RS-GD-MCL-275	Kit, 4pcs, Grounding Mid Clamp 2.75", Clear	0 Edit	23	$14.00	$322.00
29-7000-204	4-pack, End Clamp (G) 1.97", Mill	0 Edit	8	$12.00	$96.00
RF-FLSH-001	6-pack, IronRidge FlashFoot (Mill)(L-foot, lag-bolt included)	0 Edit	17	$132.00	$2,244.00
XR-100-SPLC	Kit, Splice XR100, Mill (1)	0 Edit	16	$8.00	$128.00
RS-GDST-001	Kit, 2pcs, Grounding Strap	0 Edit	4	$18.00	$72.00
RS-GDLG-002	Kit, 2pcs, Grounding Lug T-Bolt	0 Edit	4	$14.00	$56.00
				Total Price Ext	**$4,900.40**
				Price/ Watt	**$0.36**
				Total Weight	**419 lbs**

Figure 116 - Racking Bill of Material

Our final rail is selected, resulting in a racking **bill of material.** The report provides how many sticks of rail are needed, as well as the associated clamping hardware such as mid clamps, flashing, lag screws, rail-to-rail splices, grounding straps, etc. The racking manufacturer may provide multiple lengths of rail to reduce material waste, or particular lengths may be specified to improve shipping and handling logistics. Freight drivers hate how long sticks of solar rail sit take up space in a long-haul freight trailer. Many solar installers have had long sticks of solar rail lost in transit. Hauling long sticks of solar rail to site can be complicated too.

Inverters

To complete our specialty material list, we must learn about inverters.

Remember that solar cells are prepackaged into solar modules, and circuits of solar modules are nicknamed by industry jargon as strings.

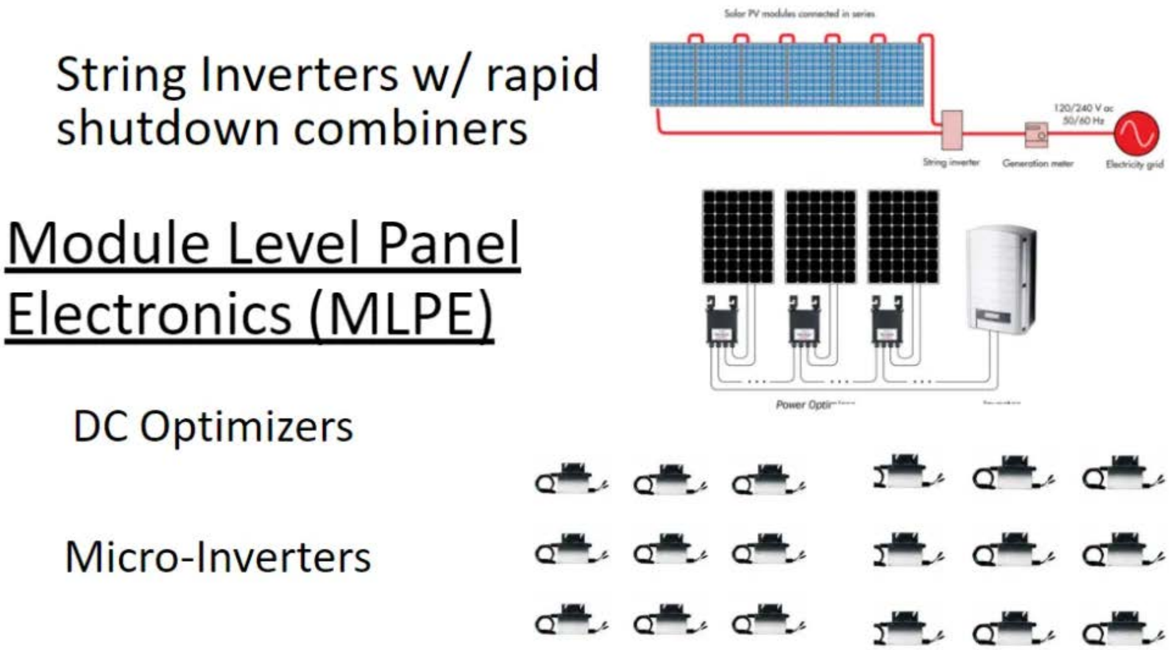


Figure 117 - Inverter Selection

So, there's an inverter called a **string inverter** that usually inputs multiple strings. The opposite approach is to use **microinverters** where there's one inverter installed behind every single module on the roof. Microinverters are particularly interesting because the produce AC instead of DC output up on the roof, eliminating the DC home run cable requirement to be in metal. Which I think is nothing more than DC discrimination.

Then there's another system that is somewhat of a hybrid between the two, called **DC optimizers.** It is like a microinverter system as there's an electronic box installed behind every solar module providing similar benefits, but DC optimizers only regulate DC voltage rather than outputting AC. The DC to AC inversion instead happens at a string inverter down on the ground. The string inverter has less stuff in it, because the voltage has already been converted by the optimizer on the roof.

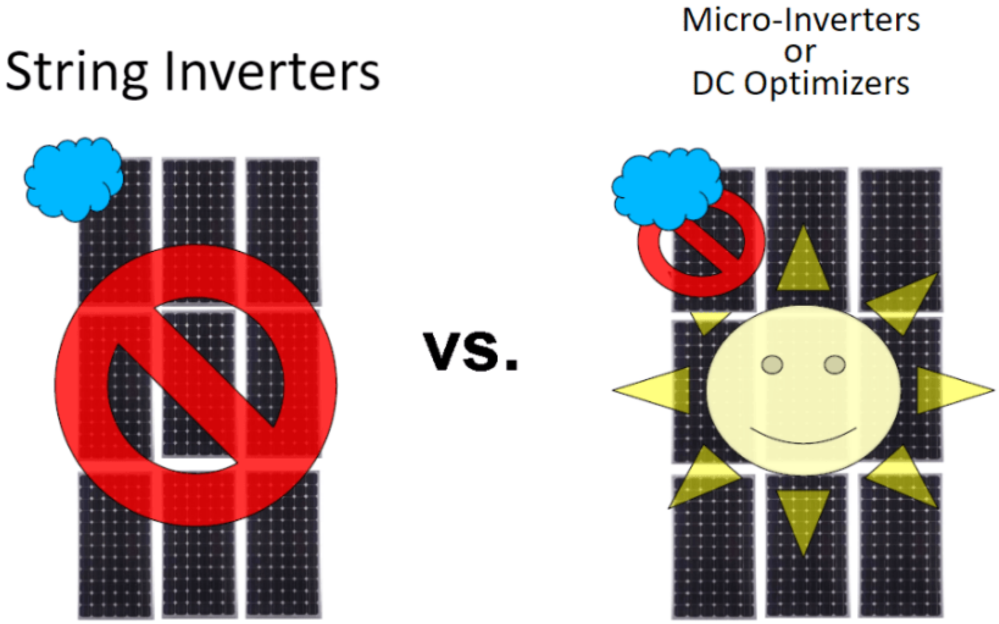


Figure 118 - Shade Impact

Both micro-inverters and DC optimizer systems are more expensive than string inverter systems. But string inverter systems are less accommodating of shade. Likewise, updates in electric code strongly encourage, if not mandate, the use of module-level control boxes on rooftop solar arrays. Counter to that mandate is a real concern that putting a bunch of electronic boxes on a dangerous roof is a bad idea. The sad reality is that if a box fails on a roof, the best answer may be to leave it be until another box fails, rather than incur the cost of servicing the equipment. String inverters have fewer failure points. But these boxes serve an important safety feature, which is to de-energize the solar array if ever the need arises.

But that's not why these boxes were invented. originally it was about shade. At a very basic level, if one solar panel becomes shaded, it can have an impact on the entire circuit. Likewise, one circuit can have an impact on other circuits. At the very least, shading causes the inverter to get confused as the voltage jumps around, resulting in lower efficiency. It used to be that a tiny amount of shade would shut down the entire system. Both DC optimizers or micro-inverters allow the solar modules to function independently, meaning a shaded solar panel would no longer shut down the entire circuit or system. But inverter electronics have steadily advanced, and most have the ability to control multiple circuits independently. Still, the loss of an entire circuit on a residential solar array is not unsubstantial. The general rule of thumb is that any shaded solar site should be a microinverter or DC optimizer jobsite.

This also lets you install on more of the roof, and care less about shade. A sundial-like shadow cast from a chimney used to be avoided like the plague. But now it becomes a usable mounting surface (with a 4' clearance for servicing). A solar panel with some shade might not be as productive as its neighbors, but economies-of-scale of a larger project can make up for it. So, the microinverters and DC optimizers really solved the temporary shading issue.

Which are better? Micro-inverters or DC optimizers? It depends who you ask, with most installers preferring DC optimizers but many do-it-yourselfers opting for micro-inverters.

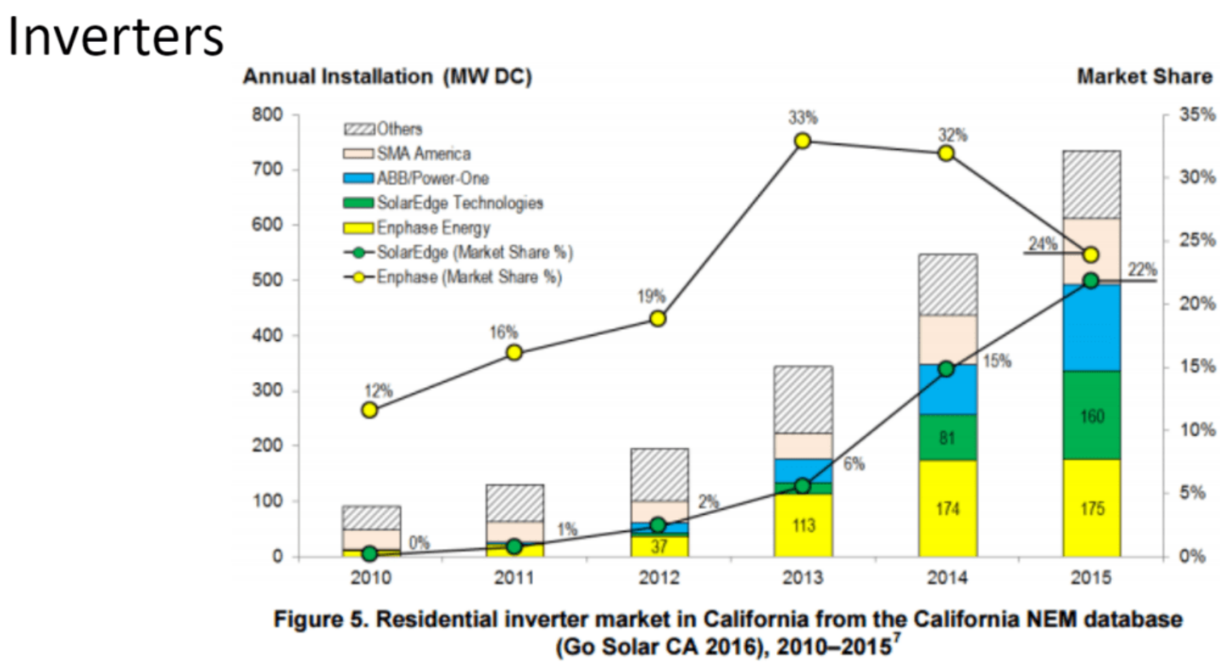


Figure 119 - Inverter Market Share

Microinverters came to market first, and are primarily made by a company Enphase. The DC optimizer solution is primarily made by a company called SolarEdge, which came to market a couple years later but is not larger than Enphase. DC optimizers remain a competitive solution even up into the commercial rooftop market. Commercial micro-inverters can be found even on 480V systems as well.

Figure 120 - String Level Panel Electronics

Micro-inverters take the solar panel DC input and output the same electricity as used in your home or business (ex. 120/240V split phase AC, 208 three phase AC). DC optimizers are different. They take the variable solar power and fix its voltage, in conjunction with other panels, to keep the circuit voltage constant. Not only is that easier on the inverter at the end of the circuit, but by raising the output voltage of the system, it reduces the amperage. This means more solar panels can be added to a DC optimizer system than on a string inverter system. Longer circuits mean a single pallet of solar panels can be distributed over two circuits instead of three, reducing the cost of the expensive MC cable. Micro-inverters, on the other hand, are very easy on electricians who are new to solar, because it places them back at home with AC electrical wiring. Micro-inverters mean the vast majority of the system equipment is on the roof. A roof is a rugged environment, a place where equipment failure should be expected. At the same time, it is tucked nice and neat, out of the way.

Buying a micro-inverter for every solar panel on the roof is expensive, compared to buying one large inverter for the entire system. SolarEdge splits the middle in terms of price being less expensive than micro-inverters but more expensive than string inverters. But string inverters have fallen out of favor in National Electric Code.

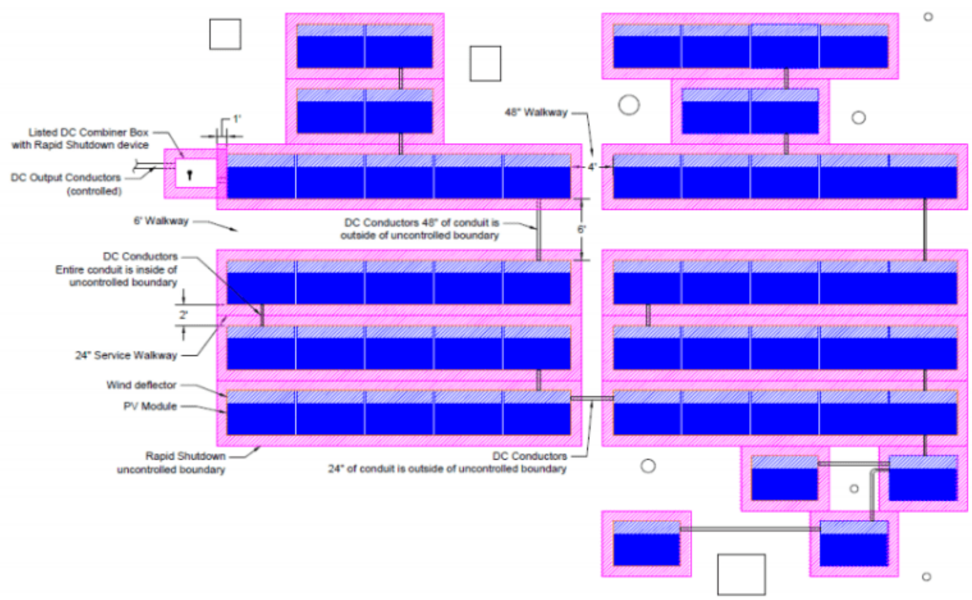


Figure 121 - Rapid Shutdown Boundaries

National Electric Code now says that any conductors outside of the array perimeter must be de-energized. It's a section that continues to be redefined and constricted. Recent solar fires by Tesla bring this importance back into focus. If there is something going wrong with the solar array, it can be turned off outside a 1' perimeter. The strictest and most common interpretation of the most recent code mandates the use of **module level panel electronics** on the roof, such as micro-inverters or DC optimizers. Because if the solar array is causing or contributing to a fire on a sunny day, it can become difficult and dangerous to turn off. Microinverters and DC optimizers can turn the module off completely. String inverters would only turn off the array at the circuit level.

These changes to National Electric Code have essentially left string inverters for other markets, such as ground mounts at the residential level. At the utility-scale level, string inverters are much larger, called central inverters, but essentially do the same thing as string inverters but with more circuits.

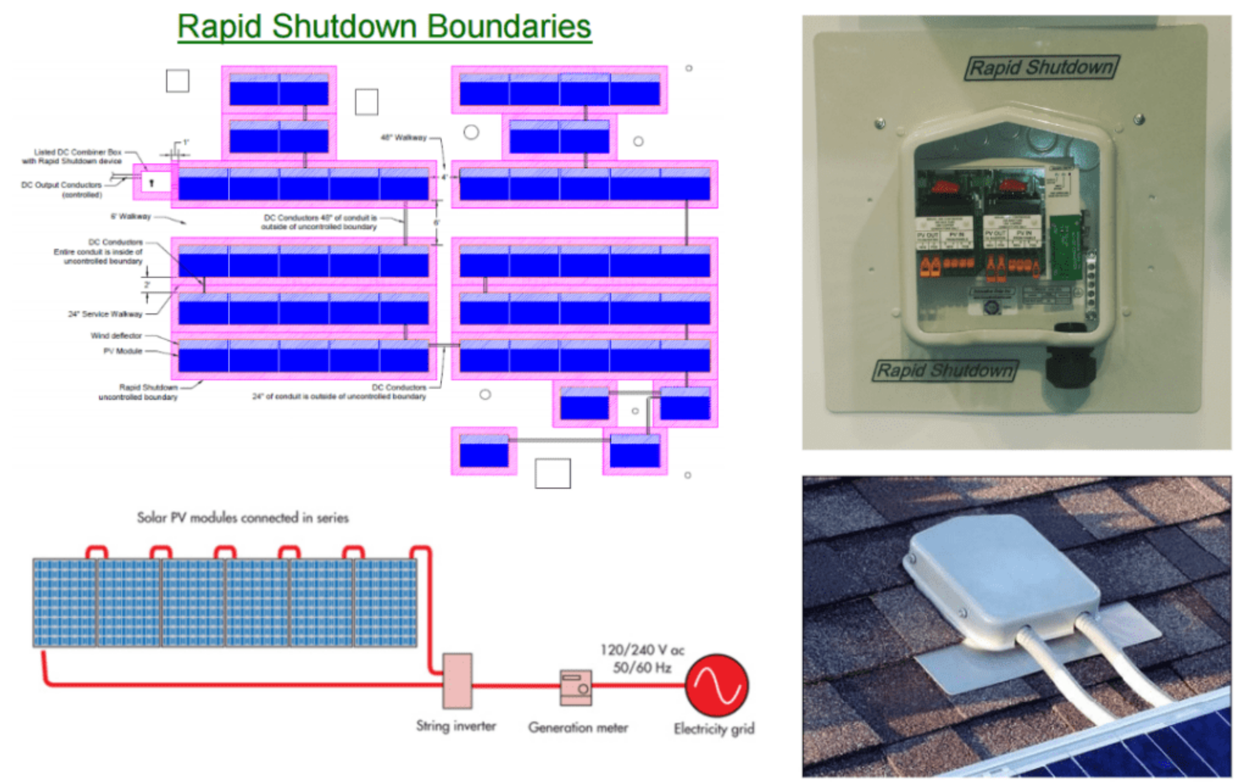


Figure 122 - String-Level Shutdown May Be Insufficient

Sometimes it can make sense to use a string inverter on a roof. Code does allow for the use of string inverters if your transition box is located within the 1' array perimeter and can disconnect the array circuits at the circuit level. The array can then be field labeled to explain the rapid shutdown system being used. So, the rooftop transition box may not just be a simple junction box, but contain some intelligent electronics to facilitate power optimization and rapid shutdown requirements. But these boxes are hard to find – only a few string inverter manufacturers offer them under their own brand. It is unclear whether such string-level boxes, as well as string-level micro-inverters will be phased out at a later date, with an iron-clad requirement for module-level shutdown during an emergency.

Jumper cables now apply to rapid shutdown. So, if the design calls for disconnected subarray sections, module level panel electronics are the best option. My point is it's not true that string inverters are completely banned from jobsite, it's just that they are only allowed in limited circumstances. Unless you are planning a utility-scale project, you can't go wrong on your first project by using DC optimizers or micro-inverters.

I like string inverters. I like their simplicity and cost-effectiveness. They're perfectly reasonable for unshaded arrays. As the rapid shutdown box must be located within a 1' perimeter of the array, you could accomplish this by putting string-level optimizers underneath the array inside the attic.

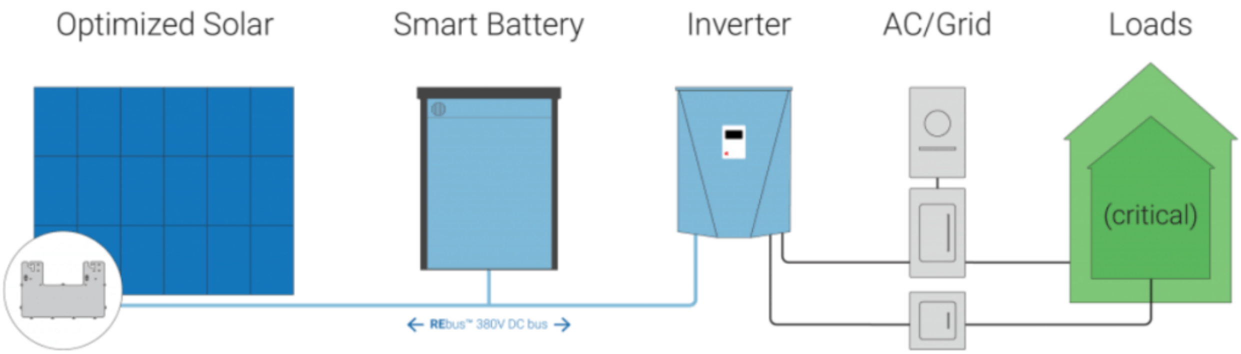


Figure 123 - Optimizing DC for Batteries

Pika – a Portland Maine based inverter startup recently acquired by Generac has such a product. I like that idea as the attic is usually more accessible than the roof. I like the idea of a serviceable box in the attic as compared to having to service every single optimizer up on the roof, so I hope an iron-clad mandate for optimizers and micro-inverters doesn't happen. But there is an uptick in safety function along with the cost increase of module-level panel electronics.

So, in general the string inverters are the cheapest option and great for unshaded ground mounts. DC optimizers are a lower cost option than AC micro-inverters and are functionally competitive with micro-inverters, so many rooftop installers use DC optimizers. But AC micro-inverters are also a popular option, especially for first-time installers.

Let's spend a little more time discussing solar power during emergencies. When there is a problem with the grid, the solar array must disconnect from the grid. But in order to cut costs while connecting solar to the grid, inverter manufacturers and solar designers removed the expensive parts required to run a building fully off-grid. Instead of emergency power, solar design has largely focused on electric bill reductions. The cheapest way to add solar to the grid is to have it simply turn off whenever the grid is offline. And so most residential solar power installed in the United States to date is unable to supply power during a blackout. This might be of use to grid operators who install distributed storage facilities. The entire grid needn't fail when a primary distribution branch needs servicing. But electrical distributors in general are pretty far away from figuring out how to optimize a distributed power grid to take advantage of consumer-owned solar and batteries.

It's not just the battery that is expensive. Inverter requirements to run a house are larger, as are the requirements to switch a house-sized electric load between on and off grid operating modes. Because of cost, most grid-tied solar homes with batteries still do not supply power to the whole house, but only protect critical loads smaller than a central air conditioner. It is kind of cool that completely off-grid inverters don't have the same five-minute safety provisions which lock the inverter from operating until the grid has been stable for five minutes (to ensure service personnel enough time to bring the grid back online). In other words, it's nice that with off-grid components, they immediately turn on when you turn on the power switch instead of waiting around for five minutes. This is more of an advanced issue which we cover in later classes. Let's return to more basic battery-less solar inverter design.

How do you determine how many modules go on a circuit on a particular inverter system? How do you determine which module is compatible with which optimizer or microinverter? Just like racking manufacturers, inverter manufacturers provide online software to assist the design process. They take the specific information from the module spec sheet, such as the voltage, amperage, and temperature coefficients and use that information to suggest configurations which are possible using their products.

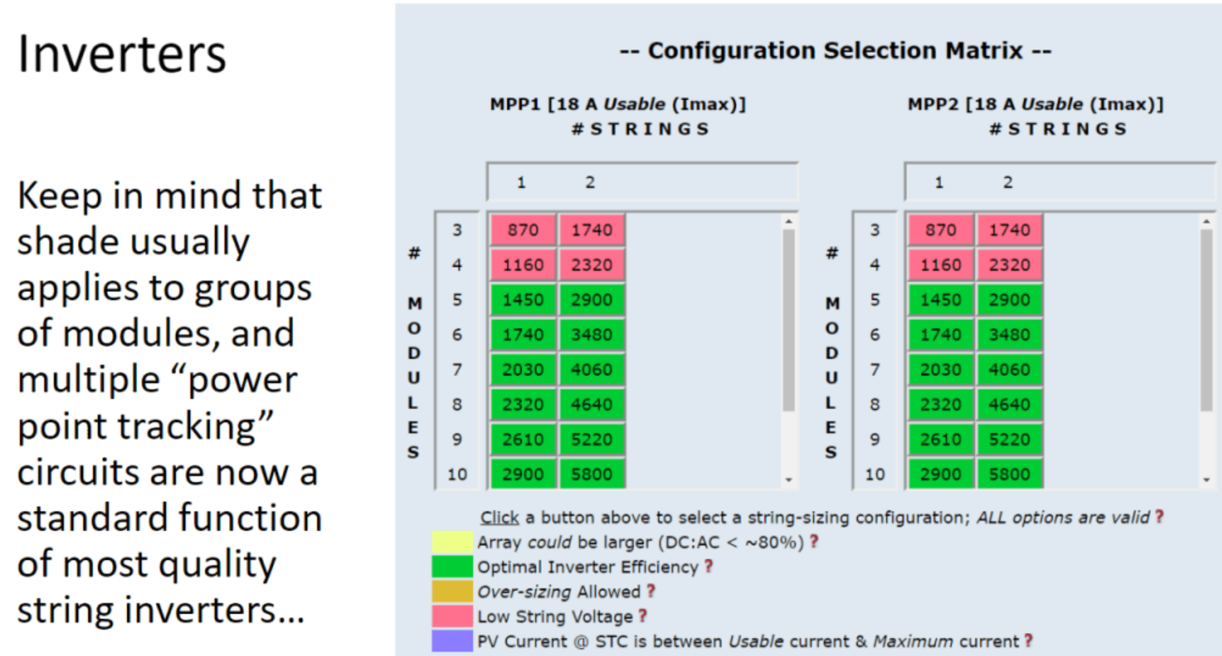


Figure 124 - Inverter Manufacturer String Sizing Software

Fronius makes a popular string inverter and here is their string inverter sizing software. The process is similar to all other software. The solar module is selected. My suggestion is to sign up for distributor email lists to know which panel can be purchased for a good price at a given time. From PVWatts, the maximum inverter size can be determined, which is typically around 20% undersized although under sizing more or less is not unusual. With DC-optimizers, you might go for a 10% undersize. But if the pallet of solar panels is 8kW then it is appropriate to select a 6-7-kilowatt inverter. After both the modules and inverter are selected, the sizing software reveals all the acceptable wiring configurations of the components. It's possible to have two circuits of five panels, one circuit of seven panels, one circuit of 10 panels, or two circuits of five, six, seven, eight, nine, or ten panels. This particular inverter has two tracking points which can accept two strings each. Shade on one string would only effect one tracking point. An inverter with **multiple power point tracking** could manage two different solar arrays, such as one facing east and the other facing west. With multiple-power-point tracking you could even get funky. Say a pallet of solar has 25 panels. This inverter could accommodate two circuits of eight solar panels facing southeast and one circuit of nine panels facing southwest for a twenty-five-panel system working on a single string inverter.

Inverter Sizing Software

- *Module Product #*
- *Quantity*
- *Location*
- *Tilt Angle*
- *Orientation*

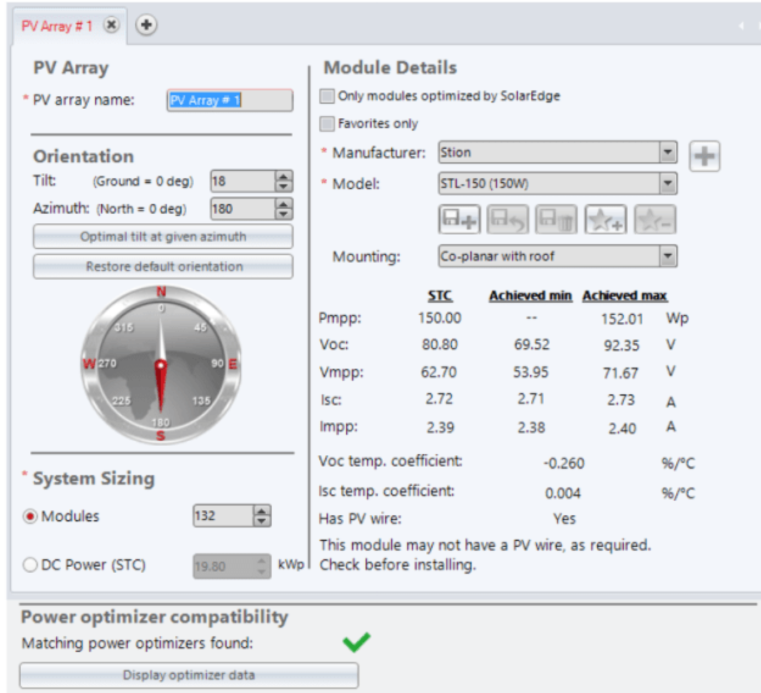


Figure 125 - String Sizing with DC Optimizers

Here's a string sizing example using SolarEdge using high voltage, low amperage CIGS solar panels. Thin-film panels commonly have higher voltages, and lower overall wattages, so this design process accommodates a wide range of solar panels.

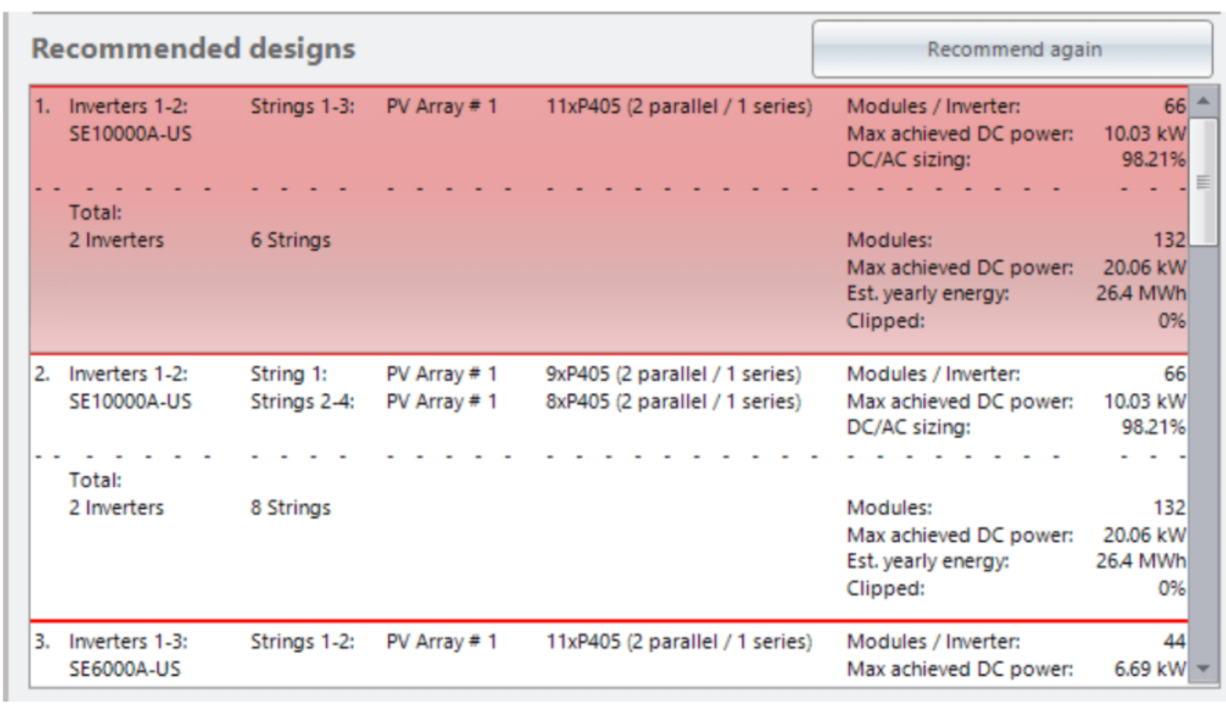


Figure 126 - DC Optimizer Selection

For our 132-panel layout, it says that 132 panels are a 20 kilowatts array and suggests using two 10kW inverters, using a total of six circuits. It selects a DC optimizer to accommodate the unusual solar panel – in this case the P405 model.

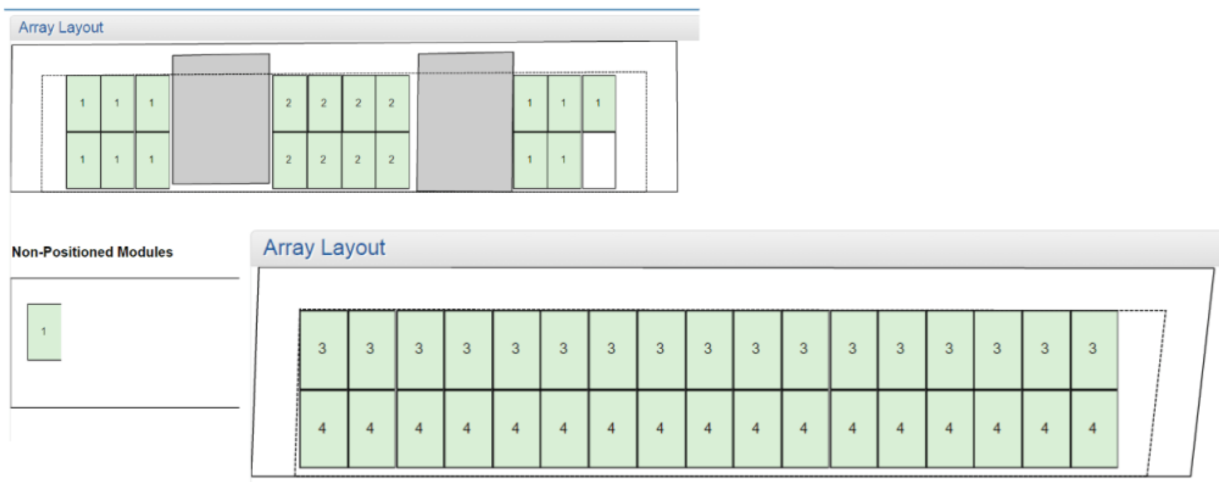


Figure 127 - Circuit Layout

Now that we know the number of circuits the array will have; the next design step is to identify where the start and stopping part of each circuit. This information is useful in determining where the home run circuits will land on the array up on the roof. Special care should be taken during information to make sure these circuits are plugged up correctly. Having these locations planned in advance reduce mistakes in the field.

There are two approaches to circuit layout. I think it's best to use more circuits if necessary, in order to have the circuits start and stop at logical places.

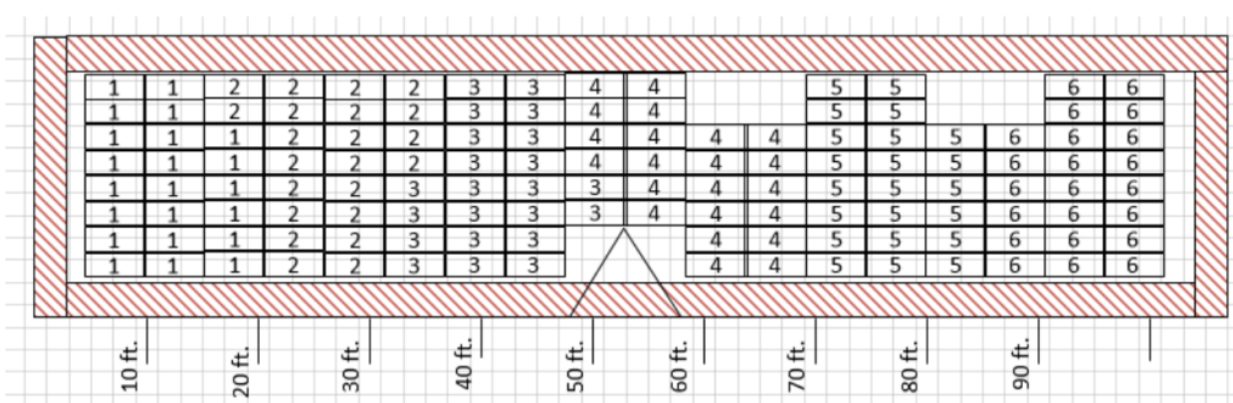


Figure 128 - Circuit Layout Typical

The alternate approach is "snakes in a basket" where the circuits randomly start and stop as a winding line is drawn throughout the array. So, if the first circuit starts, here and it ends here the second circuit starts here and it ends here, and that makes a very compact design. But then if you don't have this map, it becomes hellacious in terms of servicing the array, especially if you do not have the circuit diagram. Try to keep your circuits in clear, logical layouts simple enough for a solar installer to figure out through visual inspection.

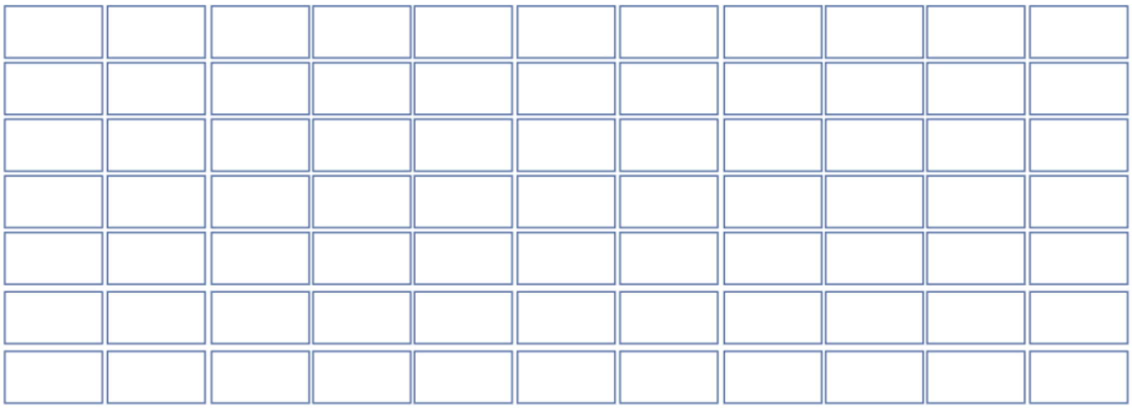
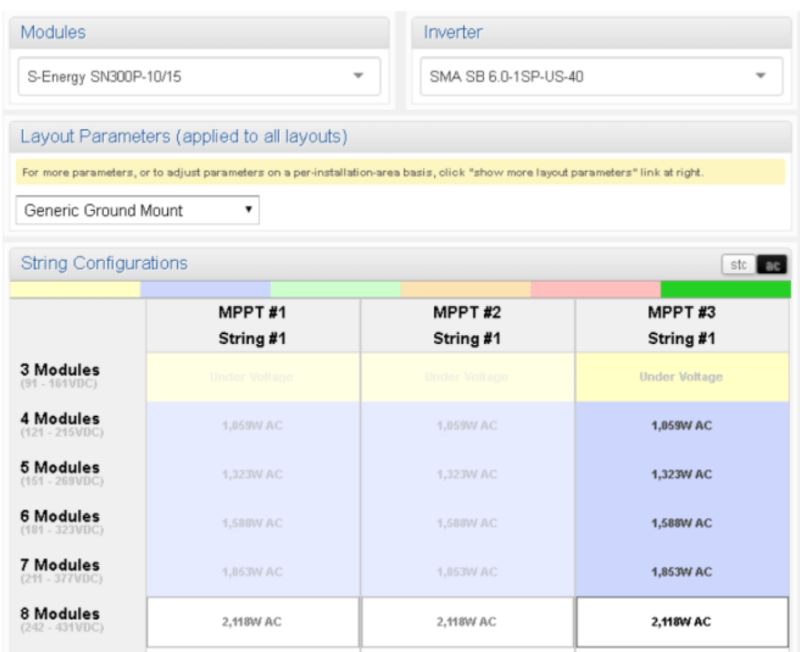


Figure 129 - Circuit Layout for Future Maintenance

But this map of how many modules go on which circuit and where is commonly committed from project documentation. As another example, here is an array with one two three four five six seven eight nine ten eleven panels by one two three four five six seven panels and so we have 77 module solar array. If we went with 11 panels per circuit with a landscape configuration, our circuits would start and stop nice and logically. Alternately we could route the circuits using a snakes in the basket approach, where the first circuit goes here, 1 2 3 4 5 6 7 8 9 10 11, the second goes here 1 2 3 4 5 6 7 8 9 10 11 , the third goes here 1 2 3 4 5 6 7 8 9 10 11, so it's the same number of circuits and same number of modules per circuit, but its more disorganized. Try to keep your circuit layouts make sense to the next person who comes along to service it.



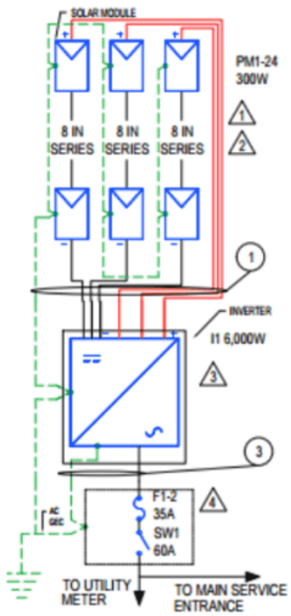
	MPPT #1 String #1	MPPT #2 String #1	MPPT #3 String #1
3 Modules (91 - 161VDC)	Under Voltage	Under Voltage	Under Voltage
4 Modules (121 - 215VDC)	1,059W AC	1,059W AC	1,059W AC
5 Modules (151 - 269VDC)	1,323W AC	1,323W AC	1,323W AC
6 Modules (181 - 323VDC)	1,588W AC	1,588W AC	1,588W AC
7 Modules (211 - 377VDC)	1,853W AC	1,853W AC	1,853W AC
8 Modules (242 - 431VDC)	2,118W AC	2,118W AC	2,118W AC

Figure 130 - Alternate String Sizing Example

As another string sizing example, here is an SMA inverter. SMA inverters are unique because they have a batteryless “secure power supply” option that can provide power during a blackout with batteries, as a plug-in. It’s only a plug-in and can only power 2kW of power, so some installers call the feature a gimmick. But even so, SMA has a good platform for adding on battery inverters and even expanding a micro-grid platform. Anyway, this inverter has three PowerPoint trackers and shows the different acceptable circuit options which can be combined to fit your array layout to an elegant circuit layout. So very inverter manufacturer has some iteration of this kind of software on their website.

In this case we pick our cost-effective 295-watt solar panel. The array size is 8 kilowatts a pallet so we select a 7.6kW inverter to have a slight undersize. Here we specify a 600-volt array, and the environmental temperature range. In the summer time, heat drags down the array performance and, in the winter, the temperature will raise the voltage, so available circuit options will vary slightly be regional temperature to stay within the operating conditions of the inverter. If 26 solar panels come in a pallet then I might do 13 solar panels on each side for a well-balanced system. Maybe the roof would better allow for two circuits of seven panels and one other subarray with one string of 12 panels for a 26-panel array. That’s also a viable configuration. Or one string of 13 and one string of 13 is also viable so **string sizing software** is simply a method of telling the designer which circuit options are valid within the limits of slight under or oversizing. But once we are done selecting our circuit layout, we are ready to complete our balance of system material list.

The remaining system material can readily be purchased by a local electrical contractor, so the next stage is to convert the preliminary design into a more finished design ready for project permitting. This may not be a final detailed design, but rather something simpler for a utility to review and an installer to interpret. Nonetheless, a good rule of thumb is the more project definition upfront, the better the result.



MODULES

REF.	QTY.	MAKE AND MODEL	PMAX	PTC	ISC	IMP	VOC	VMP	TEMP. COEFF. OF VOC	FUSE RATING
PM1-24	24	S-ENERGY SN300P-10/15	300W	271W	8.88A	8.44A	44.9V	35.6V	-0.135V/°C (-0.3%/°C)	15A

INVERTERS

REF.	QTY.	MAKE AND MODEL	AC VOLTAGE	GROUND	MAX OCPD RATING	RATED POWER	MAX OUTPUT CURRENT	MAX INPUT CURRENT	MAX INPUT VOLTAGE	CEC WEIGHTED EFFICIENCY
I1	1	SMA SB6.0-1SP-US-40 (240VAC)	240V	FLOATING	35A	6,000W	25A	30A	600V	97.6%

DISCONNECTS

REF.	QTY.	MAKE AND MODEL	RATED CURRENT	MAX RATED VOLTAGE
SW1	1	SQUARE D D222NRB OR EQUIV.	60A	240VAC

OCPDS

REF.	QTY.	RATED CURRENT	MAX VOLTAGE
F1-2	2	35A	240VAC

SYSTEM SUMMARY

	MPPT #1	MPPT #2	MPPT #3
MODULES IN SERIES	8	8	8
ARRAY VMP	284.8V	284.8V	284.8V
ARRAY IMP	8.4A	8.4A	8.4A
ARRAY VOC	359.2V	359.2V	359.2V
ARRAY ISC	8.9A	8.9A	8.9A
ARRAY STC POWER	7,200W		
ARRAY PTC POWER	6,509W		
MAX AC CURRENT	25A		
MAX AC POWER	6,000W		
DERATED (CEC) AC POWER	6,000W		

NOTES

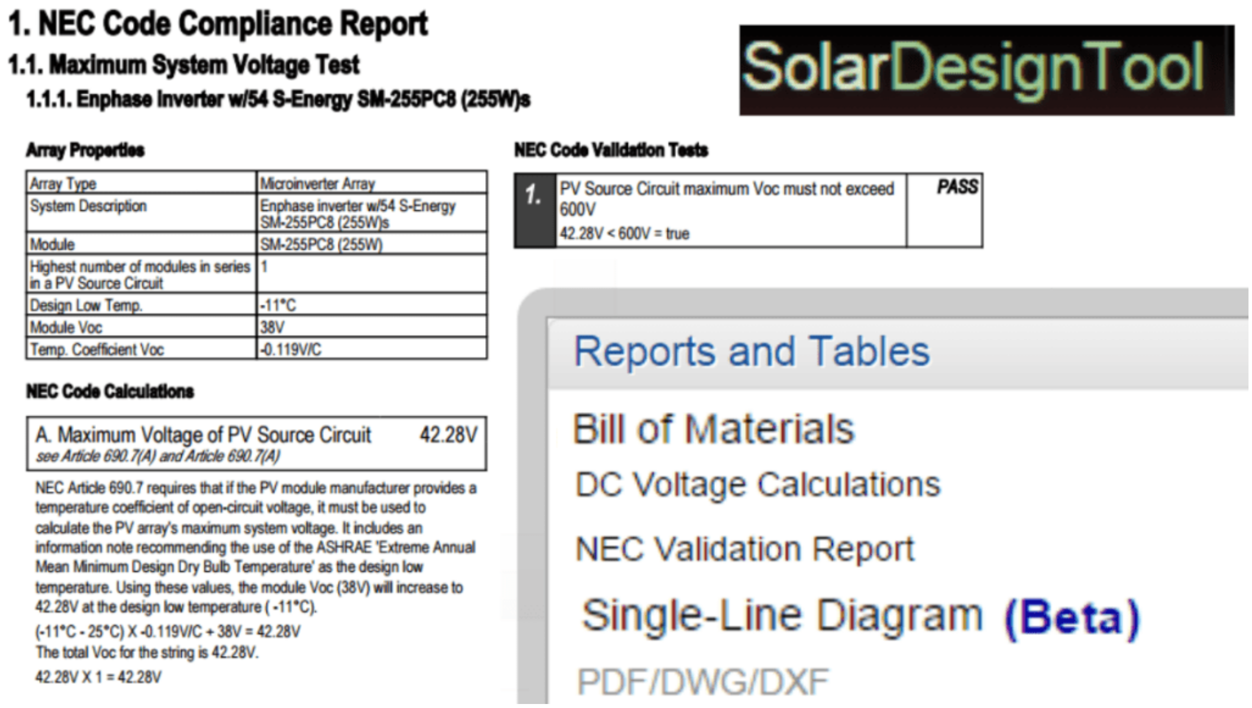
1. UNGROUNDED SYSTEM DC CONDUCTORS SHALL BE COLOR-CODED AS FOLLOWS. DC POSITIVE SHALL BE RED (OR MARKED RED) AND DC NEGATIVE SHALL BE BLACK (OR MARKED BLACK)
2. MAX DC VOLTAGE OF ARRAY IS EXPECTED TO BE 430.6V AT -41°C ((-41.11°C - 25°C) X -0.135V/C + 44.9V) X 8 = 430.6V).
3. THE SMA INVERTER IS NON-ISOLATED. NEITHER THE NEGATIVE NOR POSITIVE CONDUCTOR IS GROUNDED AND THEREFORE NO DC GEC IS REQUIRED.
4. OUTPUT OF INVERTER IS CONNECTED TO UTILITY ON LINE SIDE OF SERVICE DISCONNECT.

CONDUCTOR AND CONDUIT SCHEDULE W/ELECTRICAL CALCULATIONS

ID	TYPICAL	CONDUCTOR	CONDUIT	CURRENT-CARRYING CONDUCTORS IN CONDUIT	OCPD	EGC	TEMP. CORR. FACTOR	CONDUIT FILL FACTOR	CONT. CURRENT	MAX. CURRENT (125%)	BASE AMP.	DERATED AMP.	TERM. TEMP. RATING	AMP. @ TERMINAL
1	2	10 AWG PV WIRE, COPPER	FREE AIR	N/A	N/A	6 AWG BARE, COPPER	0.71 (57°C)	1.0	11.1A	13.87A	55A	39.05A	60°C	40A
2	1	10 AWG PV WIRE, COPPER	FREE AIR	N/A	N/A	6 AWG BARE, COPPER	0.71 (57°C)	1.0	11.1A	13.87A	55A	39.05A	60°C	40A
3	1	8 AWG THWN-2, COPPER	0.75" DIA. PVC-40	2	N/A	10 AWG THWN-2, COPPER	0.96 (35°C)	1.0	25A	31.25A	55A	52.8A	60°C	40A
4	1	8 AWG THWN-2, COPPER	0.75" DIA. PVC-40	2	35A X 2	10 AWG THWN-2, COPPER	0.96 (35°C)	1.0	25A	31.25A	55A	52.8A	75°C	50A

Figure 131 - Single Line Diagram

The design presented here is 100% computer-generated. In fact, performing electrical calculations using computer software is likely more reliable than performing the calculations by hand, being less prone to human error. But knowing code is necessary to check the design, or modify it for improvements in performance or project logistics. Calculated her is minimum conductor and conduit sizing. Number 10 PV wire is called for, along with a #6 ground. The conduits combined here are 2", with other calculations made such as conductor fill and voltage drop. All of these calculations are made as a function of the specific array design and National Electric Code inputs. In fact, a useful way to prepare for a solar example is to make a design, and then print and review the National Electric Code report. The software used in this picture is **Solar Design Tool** and they do a free 30-day trial, no credit card required. Because of that, I recommend you simulate an array layout within SolarDesignTool as a solar training exercise.



1. NEC Code Compliance Report

1.1. Maximum System Voltage Test

1.1.1. Enphase Inverter w/54 S-Energy SM-255PC8 (255W)s

Array Properties

Array Type	Microinverter Array
System Description	Enphase inverter w/54 S-Energy SM-255PC8 (255W)s
Module	SM-255PC8 (255W)
Highest number of modules in series in a PV Source Circuit	1
Design Low Temp.	-11°C
Module Voc	38V
Temp. Coefficient Voc	-0.119V/C

NEC Code Calculations

A. Maximum Voltage of PV Source Circuit *see Article 690.7(A) and Article 690.7(A)*	42.28V

NEC Article 690.7 requires that if the PV module manufacturer provides a temperature coefficient of open-circuit voltage, it must be used to calculate the PV array's maximum system voltage. It includes an information note recommending the use of the ASHRAE 'Extreme Annual Mean Minimum Design Dry Bulb Temperature' as the design low temperature. Using these values, the module Voc (38V) will increase to 42.28V at the design low temperature (-11°C).

(-11°C - 25°C) X -0.119V/C + 38V = 42.28V

The total Voc for the string is 42.28V.

42.28V X 1 = 42.28V

NEC Code Validation Tests

1.	PV Source Circuit maximum Voc must not exceed 600V 42.28V < 600V = true	PASS

Figure 132 - NEC Report

Batteries are complicating the automated design process. When I add batteries to a design, I might start it in SolarDesignTool and then finish out the one-line diagram or other necessary calculations by hand. Certain battery-specific components such as DC-to-DC charge controllers might not be in the current solar design software which focuses more on batteryless systems. Here's our battery bank. Here's our inverter, with a manual transfer switch. In this line diagram, the solar design software was exported into CAD to be finished out by hand. We get more into that in our battery classes.

Conductor and Conduit Schedule w/Electrical Calculations

Id	Typ	Description	Conductor	Conduit	Current-Carrying Cndrs. in Cndt.	Fill %	Rated Amps	OCPD	EGC	Temp. Corr. Factor	Conduit Fill Factor	Cont. Current	Max. Current (125%)	Base Amp.	Derated Amp.	Term. Temp. Rating	Amp. @ Terminal
1	2	PV Source Circuit : Series String Output to Inverter	10 AWG PV Wire, Copper	Free Air	N/A	N/A	8.9A	N/A	6 AWG Bare, Copper	0.71 (57°C)	1.0	11.1A	13.87A	55A	39.05A	60°C	40A
2	1	PV Source Circuit : Series String Output to Inverter	10 AWG PV Wire, Copper	Free Air	N/A	N/A	8.9A	N/A	6 AWG Bare, Copper	0.71 (57°C)	1.0	11.1A	13.87A	55A	39.05A	60°C	40A
3	1	Inverter Output: Inverter to Utility Disconnect	8 AWG THWN-2, Copper	0.75" dia. PVC-40	2	22.7%	25.0A	N/A	10 AWG THWN-2, Copper	0.96 (35°C)	1.0	25A	31.25A	55A	52.8A	60°C	40A
4	1	Utility Disconnect Output: Utility Disconnect to Point of Connection	8 AWG THWN-2, Copper	0.75" dia. PVC-40	2	22.7%	25.0A	35A X 2	10 AWG THWN-2, Copper	0.96 (35°C)	1.0	25A	31.25A	55A	52.8A	75°C	50A

Category	Manufacturer	Model No	Component Ref.	Quantity	Qty Per Unit	Description
Module	S-Energy	SN300P-10/15	PM1-24	24	1	S-Energy SN300P-10/15 300W, 72 cells, Polycrystalline Silicon
Inverter	SMA	SB 6.0-1SP-US-40	I1	1	1	SMA SB 6.0-1SP-US-40 6000W Inverter
Disconnect	Square D	D222NRB	SW1	1	1	Square D D222NRB Disconnect Switch, 2-Pole, 60A, 240VAC, or equivalent
Wiring		GEN-10-AWG-PV-WIRE-CU	WR1-2	4,462ft	1	10 AWG PV Wire, Copper (Positive and Negative)
Wiring		GEN-6-AWG-BARE-CU	WR1-2	2,231ft	1	6 AWG Bare, Copper (Ground)
Wiring		GEN-8-AWG-THWN-2-CU-BLK	WR3-4	36ft	1	8 AWG THWN-2, Copper, Black (Line 1)
Wiring		GEN-8-AWG-THWN-2-CU-RD	WR3-4	36ft	1	8 AWG THWN-2, Copper, Red (Line 2)
Wiring		GEN-10-AWG-THWN-2-CU-GR	WR3-4	36ft	1	10 AWG THWN-2, Copper, Green (Ground)
Wiring		GEN-10-AWG-THWN-2-CU-WH	WR3-4	36ft	1	10 AWG THWN-2, Copper, White (Neutral)
Wireway		GEN-PVC-40-0_75DIA	WW1-2	36ft	1	PVC_40 Conduit, 0.75 dia.
OCPD	Generic Manufacturer	GEN-FU-35A-240VAC	F1-2	2	1	Fuse, 35A, 240VAC

Figure 133 - Conduit Calculations

I like that SolarDesignTool goes further into final system design than other, more expensive solar software such as Aurora and Helioscope. The latter software is more about performance estimation and shade analysis rather than finalizing the balance of system material and permit package. This software will all generate a one-line diagram for project permitting, but SolarDesignTool goes further in the detail, which is appreciated by the permit office and designer alike.

Interconnection

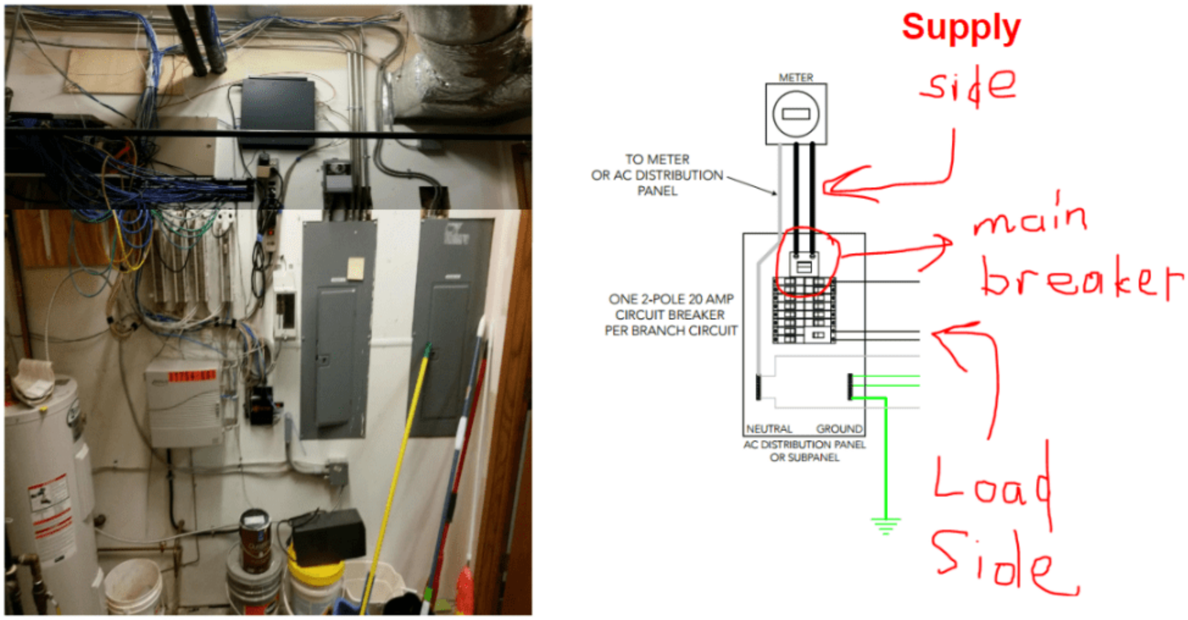


Figure 134 - Supply Side vs. Load Side Interconnection

We have yet to discuss how the solar array is physically wired into the electric grid. There are two options: a **supply side interconnection** or a **load side interconnection**. Load side connections are made at the electric service panel. Supply side connections are made between the main breaker and the utility meter, or sometimes have a stand-alone electric account.

Here is a small commercial electrical room. How are we going to interconnect into this system? The room is surprisingly code-compliant, other than the fact that this space in front of the electrical equipment should not be used for storage. But the room is messy. The last thing I want to do is bring the inspector inside this room. Instead I'd rather keep the inspection outside. Even though there are breaker slots available, it might be just as easy to connect between the meter and the main breaker. Alternately, the solar array could land on the breakers at the bottom side of the service panel.

The allowable size of the interconnection is governed by code. It is common to have a 200-amp electric service panel. This can be confusing as a 200-amp panel commonly has more than 200 amps worth of breakers. How does this panel not draw more than 200 amps? The answer is that the 200-amp main breaker prevents more than 200 amps being sucked into the panel. Not all the circuits on this panel are on at the same time, but if they were, the main 200-amp breaker would flip, meaning no more than 200 amps could flow through the panel, even with 300 amps of breakers.

Well if 100 amps of solar are then plugged into the service panel on the load side, the main breaker would add 200 amps of power and the solar array would add 100 amps of power. The panel could then be supplied with supply 300 amps of load, being pulled through is load breakers, and exceed its

200-amp rating. For that reason, code limits the total amount of amperage that can be supplied to a service panel, and it is surprisingly compromising.

If the solar array is randomly landed on the service panel, then the total number of breakers cannot exceed the panel rating. This means no more than 200 amps of breakers can be on a 200-amp panel, making it impossible to overload the panel. But again, normally there is already 300 amps of breakers on a 200-amp panel. In this event, if the solar array is landed at the bottom of the service panel, code allows the panel to be fed with 20% more power. So, if 200 amps are feeding the top of the panel from the grid, then 40 amps can feed the bottom of the panel with solar. This is because the panel is powered by a literal bar of metal, the bar of metal is literally rated for a specific amperage and voltage. The extra power is allowable because the two power supplies are located at opposite ends of the busbar, so that the power would flow to the load before overloading the busbar rating. In any event, a 200-amp service allows for a 40-amp solar array plugged in at the other end of the panel. There is even a little wiggle room beyond that, such as downgrading the electrical service to allow for additional solar amperage.

Solar arrays large enough to offset an entire building's electrical service will have an output greater than 20% of its service panel amperage. When the array is sufficiently large enough, a load-side interconnection is not possible. Instead, the solar panel is connected ahead of the main service panel, but still on the customer side of the electric meter. This allows you to connect 100% amperage, such as supplying a 200-amp service panel with a 200-amp solar array. Because no matter how much you supply, the amperage is limited by that 200-amp service panel main breaker. Load-side connections are simpler and more appropriate for small arrays or batteries. Supply side arrays are common as well, and more appropriate for larger arrays.

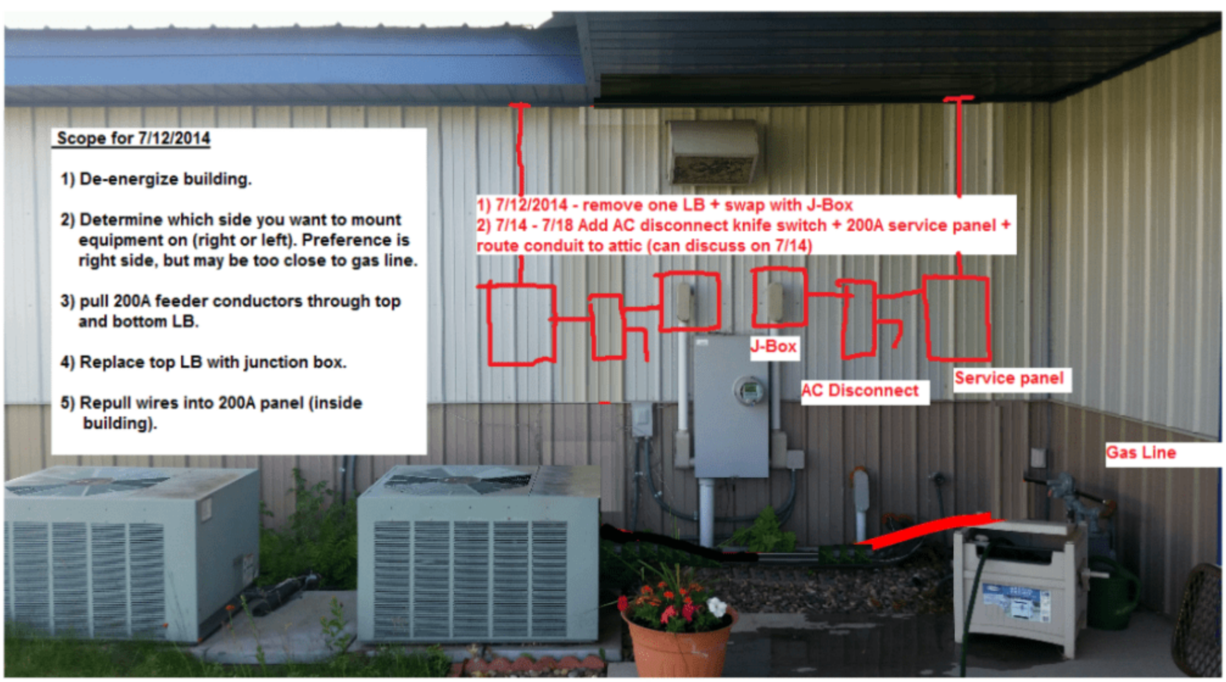


Figure 135 - Planning the Interconnection

Back on site, we look at the outside of the building and see where the electric cables leave the meter and enter the building. For our supply-side connection, we want to intercept and tap into these conductors at this point. Currently there is an electrical box called an LB where the cables enter the building, feeding the two separate 200A panels coming out of the 400A meter base. Ahead of the installation on a weekend, I specified the electrician pull the meter with utility and then pull the conductors out of the service panel and out through the LB. Then the LB was swapped with a larger junction box and the conductors are routed back through the service panel. So, when the solar array was ready to install, all that was needed to be done was to open up the junction box and tap onto the conductors.

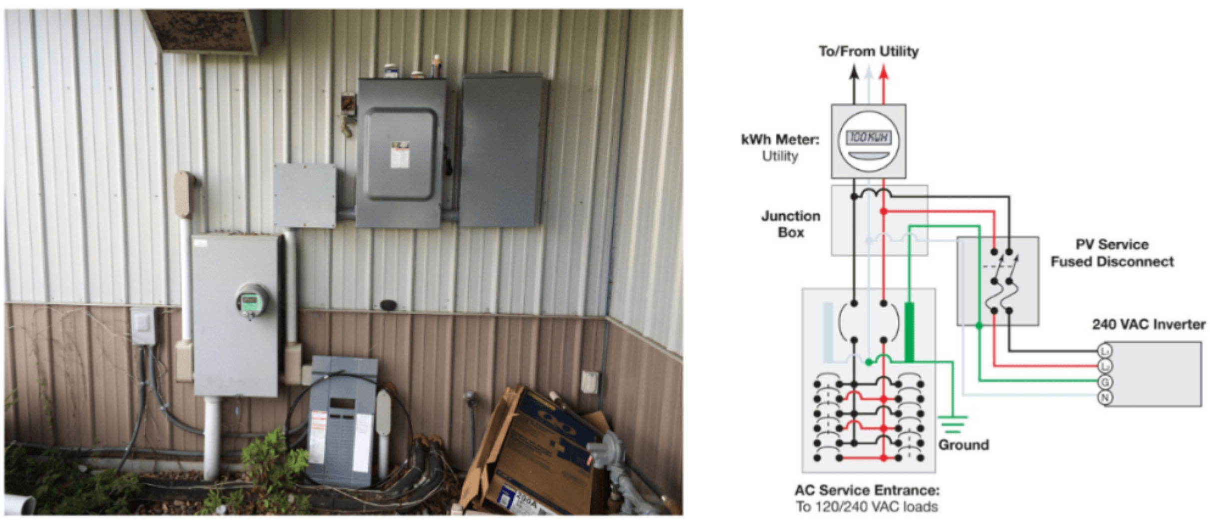


Figure 136 - Example Supply-Side Interconnection

We still need tapped conductors to be protected by overcurrent protection, and have a disconnect switch. A breaker on a service panel is a switch with built-in overcurrent protection. The breaker opens up the circuit when it exceeds its amperage rating. So, the conductors are tapped using tap connectors in the junction box, and then land on breakers in a service panel to meet the overcurrent protection and switch requirements. Sometimes the local utility also requires a knife-switch disconnect. A fused knife-switch disconnect could be specified in order to avoid the use of breakers, with the fuse serving as the over-current protection. But because this array is comprised of multiple micro-inverter circuits, similar to the use of multiple string inverters, each inverter output circuit will have its own breaker. has its own breaker. just tap on to those conductors here’s our inverter our overcurrent protection or fuse disconnect switch or you could have a breaker and an unfused disconnect and then our junction box.

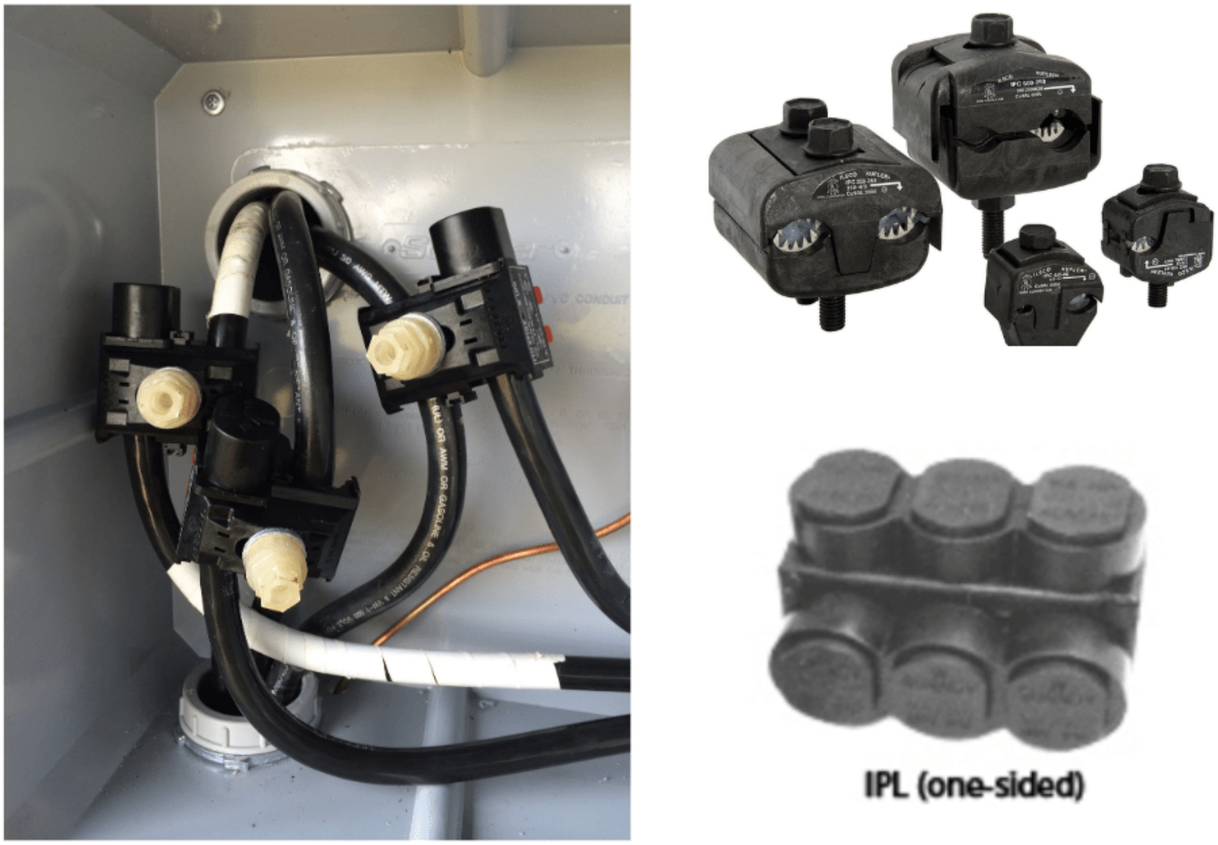


Figure 137 - Insulated Tap Connectors

Here is the cable going into the service panel on this commercial project example. I used **piercing insulated tap connectors** because cutting the conductors, stripping back the insulating jacket, and then landing the tap connectors on standard tap blocks takes time and hand strength. While there's nothing wrong with piercing insulated tap connectors, most electricians I've talked with prefer regular tap connectors where possible. They are easier to undo and reconfigure, with a more solid bolt-based tap onto solid metal rather than relying on serrated teeth biting through the cable to make the tap.

Here's the inverter with the knife switch disconnect required by the local jurisdiction. Not all jurisdictions allow for a separate disconnect and most jurisdictions have moved away from requiring the knife-switch, although I think the disconnect requirements are being increased in NEC2020. The problem with a readily accessible disconnect is that it becomes a safety hazard itself as anyone can open up this disconnect switch, stick their hand in, and electrocute themselves. So be sure to include a lock for the disconnect.

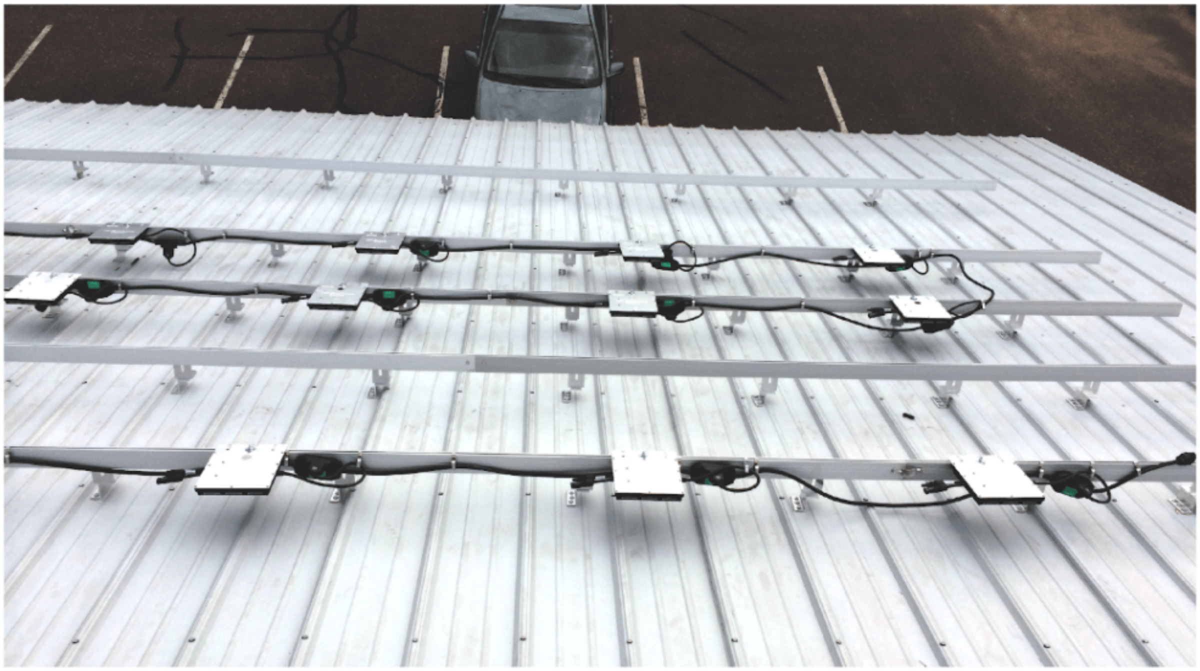


Figure 138 - Micro-inverters Mounted

This is a microinverter system so the inverters are mounted on rail up on the rooftop.

Figure 139 - Side-of-Building Equipment

There's not much space along the side of the building, here is the gas line and here is the air conditioner so there's not much space for the inverter. A microinverter array keeps it nice and neat.

Balance of System Materials

Figure 140 - Array Aesthetics

We've seen this solar array previously, and it looks pretty good except obviously there was one place where a solar module was supposed to be but had to be relocated due to a plumbing vent in the way.

Figure 141 - Plumbing Vents

It is possible to simply replumb the vent on top of the roof. Roofing vents are required to be a certain height off the roof to assist with gas dissipation. An installer might want to give the vent stack a little haircut with a bandsaw, which may be electric code compliant but could violate other building code.

To maintain the plumbing vent height, it is a simple matter of rerouting the pipe under the array and out the top, accomplished with two 90° bends of plumbing pipe.

Figure 142 - Example Project

Here is an off-grid project where the home electric load grew over time. The house went from two to three stories. It went from electric and gas to mostly electric with four refrigerators, a sauna, and electric hot tub. The stovetop is gas but the oven is electric. So, a 12kW solar array isn't enough for the needs of this 400-amp electric service home. We are accommodating this increase by having a separate 12kW inverter power each 200-amp panel, as well as implementing digital load controls to keep each panel below 12kW.

Figure 143 - Smart Energy Management

Living off-grid doesn’t necessarily mean having fewer electronic devices in the house, but it is easier on the batteries to manage the load. Consider the advantage of having two deep freezes instead of one, filling up the insides of the freezers with thermal mass such as extra water jugs frozen during the day to turn off the freeze at night for some cheap load shifting. The total load will increase somewhat, but the electricity will be used at more opportune times.

In California, there’s a company that’s making ice air conditioners that freezes ice for some load shifting. SolarEdge makes a heating element that you can put in some water tanks, (but not all), that will use solar excess solar to heat your water in the water tank instead of selling to back to the grid. There are Wi-Fi switches that you control with your cell phone.

Figure 144 - Digital Load Control

In my smart home designs, discussed later in its own class, I detail an energy monitor located inside of the electric service panel to monitor the home load and relay its data to software to help with load control. For example, the hot tub can be turned off if it is overloading the battery inverter. Before that happens, other loads such as the dehumidifier and certain ceiling fans are cycled off. The thermostats are integrated to ease back on the air conditioning during times of maximum load, cranking the AC when other heavy electric items are not in use. These service panel monitors use current transducers such as found in an electrician's clamp meter which clamps around the wire using induction to figure out how much current is flowing through them, permanently wired to the service panel inside the house. I actually think this monitoring is more important than solar monitoring system because more can be done with it.

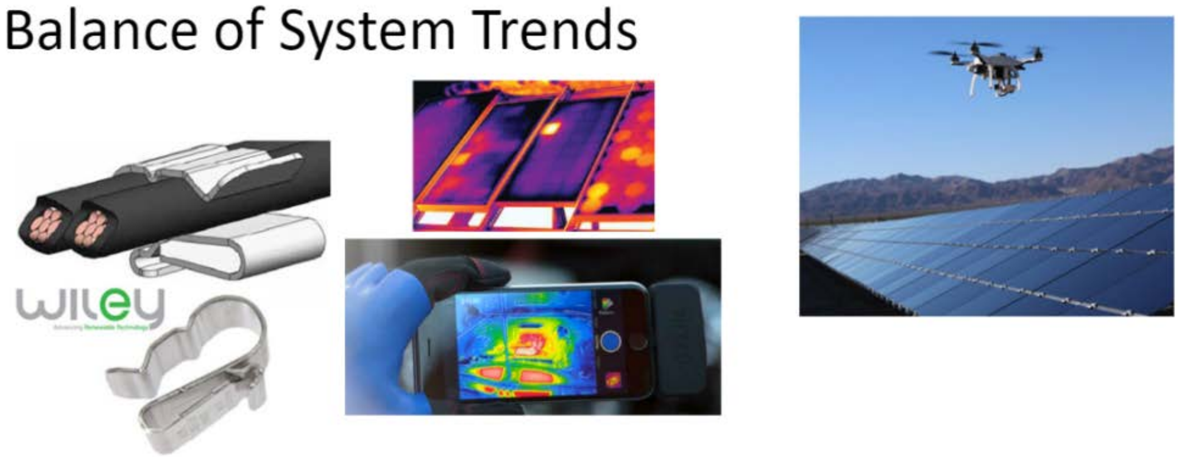


Figure 145 - Thermal Scanning

Thermal scanning a solar array can be useful for identifying faulty modules or other failure points.

Item Code	Quantity	Description	U/M	Price Each		Amount
01-SE-SN310P...	25	S-ENERGY 72 CELL 310W SN SERIES POLYSILON PV PANEL. UL/CEC LISTED WITH 25 LINEAR WARRANTY 1000V, 40T		220.8704		5,521.76
02-SCH-12430...	4	02-SCH-124303-06200-NS		73.3625		293.45
02-SCH-14000...	2	02-SCH-140004-008-NS		210.93		421.86
02-SCH-13100...	8	02-SCH-131001-040-NS		2.6125		20.90
02-SCH-13500...	20	02-SCH-135002-003-NS		3.1875		63.75
SB6000US-12	1	SMA SB-6.0-1SP-US-40		2,508.95		2,508.95
04-A-PEA-10-...	2,000	10 AWG 7Str USE-RHH-RHW UL 4703 PV 600V Black X 2500		0.17042		340.84
6SDBARECU	250	6 SOLID SD Bare		0.38		95.00
07-HEY-S6445	100	18/8 S/S CABLE CLIP		0.1334		13.34
05-WIE-02.12...	10	WIELAND FEMALE CONTACT 6MM/10GA 1000V TUV		0.22		2.20
05-WIE-96.11...	10	Wieland Female Connector Housing 1000V TUV 96.111.0053.1		1.363		13.63
05-WIE-05.54...	10	WIELAND MALE CONTACT 6MM/10GA 1000V TUV		0.22		2.20
05-WIE-96.11...	10	Wieland Male Connector Housing 1000V TUV 96.112.0053.1		1.296		12.96
s-5 vera bracket	25	S-5 Versa Bracket		3.03		75.75
09-WE-NSI-IP...	3	NSI IPCS4040 4/0 LIVE END TAP		27.00		81.00
18186RTSC	1	18186RTSC B-Line N3r RT screw cover can		87.71		87.71
09-AE-LA602...	1	600v DC lightning arrestor LA602DC HV DC Lightning Arrestor, 1100V		37.05		37.05
09-AE-LA301-...	1	240v AC split phase lighting arrestor LA301 AC Lightning Arrestor, 2-Wire		29.06		29.06
D222NRB	1	SQD Safety switch,60a 240v RT		117.32		117.32
FRN-R30	2	Bussman FRN-R35 Buss 250V RK5 Time-Delay Fuse		8.365		16.73
Ship/Handle	1	Shipping		632.27		632.27

Figure 146 - Sample Balance-of-System Cost

So here are some example material costs for reference, but keep in mind these costs go back to 2016. #10AWG solar cable costs about $.17/foot. Solar cable clips cost about $.13 each. MC connectors plus housing cost about $.50 each. Those S5 brackets that screw into the metal roof cost three dollars each.

Actual Material Costs

(plus one extra 310W panel)

Ground Mount Material List	Hard Cost	Per Watt
Modules	$5521	$0.74/W
Racking	$1600	$0.22/W
Inverter	$2509	$0.34/W
Balance of System	$1,146	$0.15/W
PV cable	$341	
Bare Copper	$95	
Wire Management Clips	$13	
MC4 connectors	$31	
Line Side Tap	$81	
Lightning Arrestors (AC + DC)	$$70	
Fused AC knifeswitch	$135	
Concrete	$360	
Junction Box	$90	

Figure 147 - 2016 DIY Material Actuals

Here is a ground mount done back in 2016, where the design and installation were done separate from the install.

Total $10,387.73

02-SCH-12430...	4	02-SCH-124303-06200-NS		73.3625		293.45
02-SCH-14000...	2	02-SCH-140004-008-NS		210.93		421.86
02-SCH-13100...	8	02-SCH-131001-040-NS		2.6125		20.90
02-SCH-13500...	20	02-SCH-135002-003-NS		3.1875		63.75

Total: $11,200 / 24 modules / 310W = $1.50/W

Add $360 Concrete /

Add $2000 payment to site labor (electricians)

Add $1400 equipment rental / tools

Add $2000 design fees / travel

= $16,960 / 24 modules / 310W = $2.27/W (May 2016)

Figure 148 - DIY with Subcontracting Cost Example

An electrician was paid $2000 to show up for two days to help with the installation and inspection, operating the trencher and assisting with the array construction, as well as performing the wiring. Doing most of the project yourself doesn't mean you can't hire skilled labor for the day. I'm currently buying my solar panels for around $.44 a watt. They can be a little bit cheaper if they're 72 cells silver framed silicon with white back sheets. My 60 cell all-black typically cost between $.44/W-$0.52/W – prices kept high due to import tariffs. Racking cost around $.22/watt. Grid-tied solar inverters cost around $.34/W for microinverters or high-end string inverters like SMA. The SolarEdge system is a little cheaper around $0.26 a watt, and the cheapest quality string inverter system such as Fronius is closer to $0.20 per watt. Balance of system material budgets can range between $0.15-$0.30/W on residential projects, assuming the electrical service does not need substantial rework.

Payback Calculations

So how do you calculate your solar payback? Well it gets a lot more complicated if you don't have net metering.

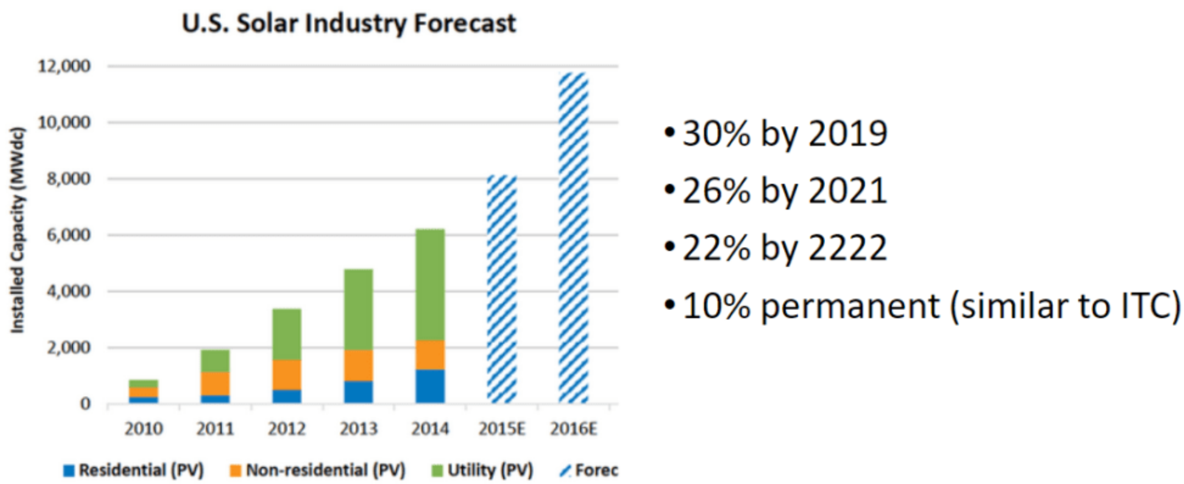


Figure 149 - Federal Tax Credit

If you do have net metering, the total installed price (in this example, \$2.50/W) is reduced by the 30% Solar Tax Credit, which is currently scheduled to step down to 26% in 2020 and then phase out over the following years. I don't see costs falling much over the next couple years, as new import tariffs are keeping the costs high. But we don't have much control over such policies at the local level. So, after subtracting out the tax credit from the installation price, dividing by the energy produced and value of the energy will give you a simple payback year.

Simple Payback

= Install Price x 70% tax credit / [annual kwh x \$/kwh]

\$2.51/W x 70% / [***1.4 kwh/W/yr*** x \$0.11/kwh]

from PVWatts *electric rate*

\$1.26/W / \$0.156W/yr = 8 year

Figure 150 - Simple Payback

If you have an $0.11 per kwh generation rate and you get true net-metering and solar outflow is also worth $0.11 per kwh, the math becomes pretty simple. We take that PVWatts number from the beginning of class, that local ratio we learned one watt of solar produces 1.4 kilowatt hours per watt per year, along with our kilowatt hour rate. These numbers multiply together and the kilowatt hour unit falls out, resulting in a $/W/yr. payback number. Dividing by the tax-credit adjusted $/W install price results in an 8-year simple payback for this solar array, installed at $2.50 a watt and net-metered at $0.11/kwh.

I like taking PVWatts production value and multiplying it against my effective generation to get a $/W payback figure, in this case $0.15 per watt per year. That gives me a good benchmark for cost analysis – if I know I add $0.15/W of cost to a project due to some material upgrade, I know it will push my payback off a year. Likewise, I know if I am saving $0.15/W/year, to achieve a 10-year payback I need a $1.50/W installation price after the tax credit. That's way below national installation pricing, but it's not impossible to achieve. Import tariffs are keeping costs high, but the federal tax credit also gives that money back and then some. Whether that is a good system is a matter of intense debate.

Sample Panel Efficiencies	STC
SunPower	21%
Canadian Solar	17%
Requires	~23% more surface area
Added "Premium" Cost	+$0.25/W to +$0.50/W
Added Payback?	1 – 4+ Years

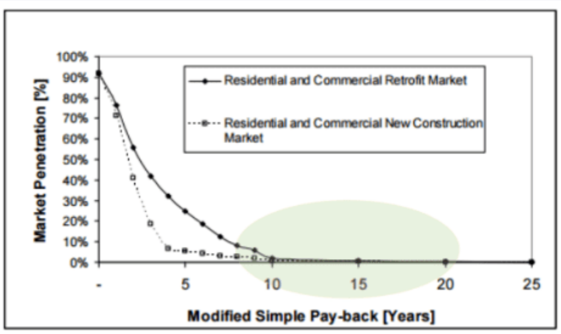


Figure 8. Market penetration curves used

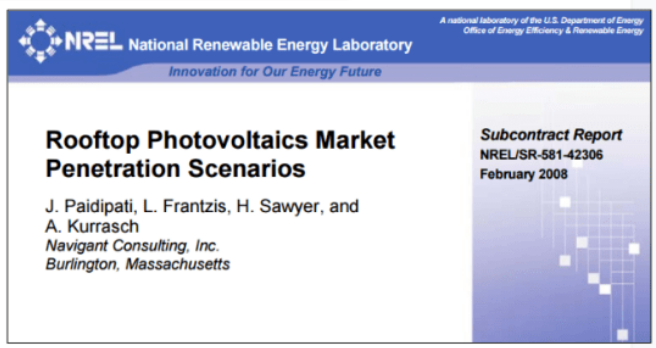


Figure 151 - Expected Payback

But remember that solar only produces during a portion of the day, whereas the electric bill is tabulated over a 24-hour period. The larger a solar array gets, the more it will outflow onto the grid, to the point where over 2/3rds of a solar array which offsets 100% of an electric use will either outflow onto the grid or need to be stored in batteries. For a batteryless solar array that outflows onto the grid at a $0.06/kwh rate, then only 1/3rd of the electricity is worth $0.11 and 2/3rds is worth $0.06/kwh, resulting in an effective generation rate closer to $0.08 per kilowatt hour, which would substantially increase the payback rate. So, performing the economic calculation as a true function of your local net-metering policy is very important.

So, in this example, with an $0.11 net metered electrical rate, take the installation cost and back out the tax credit to get a $1.76/W installation price. Divide by 1.4 kwh/year and $0.11/kwh to get an 11.5-year payback.

In today's era of solar, where you get still get the federal tax credit, more than likely you have a net metered electric rate, although the rate is usually less than full retail price of electricity. As such, solar payback is often over 10 years, unless there are additional state and local incentives or you have a tightly managed project.

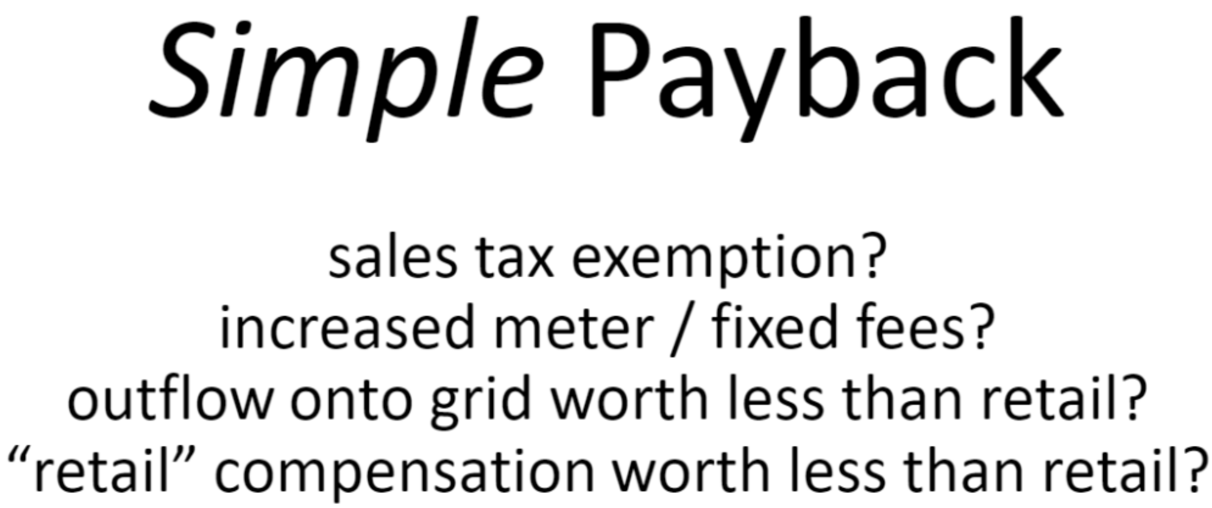


Figure 152 - Payback Considerations

Sales tax incentives are common. The **dsireusa.org** website compiles a list of federal, state, and local energy incentives and policies (such as net-metering and interconnection details), and it's worth checking out before heading into a solar project.

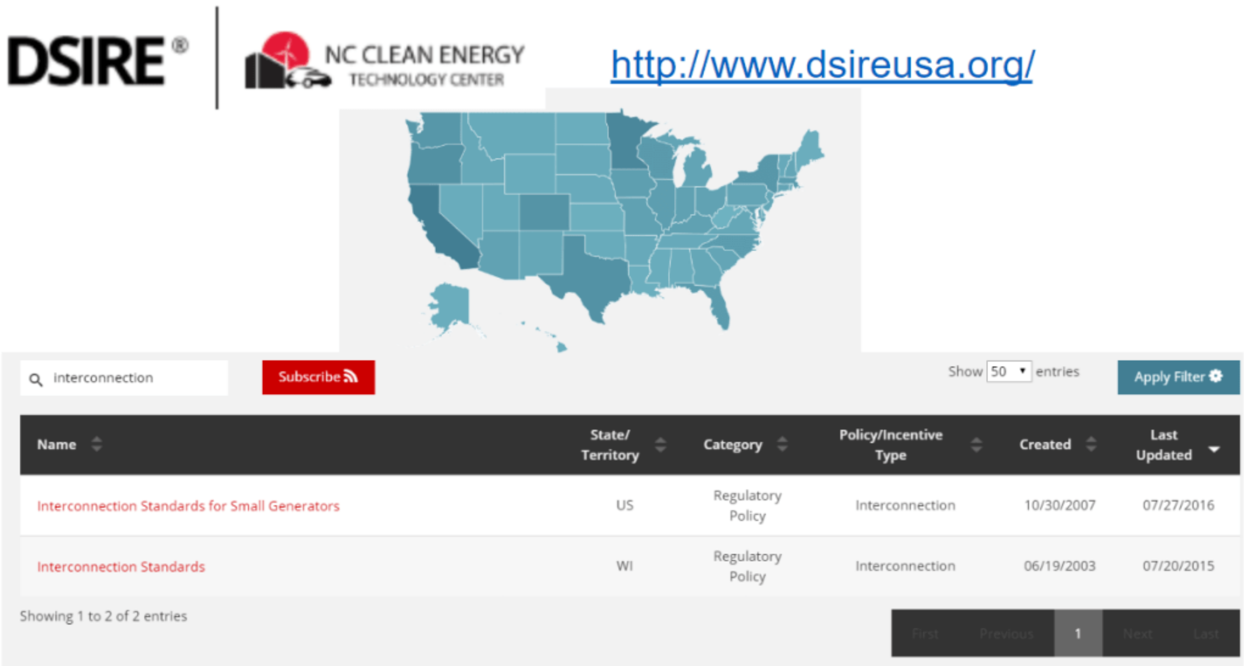


Figure 153 - DSIREUSA.org

Property tax exemptions are common as well. The idea behind these tax exemptions is to place the consumer on a level-playing field with the power industry which commonly enjoys these exemptions as well. But not all states extend these advantages to consumer-owned solar. By in large, the focus on solar subsidies distracts from these other opportunities for fair play solar policy.

There are solar customers who are satisfied with an 11 to 15-year payback on solar, preferring to invest in their own property and reduce their bills. But these customers generally have some money to spare. For those who want solar to radically transform the electric grid, I would refer them to this chart, which is not just a solar chart but more a chart showing consumer adoption rates of various energy technologies as a function of their simple payback. Solar for much of the US is still outside the <10-year payback preferred by most consumers. Obviously if the payback were even quicker, there would be even faster adoption. But we are seeing that a larger solar project, perhaps a 15kW array spread across two pallets of solar panels, competitively bid at $2.50/W with net-metering will net about an 11-year payback. In a market like Mississippi, where there are no sales tax exemptions or net-metering for residential customers, the installation price must be even lower to get customers interested. In fact, certain states have policies which punish solar owners, under the justification that by purchasing less electricity, they make electricity more expensive for everyone else. In these states, what little solar market exists is incentivized to go 100% off-grid.

Paybacks of 10-15 years are not enough to get most consumers to jump out of their seat and go buy an array. However, most residential homes are financed via 30-year mortgage. If a 15-year payback is put into a 30-year mortgage, it will take more money off the mortgage payment than it will add to the electric bill. Unconventional long-term financing is available for solar owners as well. Although customers should keep in mind that basic fundamentals such as project cost still apply when obtaining long-term financing.

Some solar financing companies offer zero interest loans for 20 years, but these projects are often sold at prices well above the industry average, manipulating the value of the loan, tax credit, and interest rate. Don't proceed into a long-term solar loan blindly, but long-term financing for solar can be a valuable tool. For that matter, when a utility-scale power plant is built, the developer often seeks guaranteed long-term financing mandates to be repaid by the general public in the form of electric rate increases.

At any rate, there is a motive for building developers to incorporate solar into their projects if the building is being financed over a longer term than the energy payback period. Essentially 15 years' worth of electric bill cost savings can be added to the project value.

But price is a motivating factor, which is why in cheap electricity markets, it is not a good idea to select an ultra-premium product which will substantially push the payback window out into the future. In New York, a $0.30/W price increase in project cost can be paid back in a year, or even sooner if subsidies are available. But in a smaller market, it might push the solar price to the point where the customer is no longer interested.

So, the solar tax credit is down to 26% for two years next year, followed by a year at 22% and then an ultimate step-down to 10%. Prices have dropped in the industry, but import tariffs have stabilized the price decrease. So now is a good time to move forward with a project, as waiting will have you miss out on some tax credit.

The exception is that lithium ion battery pricing, at least at the residential level, has not yet begun to drop. While Tesla reports buying lithium ion batteries near $100/kwh, distributor pricing to the consumer for lithium batteries is closer to $600/kwh. When I got into solar in 2008, module pricing was over $3 per watt. Now an entire solar array can be installed for less than that. Over the next ten years, lithium ion pricing is likely to follow a similar path, whether it be through cost reduction or quality improvements which are already going. A valid solar project strategy could be to install batteryless solar today, perhaps with a small battery protecting critical loads and reducing outflow issues. Then plan for a larger solar + storage upgrade later on.

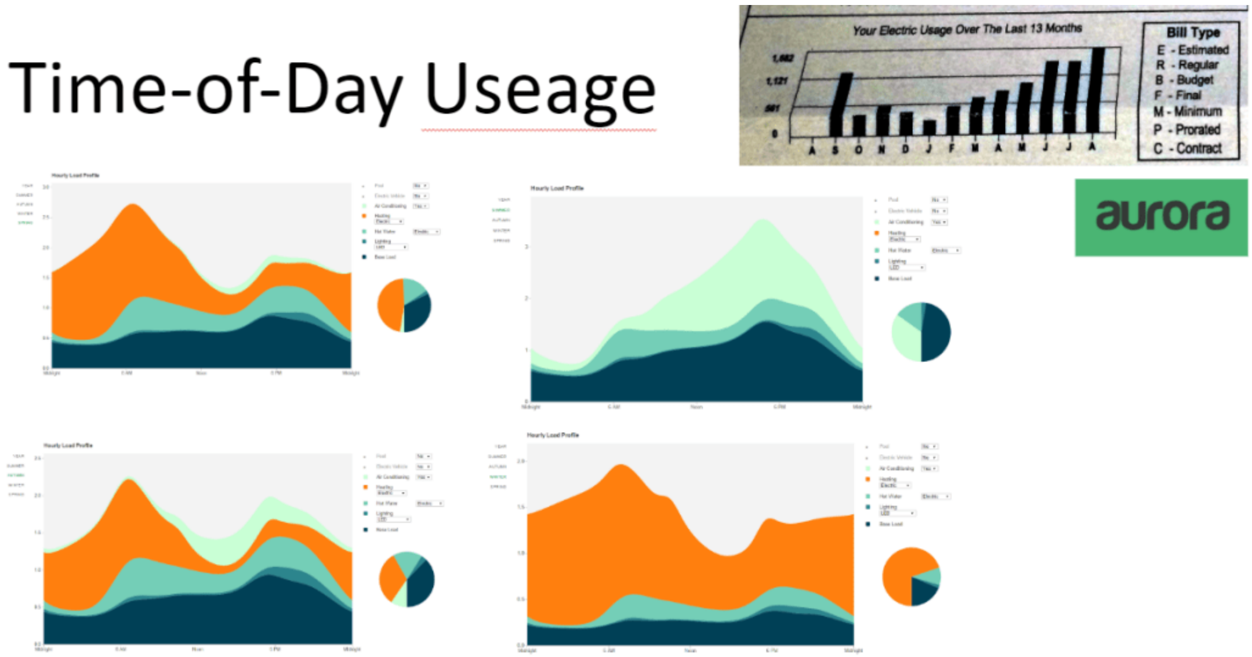


Figure 154 - Load Profile Modeling

Computer software can be of great assistance to the solar design process. For example, Aurora Solar has a feature which can be used to at least visually estimate how much of a solar array's production will outflow onto the grid. They take monthly electric bills and add in a survey of the client's heavy electrical appliances, such as a swimming pool, electric water heater, electric ovens, air conditioning, LED lightbulbs, and the region where the building is located. This is probably a northern climate as they show significant heating load in the winter, with heating in the morning and air-conditioning in the evening during spring and fall, with the air conditioning taking over in the summer in this cool color. Not all residential load profiles look alike, and so assumptions are made which can be better fine-tuned if you have specific load profile data there's only so much, we can do but based on how much electricity you use per data. But guesses can be made. Perhaps a smaller solar array with a small lithium ion battery won't produce a terrible amount of outflow.

$0.23/kwh

On-Peak Period

- Monday through Friday, 12 hours
- 60 hours per week
- 35 percent of the week is on-pea

$0.06/kwh

Off-Peak Period

- The off-peak period covers 108 hours per week, or 65 percent of the total week. Customers may choose their Monday through Friday off-peak periods from the following list of time periods:
  - 8 p.m. to 8 a.m. (maximum: 3,500 customers)
  - 8:30 p.m. to 8:30 a.m. (maximum: 3,500 customers)
  - 9 p.m. to 9 a.m. (unlimited number of customers)

Figure 155 - Peak Electric Rates

Maybe the utility offers a time-of-use electric rate that can benefit the system economics (although some of these structures can make the economics worse!).

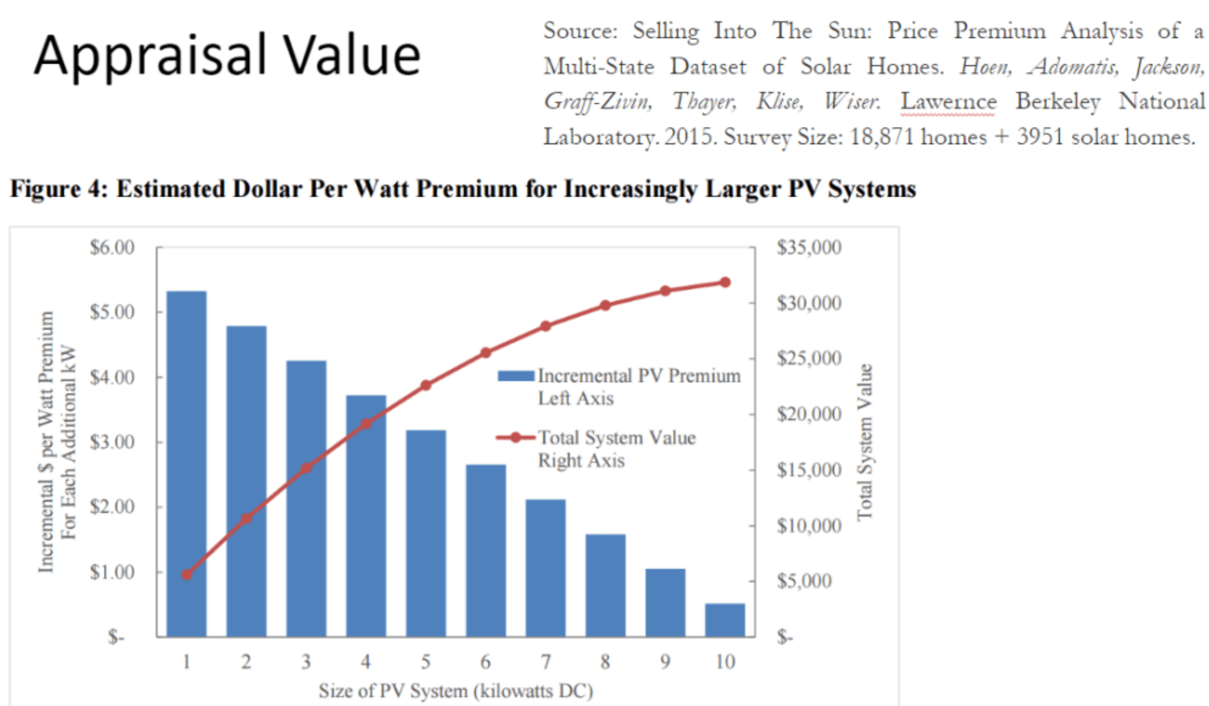


Figure 156 - Real Estate Appraisal Value

When determining system value, real estate appraisal value is often overlooked. Essentially the data shows solar will add roughly $15k to the home value at the time of resale, regardless of the array size. This could be because the data itself does not have much definition, or that a homebuyer lacks the sophistication to know the difference between differing solar array values. But one upside of this data is that a small solar array with a seemingly distant payback can recapture its project cost when time to resale the home.

Solar homes are popular, even with uneducated customers. Most people want solar. Everyone wants a low electric bill. Many are concerned about the environment. Price drops continue to overcome any regulatory hurdles. $15k spent on a self-managed project can go a long way. Whether it be a battery inverter for a couple hours of home back-up power with just a few solar panels, or an 8kW batteryless project with consideration given to batteries down the road, there is significant reward for the building professional who wants to dabble in a small home improvement project to get involved. $50k spent on a professional installation in a net-metered state could reduce an electric bill to its absolute minimum. $100k spent on a luxury home could take it fully off-grid. Commercial applications become even more cost-effective, as they can have rate structures which take better advantage of battery-based systems.

Appraisal value is tricky. It's the curbside value that a potential home buyer mentally adds to the house when rolling up to the curb and saying "that's a solar home, that's a home I want to live in, because it has low electric bills and helps the environment". Any home upgrade can run a risk of making the home more difficult to purchase, so there is not a strict correlation between investment value and real estate appraisal value, such as there would be in commercial financing. But this same argument can be used to put a small solar array on every home. If for now it can't produce power during a blackout, then perhaps use the SMA inverter that can provide at least a little power during the day for the time being. Having some energy piece of mind can be useful on rural grids where electricity is unreliable, as well as areas prone to hurricanes or other extreme weather events. The importance of solar has even resulted in cities enacting rooftop mandates.

Residential Payback (pre-tax)
= Price x 70% / [annual kwh x $/kwh]
Residential Customers don't claim their electric bill as a tax deduction.

Commercial Payback (post-tax)
= Pre-tax Payback + ***depreciation*** **-** income tax
Commercial customers claim equipment depreciation,
but a reduced electric bill increases profit, which increases income taxes.

Figure 157 - Depreciation Considerations

There is solar design software available focused more on the commercial market for economic modeling, with and without storage. Solar installers commonly overstate the value of depreciation, in part because there are depreciation benefits for businesses which are not available to residential customers. But these benefits come with a cost. Every dollar a residential customer saves on an electric bill is tax-free. But for a business, a lower electric bill means more profit. In other words, there is a tax effect on the cost savings that the solar array produces for a business. To some extent, depreciation exists to offset the cost of this tax-effect. The danger is that the solar installer presents a business with the value of the depreciation, but omits the tax effect of the cost savings. Economists would chastise the solar installer, telling them to either do a pre-tax analysis without depreciation or the tax effect, or a post-tax analysis which includes both items.

3.1 Cash Purchase

ENERGY TOOLBASE™

Inputs and Key Financial Metrics

Upfront Payment:	$375,000	Electricity Escalation Rate:	2%	30-Year NPV:	$204,563	10-Year IRR:	1.04%
State Income Tax Rate:	6%	Solar Panel Degradation Rate:	0.8%	Payback Period:	9.1 Years	20-Year IRR:	6.53%
Federal Income Tax Rate:	34%	Discount Rate:	1%	30-Year ROI:	69.45%	30-Year IRR:	7.55%

Years	Project Costs	O&M / Equipment Replacement	REC	Electric Bill Savings	State Tax Effect	Federal Tax Effect	Cash Flow	Cumulative Cash Flow
Upfront	($375,000)	($1)	-	-	$0	$0	($375,001)	($375,001)
1	-	($4,000)	$10,245	$18,763	$3,000	$124,653	$152,660	($222,341)
2	-	($4,120)	$10,163	$18,985	$5,698	$24,233	$54,959	($167,382)
3	-	($4,244)	$10,081	$19,209	$2,817	$11,335	$39,197	($128,184)
4	-	($4,371)	$9,999	$19,433	$1,088	$3,594	$29,743	($98,441)
5	-	($4,508)	$9,917	$19,660	$1,088	$3,592	$29,748	($68,693)
6	-	($5,637)	$9,835	$19,887	($149)	($1,896)	$22,040	($46,653)
7	-	($5,806)	$9,753	$20,116	($1,444)	($7,690)	$14,928	($31,725)
8	-	($5,980)	$9,671	$20,346	($1,442)	($7,682)	$14,912	($16,813)
9	-	($6,160)	$9,589	$20,577	($1,440)	($7,672)	$14,893	($1,920)
10	-	($6,345)	$9,507	$20,809	($1,438)	($7,661)	$14,872	$12,952
11	-	($6,535)	$9,425	$21,042	($1,436)	($7,649)	$14,847	$27,799
12	-	($6,731)	$9,343	$21,276	($1,433)	($7,635)	$14,820	$42,620
13	-	($6,933)	$9,261	$21,511	($1,430)	($7,619)	$14,790	$57,410

Figure 158 - Economic Modeling

In any event, **EnergyToolBase** produces economic calculations which will make a CFO smile. These are clear and thorough calculations similar to cash flow modeling taught in engineering economics classes. Here the cash flow is modeling depreciation, and here is the tax effect modeled as well. Their software is also critical in modeling the value of commercial solar batteries, which we have an entire class dedicated on.

PURPA

Montana commissioner caught red-handed trying to kill solar

Thanks to a hot mic, regulations instituted to gut PURPA in Big Sky Country have been overturned and the door to solar development has been re-opened.

APRIL 8, 2019 TIM SYLVIA

INSTALLATIONS LEGAL MARKETS & POLICY POLICY UTILITY-SCALE PV MONTANA

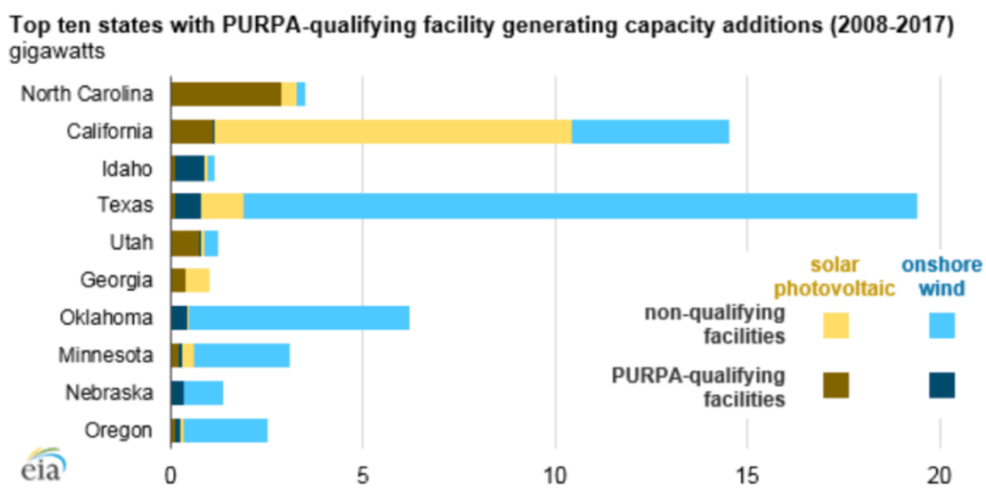


Figure 159 - Solar Rankings

The United States is about 3% solar powered. There is a federal law, called PURPA, which mandates renewable purchasing provided the renewable power is purchased at avoided cost. Avoided cost is a value determined by public utility commissions, but its basic definition is the raw material cost of coal or gas purchased by the power producer before it is refined into electricity and distributed. At a high level, PURPA was established as a way to encourage renewables to come to the grid without increasing the cost of electricity. It did so by providing customers the right to interconnect their own power generators to the grid and be compensated for outflow, provided the outflow was cleaner than the grid and purchased at avoided cost. While controversial, PURPA is less controversial than net-metering, which commonly mandates the solar electricity to be purchased at much higher rates. EnergyToolBase accurately model's utility rate structures.

Recent Residential Project – 15kW

Dollar Per Watt Cost	Target Budget
Balance of System Material	$0.14
Solar Modules	$0.44
Inverters	$0.33
Racking	$0.15
Direct Manhours (Subcontract)	$0.59
Soft Cost (supply chain markup, shipping, profit)	$0.70
Sales Tax @ 8%	$0.16
Total	$2.51/W
Battery Inverter Upgrade	$0.00-$0.22/W
Charge Controller or "AC Coupled - Solar Inverter"	$0.25/W
60 kwh FLA batters at $200/kw 80% depth of Discharge 3000 cycles	$0.80/W
Additional BOS/Labor/Profit	$0.50/W
Suggested Residential Off-Grid Budget	$4.28/W

Figure 160 - Sample Off-Grid Budget

To finish out class today, I'd like to end with what you can do with $15k put towards a residential solar project to demonstrate what we have learned. First, let's assume we use one 8kW pallet of all-black solar modules, delivered to the jobsite for a total of $0.48/W. Next, let's add an inverter system with DC optimizers, costing about $0.39/W, which will be shade-tolerant and code compliant. We add a flashed racking system cost about $0.22/W and a substantial balance of system material budget at $0.30/W and a shipping budget of $0.20/W for a total material cost of $1.59/W.

$15k divided by 8kW of panels gives us a budget of $1.88/W. This still leaves us roughly $0.30/W to spend on labor. 8000 watts x $0.30/W is $2,400 so you may have to do some of the installation work yourself.

We learned from PVWatts the 8kW solar array will produce 1.4kwh per watt per year, coming to about 11,000 kwh per year. If the value of its electricity is $0.10/kwh, the savings will be roughly

$1,100 per year. $15,000 minus the 30% tax credit is $11,500. The solar array will have a 10-year payback. In other words, 70% of $1.88/W is $1.32/W. At 1.4 kilowatt hours per year and $0.10/kwh, the array pays back at $0.14/w/year. Therefore, it will take roughly 10 years payback. In the meantime, the solar array should retain its value if the home needed to be sold. This is a beneficial project to an ambitious do-it-yourselfer today, but could also be a standard item for new construction as well.

This is not the end of the solar story, but it is the end of my introductory solar class. I hope this has served as a good launch point on your personal solar journey.

The next program explores battery fundamentals, a rapidly growing industry which helps complete a solar array. Batteries add cost to a project, but can make the array more cost-effective in addition to being more functional. Different battery chemistries have different costs and values, which impact commercial and residential markets differently. Later classes focus on commercial grid-tied or residential off-grid applications in more specifically.

Other classes explored are National Electric Code and a smart home class coming soon.

If you enjoyed this class, I hope you will further your studies with my other classes. I recommend you start with the battery class. But we do have classes specifically for residential or commercial solar + storage if you'd rather skip ahead. The residential class covers off-grid battery design, with some consideration to grid-tied battery systems. The commercial class explores lithium ion batteries for facility demand management with some community solar planning discussion.

Some continuing education tracks require dedicated content on National Electric Code – our program is written for designers and installers who want to better understand electrical fundamentals in greater detail, based on my career path of starting out as a mechanical engineer knowing very little about electrical design to passing the master electrician exam.

One takeaway from this class is to show how upfront project planning can reduce cost and increase value in the solar project life-cycle. It is possible to have a career as a solar designer or project consultant; whose role is to better define project scope to obtain better bids at the very least. Not all design and material selection choices should be left to the low-bid installation contractor, and not all solar work is done on the roof.

You can be a solar consultant without being installation contractor. For example, I charge $1000 for basic residential bid packages or commercial demand charge optimization modeling and you can too. This is a growing market and it will continue to grow.

If you would like consulting services for your project, you can find the program author at www.levll.com

Quiz

1. A watt, rather than a watt hour, is a measurement of ___________.
   A. Energy
   B. Power
   C. All of the above
   D. None of the above

2. Typical slanted residential roof clearances from the top and sides of the roof, where required, are how many feet?
   A. 0 ft
   B. 3 ft
   C. 6 ft
   D. 9 ft

3. PVWatts calculates its annual energy data based on:
   A. Manufacturer-specific data
   B. Local weather data including cloud coverage
   C. Performance of nearby solar arrays
   D. None of the above

4. Increased operating temperature impacts the solar array in which way?
   A. Increased voltage and decreased amperage
   B. Decreased voltage and increased amperage
   C. All of the above
   D. None of the above

5. “Supply Side” interconnections referenced in National Electric Code are made at which point on a residential electrical service?
   A. On the customer side of the main breaker on the main service panel
   B. On the utility-side of the main breaker and on the customer side of the meter
   C. All of the above
   D. None of the above

6. Consumer net-metering policies might reconcile a customer’s outflow against their electric bill at which point in time?
   A. End of the year
   B. End of the month
   C. Beginning of spring
   D. Any of the above

7. Which unit price was covered in the budget discussion of class?
    A. Dollars per watt
    B. Dollars per square foot
    C. Dollars per kilowatt hour per meter squared
    D. None of the above

8. Module efficiency as found on a product specification sheet indicates which of the following?
    A. How much power is converted from what sunlight is available at standard test condition
    B. How much power is converted from what is available at maximum operating temperature
    C. A benchmark quality score
    D. None of the above

9. Which DC component has similar performance advantages as micro-inverters?
    A. DC optimizers
    B. Batteries
    C. Combiner Boxes
    D. String inverters

10. Which is a disadvantage for micro-inverters compared against other kinds of inverter systems?
    A. Shaded rooftops
    B. New-to-solar installer
    C. Upfront material cost
    D. One inverter per solar panel

11. Net-metering is a Federal mandate.
    A. True
    B. False

12. On average, 1 watt of south-facing rooftop solar produces how much energy across the USA?
    A. <0.5 kwh/year
    B. 0.5 to 1.0 kwh/year
    C. 1.0-1.5 kwh/year
    D. 1.5-2.0 kwh/year

13. If a single “string” of solar modules isn’t reporting power to the inverter, a common failure point is the _________:
    A. Solar module
    B. MC4 “home run” connector
    C. Inverter
    D. AC disconnect

14. What pokes a hole in the roof?
    A. Solar positive attachments
    B. Plumbing vents and chimneys
    C. Roof-mounted air conditioners
    D. All of the above

15. “Load Side” interconnections referenced in National Electric Code made at the bottom of the busbar can be sized for how much of the busbar amperage?
    A. 100%
    B. 120%
    C. 200%
    D. 300%

16. Which solar energy software is made public by the government for solar production estimating?
    A. PVWatts
    B. SolarDesignTool
    C. Navy Sun Angle/Azimuth Chart
    D. None of the above

17. Which of the following protecs a solar array from squirrels and bird nests?
    A. An array skirt
    B. Minimum operating voltage controls
    C. Cable management clips
    D. None of the above

18. NEC Rapid Shutdown boundaries require which item?
    A. De-energizing array conductors during a blackout
    B. Stowing a solar tracker during high winds
    C. Disconnecting an array when overcharging a battery bank
    D. None of the above

19. Which kind of solar modules allow you to “see the cells” underneath?
    A. Thin Film
    B. Bi-Facial
    C. Building-Integrated
    D. Frameless

20. Which budget item is why residential solar costs so much more than commercial or utility-scale solar?
    A. the solar modules
    B. soft costs of supply chain mark-up, overhead, and profit
    C. direct design and labor
    D. none of the above

21. The largest market segment in USA solar is:
    A. Utility-scale ground mounts
    B. Residential solar
    C. Commercial roof mount solar
    D. None of the above

22. Outflow refers to which item?
    A. How much power leaves the solar array
    B. How much solar power supplies the load
    C. How much solar power flows onto the grid
    D. The amount of money the client has to spend

23. Which item varies the most across the country?
    A. The amount of sunlight
    B. The cost of electricity
    C. The cost of a solar panel
    D. The module warranty

24. In areas of heavy snow, which region should be particularly reinforced?
    A. the corners of the array
    B. the bottom row of the array
    C. the top row of the array
    D. the interior of the array

25. In areas of heavy wind, which region should be particularly reinforced?
    A. the corners of the array
    B. the bottom row of the array
    C. the top row of the array
    D. the interior of the array

26. On a commercial flat roof with a TPO membrane roof, which installation technique reduces the amount of concrete ballast blocks required?
    A. You must use concrete ballast blocks only
    B. Positively attaching to the roof through penetrations
    C. Strapping the array down with rope
    D. Solar cannot be installed on TPO membrane roofs

27. The rooftop transition box serves which purpose?
    A. Transitioning the rooftop cable into the attic
    B. Circuit-level disconnection for rapid shutdown compliance when required
    C. Reduces or eliminates visible external conduit on the roof
    D. All of the above

28. Rail-less racking systems have which advantage?
    A. Ease-of-installation
    B. Better load distribution on slanted roofs
    C. Integrated cable management
    D. None of the above

29. Which ground mount technique eliminates the need for concrete foundations?
    A. Helical posts
    B. Thin film
    C. Double-axis tracking
    A. None of the above

30. Which hand-drawn or computer generated document is commonly required by local permitting office?
    A. Single-line diagram
    B. Bill of Lading
    C. Balance-of-system bill of material
    D. Structural blueprints of the home