OFF-GRID, GRID-TIE AND HYBRID SOLAR POWER INSTALLATION FOR BEGINNERS

A Simple Guide to Understand Energy-Saving Systems, Operation and Maintenance and How to Decide Which One Is Right for Your Home

BENZ JOE

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INTRODUCTION

> *More solar energy falls on Earth in one hour than all the energy our civilization consumes in an entire year. If we could harness a tiny fraction of the available solar and wind power, we could supply all our energy needs forever and without adding any carbon to the atmosphere.*
>
> — *COSMOS: A SPACETIME ODYSSEY, EPISODE 12*, "THE WORLD SET FREE."

NEVER AGAIN

February of 2021 wasn't a lot of fun in Kileen, Texas. We weren't used to the cold weather that winter, and it was rough for many people. By the time the dust had settled and everything returned to

normal, they said 246 people were killed directly or indirectly by the storms that month (Hellerstedt, 2021).

Three storms in a row brought us temperatures way below freezing. They saw -2 ℉ in the capital, and that's further south than us. Our house doesn't have a big heater, but it didn't much matter since it's electric and the power was out for over two weeks.

You only realize how many things rely on electrical power once the power goes out. The lights don't work, but that's good. You can use flashlights and candles if you have them. You can still drive your car to the store if you don't. But when the store has no power, you can't use your bank card to get any money, and you can't use your credit card.

You can always use your phone and recharge it in the car. Sure, that works, plus you can keep warm in the car because the heater works. But when you run out of gas, you've got a problem. Even if you recognized it in time and drove back to the gas station, you discovered they couldn't pump the gas because the pumps were electric.

It wasn't so bad for me. Our kids are not babies anymore, so it was much easier for us. We could cuddle for warmth if we had to. We didn't have to keep a baby warm or learn to warm baby food. I felt terrible for the old folks. They had difficulty looking after themselves anyway, but cooking was hard. It took a lot of work for people to visit and check on them. Having the power go out seems like a big adventure when you're eight and get to use candles. There's not a lot of fun when you're 80, with no one to talk to, shivering under a blanket by yourself.

You'd think the refrigerator being out would have been a problem, but it was so cold out that we could keep food outside without worrying it would spoil. Well, not by going bad. Some of it froze so hard it was no good anymore.

The bottom line was that the electrical grid and the power system failed us. I realized that the problems were going to get worse and worse. More and more people are living on this planet every year. Just under 8 billion when I checked last (US Census Bureau, 2021). And they were increasing like crazy; the power companies must keep up with that demand.

Climate change is something we can't deny is a problem. But I know you may ask, "Benz, how can you believe in climate change when you had a frozen winter like that in the middle of Texas?" Well, extreme weather is a symptom. And we've been having hotter summers, which are also causing problems with the electrical grid.

Our next move will be electric vehicles to fight climate change. So whether you are ready to buy one yourself or not, that's where we're heading. And that will not ease things up on the electrical grid either. So we have to find some different ways to do things.

I'm not one to mope around crying over problems. So I started to think and asked myself, "If I had to come up with a way to power my home on my own, how could I do it?" Well, all you have to do is look around you any day you like. There's light to see by is due to the sun. Nothing humans have ever built has come close to even a bit of what the sun puts out. So all this energy is just flooding down on us!

I had heard about solar energy. People have been playing with it since the 70s, but there has been more progress in recent years. So I decided to check it out, and I've learned that the people who can't be bothered to use solar power don't have a lot of room to complain about our energy problems. But, on the other hand, it's available, getting cheaper, and not requiring a college professor to put it together.

Now that I've had a chance to play with it and get things working, I owe it to everyone else to share. Every person I can help get off the grid improves two peoples' lives: those who got off the grid and those who don't have to fight so hard to stay on the grid. The result is the book you're reading right now. I hope it helps you out.

WHY DO WE NEED CLEAN, GREEN ENERGY?

Fossil Fuel Drawbacks

If it weren't for energy, we'd be living in the stone age. Instead, the 20th century brought about so many labor-saving devices and appliances that we depend on daily: dishwashers, microwaves, coffee makers, refrigerators, washing machines, vacuum cleaners—the list goes on and on.

We have filled the time we used to spend doing menial tasks with entertainment, but what does that require? Energy. Radio, television, movies, video games, computers, and the internet all rely on the fact that we can make electrical energy available to so many people inexpensively. It seemed like we would have cheap power forever.

This has created some bad habits. According to the Center for Resource Solutions, "The average US home uses about 11,000 kilowatt-hours [kWh] per year, and a large portion of that energy is wasted" (2017). It would be great if everyone could reduce their energy consumption. LED lighting and more efficient appliances all help, but only so far you can turn the thermostat down in the winter. And it's only the real die-hards who are arguing that climate change isn't real, so air conditioning is on the upswing.

Meeting demand is a part of the picture, but there's more to it. The ways that we have generated electricity in the past are responsible for many pollution troubles. According to the US Environmental Protection Agency, 37% of US carbon dioxide (CO_2) emissions come from generating electricity, 66% of sulfur dioxide (SO_2) does, 40% of mercury contamination is power related, 25% of nitrogen oxides are released, and coal-fired power plants are the biggest producers of particulate matter (Center for Resource Solutions, 2017).

Carbon dioxide is a greenhouse gas responsible for raising the planet's average temperature, creating extreme weather, and causing many problems, including drought, crop failure, loss of biodiversity, etc. Sulfur dioxide is responsible for causing acid rain, which contributes to the loss of forests and other plants and damage to things humans build, like infrastructure and buildings. Mercury is incredibly toxic and contaminates animals, and causes congenital disabilities. Nitrogen oxides are a significant contributor to ozone problems and smog. And particulate pollution causes haze and makes breathing difficult for others, which generates high health-related costs. (Center for Resource Solutions, 2017).

So, fossil fuels were suitable for generating power a hundred years ago when there were fewer people and power plants, but there are better ways to go. There's also the simple matter of scarcity. Wars have been fought over oil, and they're just not making it anymore—or at least not if you don't have a hundred million years to wait for the next batch.

Renewables

The search for new energy sources has been going on for a while. Since fossil fuels will be used up, finding an energy source that won't be used up makes sense. It would be best to solve the problem and have it stay solved. So that means we have to find renewable energy sources that will continue forever.

That sounds like something too good to be true. Well, the truth is it's not. The sun, for all practical purposes, is a permanent solution. Okay, strictly speaking, it will die in about five billion years (Wendel, 2022), but it's hard even to understand how long a billion years is, so we've got a few million years to figure that problem out!

The sun is the source of all energy on Earth. Plants use their energy to grow. The Earth is warmed by the sun. The wind is generated as the atmosphere heats unevenly. Wind, solar, and water power are all considered renewable because no matter how much we use, more will always be available.

Advantages of Solar Power

Of all the renewable energy sources, solar power stands out as the one that is the best choice for most people. Water power is too complicated, and a person must live in the right place to have a flowing energy source. Some systems use the action of waves, but that technology isn't available on a small scale, and again, you'd have to live on a lake or near the ocean.

Wind power is an option for some people, but it is expensive. The return on investment is only good if you're putting in an industrial-scale wind farm. And with wind's intermittent nature, you can go for days without it in some places, which means that battery systems to maintain the power are very large and expensive.

Solar power, on the other hand, is hard to avoid! Some places get more sun than others, but sunlight falls on every inhabited part of the Earth at one time or another. Solar panels, covered later, have dropped in price by over half in the last ten years. Photovoltaic cells' technology for generating electricity directly from the sun dates back to the '50s. However, they are still being developed and have reached efficiencies of nearly 50%—which is serious when you remember that they produce no exhaust or pollution. And the critical point is that solar panels will have more energy over their life than it takes to make them, which is challenging to do with wind power (Office of Energy Efficiency & Renewable Energy, 2020).

Solar power is good for the environment and will help meet demand. By planning correctly, you can reduce your bills, and you will reduce your dependence on power companies. Even if you power yourself partially, you will have more control over your energy security. Or, you can go off-grid, which has several different meanings.

One example might be that you have a cabin in the mountains. Unfortunately, it might be prohibitively expensive to connect to the local power company—running long lines to serve one customer is not something that utility companies do out of the goodness of their heart, and it can cost tens of thousands of dollars. But a suitable solar

power system can often be installed at a lower cost, and you retain control of it (afox, 2019).

What's Involved

They say that something worthwhile is challenging. But, even if you're convinced that solar power is right for you, there's more to it than just finding solar panels and buying some. First, you must determine what kind and size they should be. Then, you'll need to know how to connect them to your house's electrical system.

In some places, the utility company will buy energy you generate that you don't need, so you'll need to know how to talk to them, how to get the proper permits, and how to connect your system to the grid so that it meets their criteria, and is safe. In addition, you'll have to understand how to ensure your system complies with the National Electric Code and local regulations and codes.

You will want to know how to set your system up to take the best advantage of the available sunlight at your location, setting it in the right place and at the right angle. That will require a certain amount of hardware. You'll also want to consider maintenance and clearing snow from them.

You will need to understand battery and storage systems and how much power you use at a time if you want to run everything off your solar panels. Nobody expects solar power to work at night, of course. You may think they won't work on cloudy days, but they generate some power, just not as much. So you'll want to factor this into your thinking too.

It sounds like a lot, but it's okay, and the upcoming chapters will help you get your bearings to develop a system that fits your needs.

SAFETY

Remember, you must be careful and responsible when working with electrical systems, using power tools, or climbing a roof. Injury and death can result from not taking precautions, and this book shouldn't be considered a replacement for proper training. Be sure to consult with a licensed electrician to be sure you meet code requirements or hire one to do anything you are uncomfortable with.

You may find yourself working on a roof or structure, so be sure you know proper precautions when working at heights, fall restraint techniques and equipment, don't work alone, and wear appropriate Personal Protective Equipment.

PART I

FOUNDATIONS

Any sufficiently advanced technology is indistinguishable from magic.

— ARTHUR C. CLARKE

1

HARNESSING THE SUN

There are several ways that you can get power from the sun. First, you can get heat directly, and that can be used to heat greenhouses or even our homes. Systems like that are known as passive Solar. Plants get their energy from the sun through a chemical process called photosynthesis. Solar chemistry isn't something you would find outside laboratories. The primary way of getting energy from the sun that I want to share with you is using the sun to generate electricity.

One way to generate solar power is "concentrated solar power" (Cal Tech, 2022). You might have seen pictures of large arrays of mirrors in the desert pointing at the top of a tower. You can use lenses like kids will try to burn ants with a magnifying glass, but you do it; the idea is to heat something to very high temperatures. Then, by running water or fluids, you can generate steam and run a turbine—if you happen to have a tower and mirrors in the desert and have a spare turbine lying around, but I bet you don't.

The way that electricity is actually being generated, the way that everyone is talking about, is with solar panels. These are usually thin black panels. You can buy small ones that work to keep your car

battery charged when you leave your car for a long time or large ones that you've seen on rooftops or even in open fields.

HOW SOLAR PANELS WORK

How does a solar panel take energy from the sun and turn it into electricity? They work by using the photovoltaic effect, which is nearly 200 years old. It was first discovered by the physicist Edmond Becquerel in France in 1839 (Donev et al., 2015). He found that wet cells, a kind of battery using silver plates, would have a higher voltage when placed in sunlight.

In 1893, the first version of the modern photovoltaic (PV) cell was made by Charles Fritts, which used selenium crystals and a gold film (Mr. Solar, 2018). In the 1940s and '50s, Bell Laboratories invented silicon solar cells, which you usually find today. It's no coincidence that this was the same place where the transistor was invented in 1947. Silicon solar cells use the same materials we use for transistors now. It's also no surprise that as we've gotten so much better at making computer chips with transistors, we've also gotten better at making PV cells.

The way a PV cell works on the inside is that there are layers of two different semiconductors that have a crystal structure. That means there are lots of electrons around each atom, and those atoms are arranged in a regular pattern. So when light hits the cell, it adds energy to some electrons, allowing them to move from one atom to the next.

One of the semiconductors is called a P-type (for Positive) semiconductor, and the other is an N-type (for Negative) semiconductor, which means that the electrons can cross from one side of the P-N junction to the other but only in one direction. When they do this, it leaves a hole where it used to be, which changes the

charge, and another electron is attracted to fill the gap. So put, light hitting them starts electrons flowing when you use suitable semiconductor crystals. The more light hits them, the more electricity they make (Donev, 2018).

A single PV cell doesn't provide very much power, only about 2 Watts for a 4" square cell (Ashok et al., 2019), so several PV cells are connected, the same way you use more than one AA-size battery to power your TV remote. Technically, you use AA cells, and a battery is a group of more than one cell. For example, a car battery is six cells, so there are six little caps for filling them with water and acid, but that's not important now. The important thing is that it takes more than one PV cell to make up a practical solar panel, the way it takes more than one voltage cell to make up a battery.

Different Types of PV Cells

There are quite a few different kinds of materials that can be used to make PV cells. Silicon is the primary type, but you will run into two types of silicon cells: monocrystalline and polycrystalline. Those are just what they sound like—mono means "one," so a monocrystalline cell is made of one crystal. Polycrystalline cells are made of more than one crystal (Marsh, 2018).

Since monocrystalline cells are one giant crystal, there are no gaps or seams, and electrons move as easily as possible. Polycrystalline cells comprise smaller pieces of silicon that are joined together. If you ever rode a skateboard over concrete, you know that it's just a little easier to ride over one solid piece of concrete than it is to go down a sidewalk that has cracks every so often. It's much the same for electrons.

You might hear of other materials: Thin-film PV cells made from different semiconductor elements. These can be made to be flexible, but they are not as efficient—it takes more light to generate the same power output. But utility companies are using them in large-scale power generation (Marsh, 2018).

You may have heard of Organic LED lighting, and since LEDs are a kind of semiconductor, people are looking into ways to make PV cells using organic materials. Another type you might run into in the future is made of Perovskite, a crystal made of calcium titanium oxide (Marsh, 2018). It would be best if you didn't hold off waiting for the next great thing, or you'll miss out on a lot of solar power you could be generating. Things are good now, but you will have better options when your solar panels age and eventually need replacing!

PERFORMANCE CHARACTERISTICS OF SOLAR PANELS

A PV cell only makes about 0.5 V to 0.6V with maximum light. That sure seems like I need to do more! But, if you hook them up in a chain (in series), their voltages add up. That's the basic idea behind solar panels. I'll keep calling them solar panels, but if you look at older information, you might see them called "photovoltaic arrays." That's just a rose by another name—it means the same thing!

Another essential thing to remember is that I said the electrons only flow in one direction. This flow of electrons is called current, as in Alternating Current or Direct Current. You probably know that alternating current changes direction back and forth, but direct current keeps going in one direction, like a river. That's what solar panels give us. Of course, there are ways to convert between the two, which you'll need to do if you want to power your regular 120VAC appliances or sell your electricity to the power company, but that's a subject for a later chapter.

What does it mean to hear someone talk about how efficient a solar panel is? If a solar panel were 100% efficient, it would turn all the energy hitting it into electricity. It is impossible in the real world, no free lunch. Engineers and scientists have developed a measurement

known as Standard Test Conditions. Suppose a solar panel that was 1 meter on a side was tested at 25℃ by hitting it with 1000W per square meter of light energy (Vourvoulias, 2019). In that case, efficiency is the ratio of the output power to the input. A solar panel that produced 200W under standard test conditions would be 200/1000 = 20% efficient.

There is maximum theoretical efficiency for a single PV cell of about 33%. This efficiency is determined by the Shockley-Queisser limit for P-N junctions (Planète Énergies, 2019). The current idea is that if it is possible to make panels with more than one junction, it will be possible to get greater efficiency out of a solar panel.

Several things in the real world will reduce the efficiency of a solar panel. These come down to ways your situation differs from the standard test conditions.

Obscured conditions

People who don't know better may ask how solar panels can work on cloudy days or even make fun of solar technologies because they assume wrongly that no power is generated without full, bright sun. This thought is false. PV cells generate energy proportional to the amount of light, which is true. You won't get their rated output power in cloudy weather, but that doesn't mean they don't produce electricity.

An excellent reply to such comments is, "When it's cloudy out, you can't see as well either, but you can still see." According to Solar Alliance, "On cloudy days, a solar panel can typically produce 10 to 25% of its typical power capacity (Brock, 2022)." Of course, this will depend on exactly how cloudy it is. But, as I'll show you throughout this book, solar power isn't an all-or-nothing proposition. Having some free energy is still better than having none.

Snow is another factor that can obscure solar panels. Again, it isn't like an on/off switch. Light snow dusting will reduce the output but not stop it completely. But if you have more than a couple of inches of

snow, the solar panels won't work (Vasoulias, 2019). Removing snow is a manageable problem, especially if you plan. You'll want to choose your placement and angle the panels for your particular conditions. If you have a tall roof and live in a snowy area, there might be better places to install your solar panels.

Dust can obscure solar panels over time, reducing their efficiency, so cleaning them is part of maintenance. You must monitor the system's efficiency if you live in arid and dusty conditions. Wind also causes problems, not just with dust; solar panels can be vulnerable to hail in storms. Most solar panels are built to withstand this kind of treatment.

Temperature

You saw that temperature was part of the standard test conditions for solar panels, but the temperature can change outdoors. Solar panels don't produce as much energy when they get hot. Humidity and high heat are not excellent conditions for PV cells, so manufacturers try to build units that will not fail when the weather gets swampy.

While wind can kick up dust and comes along with hailstorms, it can help cool solar panels. Because solar panels prefer cold temperatures (Brock, 2022); if you doubt this, remember that there are solar panels in space powering satellites and the International Space Station, where the outside temperature is hundreds of degrees below zero!

Chemicals and UV

Remember that blocking a PV cell to reduce output isn't necessary. Smoke and haze in the atmosphere can reduce the output, but sometimes you can get caked on soot and particles. (Don't put your solar panels downwind from your chimney!) Rain can help wash the panels, but it takes a certain amount. Cleaning them the same way you would clean windows so you can see it is essential, though you

must follow the manufacturer's instructions in case there are cleaners you should avoid using.

Since their introduction, plastics have come a long way, but solar panels must resist ultraviolet (UV) light. This is a no-brainer since PV panels are supposed to spend their lives in direct sunlight. Unfortunately, some panels develop a thin layer of boron oxide in the first 1,000 hours of use (Vourvoulias, 2019). This will reduce the efficiency by a couple of percent, but it happens internally in the panel, so it's something you can only do something about.

Location, Location, Location

They say three things are important in real estate: "Location, location, and location!" This saying is true when you install a solar power system, too. Nobody would see any sense in putting solar panels in the shade, whether they came from trees or buildings. If you live in a condo or townhouse, you may have little land at your disposal, but you can put panels on your roof. The more space you have, the more options you have for where to put solar panels.

Another important factor when planning out where to put your panels is the angle the sun hits them. The best situation is if the sun hits them perpendicularly. Unfortunately, since the sun moves every day, that's just not possible. And not only does it move every day, but it also appears at different places in the sky with each season! This means that you will have to find a location that is the best compromise.

Yes, there is technology to make solar panels follow the sun. They are called trackers, but the truth is that they cost more than the solar panels themselves (Unbound Solar, 2019), so for most homeowners, they aren't worth the money. You'll never pay them back.

FROM PV CELLS TO A COMPLETE SYSTEM

Now that you have a basic understanding of solar cells and some factors that will determine how well they work, I want to share a little road map with you. Of course, the solar panels aren't enough, so here's a quick overview of some of the other parts of the system that you'll need.

Not every system needs every one of these components—for example, if you're going to be completely isolated from the power grid, you won't have to worry about interconnections—but since I don't know your requirements and exactly what kind of system you are going to build. I don't want to restrict your options. So here it is in a nutshell:

- Solar panels: You know these are part of the system that converts sunlight into electricity. You'll learn to figure out where to put them and how many you need.
- Inverter: A device that converts DC power from your solar panels into AC power that you can use to power appliances. If you do that, it is also involved in tying your generation capacity into the grid.
- Racking: The frames and bases on which you mount your solar panels; racking is the physical support hardware.
- Batteries: If you are off-grid, you may have batteries, which will store energy that you generate so that it is available when the sun goes down.
- Charge controller: this regulates the charging rate of the batteries and is sometimes considered a part of the battery system.
- Electrical components: You will need wiring and fuses—what electricians call "disconnects"—to interface your solar system

with your house wiring and/or the electrical grid.

CHAPTER TAKEAWAYS

The main point to remember here is that solar panels use the photovoltaic effect to generate electricity. Several factors will determine how well they work, but you should remember that while efficiencies are constantly improving, they are good enough to be useful right now. In the future, they will only get better. Finally, you saw that several other components are required to turn solar panels into a complete system that will generate energy for you and your family. The next chapter is where you'll learn about the kinds of systems that are available and what purpose each of them serves.

2

LET THERE BE LIGHT

THE DIFFERENT TYPES OF SOLAR POWER SYSTEMS

One of the most important questions when considering solar power is how you want to be connected to the rest of the world. Some people don't! The idea for them is to disconnect from the grid, so that's one option. Other people want to generate electricity to help contribute to the grid system. For example, in a sweltering summer, people can run their air conditioners while offsetting their energy use during peak demand. And still, others want to be able to sell power back to their electric utility and reduce the amount on their power bills, but they still want to draw from the grid when they need more power.

You have to understand the different systems. Some of the components will remain the same, but some of the features will change. The size of the system will vary. If you only need to provide a bit of backup lighting, you will only need a few panels as if you are

trying to power your entire house. So let me explain the three main types of systems.

Off-Grid Solar

In some ways, the most straightforward system for generating electricity is called an Off-Grid System. The power grid has no helping hand, but you don't have to worry about the complications from connecting to it. If you have a solar panel battery charger that keeps your car battery charged when it sits in a parking lot, that's an example of the most straightforward off-grid solar power system. There's nothing to it other than a single panel and a load—in this case, charging a battery.

There are many ways to have small portable systems for camping like this. They provide the power that you would be able to get from batteries. RV and camping shops are selling more systems like this. Those are what I'd call temporary systems, though, so we won't talk much more about them. What's more interesting is when you have a system large enough to run your house, including lighting, powering appliances, heating and cooling systems, and even pumping water.

A basic off-grid system is like a windmill. A windmill only pumps water or makes electricity when the wind is blowing. If you have a solar panel, you will only generate power when the sun shines on the panels—pretty simple. One of the main reasons people want electricity is for lights, which they need when the sun goes down. So, in that case, you need to have a way to store the energy for later use.

Batteries are the obvious solution, but they have just recently been convenient. It takes a lot of batteries; the most common kind has been lead-acid batteries, like car and marine batteries. These are heavy and large, and charging them produces hydrogen gas, which is highly flammable. Building such a battery system is possible, but it's been expensive and impractical.

Lately, there has been a lot of improvement in battery technologies. Lithium-ion batteries can hold more significant charges in smaller spaces (they call that “Energy Density.”) Costs have also been dropping. So, the battery portion of a solar system is more attainable than ever before, but it is still a significant undertaking.

Batteries also require some electronics to interface with the solar panels, called a charge controller. A battery—any battery—is a chemical reaction. It converts electricity to chemical energy and vice versa. So if you try to overcharge batteries, you can boil them or shorten their lifespan. Charge controllers ensure batteries aren’t over-charged (Hyder, 2019).

If you’re running a minimal system, you might use DC power, but you will want to convert the power to AC for a whole house or regular devices. In this case, you need an inverter. An inverter takes DC and converts it to AC power. You may have seen smaller ones that you can buy for your car. You could run small TV sets or other appliances with these. In RVs and semi-trucks, inverters are used to power fridges and microwaves.

Some inverters are also used to convert AC back to DC. Why? Because your batteries are only going to last so long without sunshine. It seems like cheating, but some people need a backup generator to charge the batteries and power the system. Some generators have AC outputs, meaning they must convert to DC to charge the batteries. Some generators have AC outputs, which means they will charge batteries but still need the inverter to power the house directly.

There are benefits to being off-grid. If you live in a remote area, it may be necessary. Whatever problems your local power company has, they won’t affect you. But there are a few cons: off-grid systems are more expensive, primarily because of the batteries and because you have to make the system large enough that it will supply all your energy. In addition, you have to make all the regulations that the

power company would do, and you can't call them to fix it if it breaks —you'll either have to call an electrician or do it yourself.

On-Grid

On-grid, or Grid-tie systems, as they're sometimes known, are another way of doing solar power. You still have solar panels that generate power and are tied to the electric grid. So if your panels are buried under snow and not generating any power, you can still get power, as usual.

If it's a sunny day and you're away, your solar panels may generate much energy you're not using. In this case, the electric grid allows that power to go instead of into storage batteries. (If your batteries are fully charged, any power you're not using is lost.)

The power company will pay you for the power because it adds to the "pool" of energy available to all electrical customers. Some regulations in 39 states and the District of Columbia say power companies must do net Metering, offering credits for customer-generated power. Six states have rules about paying for compensation that works on a different system. Only Idaho and Texas don't have rules that apply across the state. In those cases, it's up to each electric company to set its policy (Wolf, 2022b).

For an on-grid system, you do not have the up-front expense of batteries because you can send excess energy to the grid, and when you don't have enough energy, you draw from the grid. That sounds good, but you may have to jump through some hoops to get permits. Besides all the work you must do to install your panels and the hardware, you may have to do more paperwork. Also, depending on where you live, the rate you sell electricity to the power company may be less than what they charge you to buy it.

Some unexpected things happen if there's a power outage. You may have to shut down your power generation is tied to the grid. Say, for example, that the power goes out because a storm causes some power lines to fall. You have to turn your system off, or at least make

sure it's disconnected from the grid so that you aren't pushing power back onto electric lines that utility workers are fixing (Wolf, 2022b).

A lot of this is taken care of with the inverter. To put your system on the grid, you use what's called a Grid-tie Inverter (GTI,) also known as a synchronous inverter, which makes sure that your 60 Hz AC is in tune with the power grid—it's the same thing as tuning a guitar to match the rest of the band.

And the other thing that is different with a grid-tie system is that they may have to replace your power meter. Some old-style meters will run backward (Olson, 2015), but many places have upgraded to digital meters and meters with remote reading. To do net Metering, you need a bidirectional meter to measure the energy going out and in.

Hybrid

A hybrid system is just an on-grid system with batteries. You still have solar panels connected to the grid, but when you add batteries, you add the capability of being "fault tolerant." That's a fancy way of saying you can fall back on your batteries if the power grid cuts out.

The battery doesn't have to be as large as a completely off-grid system because you're betting that the power company will fix things reasonably quickly. In addition, you won't need to have a backup generator. Both items can save you money (Hyder, 2019).

An excellent advantage of a hybrid system is that it can still use net Metering to sell excess power back to the power company. If your system is still generating more energy than you need after your batteries have fully charged, you can sell the excess back to the power company if they have a net metering policy. It is a pleasant situation. You have taken care of your own energy needs, you have some control over the reliability of your power, and you can help pay for the cost of your panels. Of course, if you already have, you're making a little money—but we'll talk more about finances in Part II.

CHAPTER TAKEAWAYS

To sum up, you know something about the three basic types of solar energy systems. Of course, choosing the suitable method to install needs a detailed analysis, but there are the basics.

- If you have a remote property that doesn't have existing utility services, then you will need an Off-Grid system. (Some call it "stand-alone" power for that reason).
- If you already have electrical service and are primarily interested in saving money on your electric bills and spending the least on installation, think of a Grid-tied system.
- If you want to be on the grid but be self-sufficient in the event of a power outage, then you will be interested in a Hybrid system or some form of Grid-tied system with backup power.

At an overview level, each system has its pros and cons. For Off-Grid systems, they give you complete control, but they can be the most expensive, requiring batteries and possibly generator backup. Grid-Tied systems are the cheapest to install and the quickest to pay dividends on the investment made in establishing them. But, they offer no security during grid outages. Hybrid systems offer the features of both systems and, if done carefully, can cost less than a fully stand-alone system. In the next chapter, it's time to properly examine your choice in detail.

PART II

GEARING UP FOR SOLAR

Rather than an eyesore on the roof, it becomes a home feature. People will start wanting to put (photovoltaic solar panels) on the front side of their homes to show that they have solar.

— CHRISTOPHER KLINGA (BAGGALEY, 2017)

3

ASSESSING YOUR ENERGY NEEDS

To do a good job putting together a solar energy system, you must come up with some numbers. You need to ask some questions and find answers to them about the following things:

- How much energy do I use?
- How much energy can I generate?
- How much will it cost to install?
- How much will it save me?
- How much will I get paid for electricity?
- Will the system pay for itself?
- How quickly will it be paid off?

These are things you need to know before you begin so you don't end up having to do things twice so that you are compatible with the power grid if you are going to be connected, and so that you have a good understanding of how big your system will have to be. In addition, you want to be sure that you are coming out ahead financially, how long it will take you to pay for the system, and see if you will even make some money.

Getting away from fossil fuels and creating a benefit to the environment is a great reason to install Solar at any price, but it's hard to measure how much effect you're having. For that reason, I want you to pay special attention to the cost savings potential you have. Every dollar you save is a dollar you're not putting into warming the atmosphere, so even if it's a crude measure, it's still an actual number. Unless you're made out of money, you want to get a return on your investment—the system should at least pay for itself in a reasonable number of years.

INVESTIGATING THE ENERGY EFFICIENCY OF YOUR HOME

The first thing you need to do is make sure you have plugged all your holes. You can take that in both the literal sense and as a figure of speech. There is no sense in using solar power if you waste energy at home. If you ensure your house is energy efficient before trying to run it on solar power, you can install the most miniature system to meet your needs. So, try and make your needs smaller first!

Professional Audits

One of the first things you should do is look into a home energy audit. Many utility companies will do these for free or at a small cost. In addition, you can hire an accredited professional to do the same job. When professionals come out, they may have specialized equipment to measure where you have leaking windows and doors, carbon monoxide and gas leak detectors, if there are moist areas in your home, and other signs of energy inefficiency (Home Energy Assessments, 2021).

A professional assessment will go through your house room by room. They will be very thorough, checking the energy use of lights and

appliances and measuring temperatures; they will even go over your old utility bills with you if you let them. In addition, they will look into how big your house is, how many thermostats it has and where you keep them set, how many rooms are used, how many people live there, and what hours they keep (Professional Home Energy Assessments, 2022).

An audit will reveal where you need to seal your home and where you might need to install more insulation if you have an inefficient furnace or cooling system. In addition, they can suggest changes you can make, like installing LED lighting and programmable thermostats, which will reduce your energy use and increase your efficiency.

More information on what to look for when you choose an assessor is available from the US Department of Energy Energy Saver website at

https://www.energy.gov/energysaver/professional-home-energy-assessments

Do Your Own Audit

If you're interested in powering a house in a remote location, you might need help to get an energy auditor out to visit reasonably. Do it yourself. There's no problem with that. You can still conduct an energy audit that might not be as complete and thorough as a professional with fancy meters and measurements, but you can still come up with some great information. For example, you can use tissue paper to move around areas prone to drafts, and the tissue will act as a tell-tale. If there's a draft, the tissue will move like a little flag in the wind. Remember to check around electrical outlets and where plumbing or vents pass through walls.

Again, the US Department of Energy has a great source of ideas for you at

https://www.energy.gov/energysaver/do-it-yourself-home-energy-assessments

where they have information on locating air leaks, checking your insulation, inspecting your heating and cooling, updating your lighting, and more.

You can also put your energy bills in a spreadsheet and see which months are the most expensive; if you can, go back a few years. Then, you'll be able to see how much your usage has increased (track the kilowatt-hours used every month) and the price.

If you notice changes in usage over the years, that could be because your appliances are getting old, so you can decide if it's worth replacing them with newer, more efficient appliances. And even if you have a newer house or newer appliances, don't trust that it's not leaky or that the appliances are efficient! Or at least, as the Russian proverb quoted by Ronald Reagan says, "Trust, but verify." Just because you will draw power from the deep, deep well of the sun doesn't mean it's okay to waste it.

ESTIMATE YOUR HOME ENERGY NEEDS

It seems like a simple question: "How much energy do you use every month?" And in truth, it is. You can get a great starting figure from your electric bill. For some people, that is enough to work with. If you live in a sweltering climate, you might have a big difference between summer when you run the air conditioner a lot and winter, though. And in a cold environment, you might have just the opposite situation. Either way or even if you live where the weather is more moderate year-round, you can get a great picture of your energy needs by looking at the monthly bills for at least the last 3-5 years.

What if you're building a new house or moving into a house that's new to you? You might need old electric bills to look at, or you might be getting new appliances. There are still several ways to determine

how much power you need. To put it simply, you can measure power use, or you can calculate it. If you can wait a few months, you can measure it by looking at your first few months of electric bills. If that's not an option, you can calculate how much each appliance uses. At most hardware stores, you can buy usage monitors for 120V appliances relatively inexpensively, about $25 to $50 (Estimating Appliance and Home Electronic Energy Use, 2021). The idea is that you have an electric meter for one plug, which goes between the device you want to measure and the wall.

The benefit of doing this is getting an actual reading for every device you have. You'll want to ensure that you measure how much energy they use when they are working hard and if they use any energy when sitting idle. Some devices are never completely off, like microwave ovens that have a clock. While they don't use a large amount of electricity, you might be surprised at the total when you add up all the various devices (phone chargers, TVs, and computers in standby mode, etc.).

The drawback to measuring usage is that you must record the use of each device you need to include, which can take time and effort. If you wanted to speed things up with more than one usage monitor to measure more than one device at a time, it would be faster but more expensive. Most people only use one meter. The longer you take measurements, the better your average values will be.

If you choose not to measure, you can often find the rated energy usage by reading the appliance tags. If they give the number of watts a device uses, you can convert that to kilowatt hours (kWh) by multiplying it by the number of hours you use it. In a refrigerator or freezer, your calculated wattage will be larger than the actual usage because the fridge turns off when it reaches a specific temperature. But when it comes to sizing your solar panel system, it's better to overestimate by a little.

Some appliances have energy use calculated on the Energy Guide label, a bright yellow tag you will find on many new appliances at

dealers. You can also find the information on the manufacturer's website. Unfortunately, things like furnaces and 220V devices are incompatible with most energy usage monitors.

After you have all your loads figured out, you can multiply that number by how many hours you run them daily. Of course, complex data will always give the best results, so if you can record how many hours a day your furnace runs, for example, that will provide you with good information—for that time of year! But, of course, it will change with the seasons.

Yes, it is a detailed energy estimate process, so some people opt to have someone else do it.

Whole House Monitoring and Smart Devices

You can get devices that will help monitor your house's energy usage. These products can monitor your usage and make it available directly on your computer or smartphone. In addition, some of them have ways to monitor separate circuits so that you can have an itemized measurement of where your energy is going.

There are also smart appliances now that can report their energy usage to you. Unfortunately, the Internet of Things means that refrigerators and coffee makers are not enabled. However, if you are already interested in a "smart home" or already have one, this area can be used to your advantage.

However, you may ask, "How is that different from just reading my electric meter?" Your electric meter is the most accurate measure of how much you use in your whole house, and it's what your bills are based on. However, according to an article in the New York Times, they questioned the overall value, stating, "It's not because they don't work… It's because they may not be necessary (Hefferman, 2022)." So really, it comes down to whether you want their convenience.

ASSESSING YOUR SOLAR POTENTIAL

After you assess how much energy you need to use, you will need to look at how much energy you can generate from solar power. The solar potential for your rooftop is the maximum size of a solar power installation you could install. It's based on "size, shading, tilt, location, and construction (Solar Rooftop Potential, n.d.).

The key word in that definition is location. The other parts of the definition are all things that you have some control over. For example, you decide what angle the solar panels will be built at. You can cut down trees or clear foliage that interferes. But you can't control how much sun you get every year in that spot.

Luckily, you don't have to become a meteorologist or full-time researcher. Several calculators can help you calculate how much energy you can generate. They are sophisticated and use climate data and statistics compiled by utility companies in the area, and some even use satellite images to analyze the parameters like shading from trees. Here's a list of some of them:

- PVWatts Calculator. This calculator is a project of the National Renewable Energy Laboratory. It will take your address, find your location, ask questions about the system you want to install, and generate a table showing you the amount of solar radiation and the equivalent AC energy you would generate (Schmidt, 2018; Solar Rooftop Potential, n.d.).
- https://pvwatts.nrel.gov/index.php
- Google Project Sunroof. If you have a US or Puerto Rico address, this calculator will give you quick results, including estimates on up-front installation costs, automatic sizing, and savings. It will also offer to recommend local installers.
- https://sunroof.withgoogle.com

- Solar Reviews Solar Calculator. This website will take your zip code, the name of your utility company, and some other information about your roof and analyze your costs and savings.
- https://www.solarreviews.com/solar-calculator
- Sun Number. If you are going to buy a home, you may see a rating in the listing called a Sun Number. This is a simplified rating that Zillow has developed to help people looking for homes with good potential for solar energy. The highest score is 100, and it considers how suitable the building and its roof are for installation, how good the local climate is for solar, how high local electric rates are, and how much solar energy systems cost locally. Any score over 70 indicates that the investment in Solar will be worthwhile. (Lane, 2021).

Another way to get this information is to talk to a licensed solar installer or contractor. Getting two or three bids is expected when you do a construction project. So there's no reason you shouldn't get two or three solar potentials or quotes. Even if you don't go through with the bid, you can get an idea of what the reasonable range is. Even if you have to pay for a professional assessment, it may be worth it because a real-world expert will always have better knowledge than a pre-programmed computer.

CHAPTER TAKEAWAYS

The essential points of this chapter are that you need first to make sure your home is energy efficient, then you need to know how much energy you use. After you do those things, you can figure out how much solar energy will be available to you at your location, and you'll be able to see if it's enough for you or not. The best way to do this is to utilize some combination of online calculators and professional solar installers.

I'll show you how to handle financial planning in the next chapter.

4

FINANCES AND OTHER CONSIDERATIONS

You already know you will have to choose one of three kinds of solar installations, but once you have selected one, you will still have to decide how to install it. Will you do it yourself, or will you hire a professional installer? Are you going to pay cash, or will you get a loan? Are you aware that there are rebates and incentive programs? What about leasing your system? What if you have to move—will it add to the value of your house or subtract from it? Don't worry! I will help show you the lay of the land, so you will know some of the right questions to ask.

YOUR OPTIONS FOR GOING SOLAR

Paying Cash

The first option for installing a solar energy system is the simplest: cash on the barrelhead. You pay for the system, and it's yours. It is the best way to go if you can, but it might seem daunting. Also, it depends on the size of the system. Still, as of 2014, the average cost of a residential solar generating system was between $15,000 and

$20,000 (How Much Does a Typical Residential Solar Electric System Cost? 2014).

As of fall 2022, the average has dropped slightly but is still around $16,000 (Brill, 2022). So if you don't have that kind of cash lying around, don't worry. First, you need to size your system because a small system can be as low as $3,500, and a larger one could cost $35,000 or more.

Once you've done that, you need to know that there is a federal investment tax credit (ITC), which was raised to 30% of the system's price by the US Congress in 2022 (Planning a Home Solar Electric System, 2019). This credit applies to systems that you own, though, not systems that you lease or share.

Solar Incentives and Available Financing

You will also find that grants and incentives from state, federal, and local governments will reduce the cost—more about those later. And there are other ways to pay for your system besides paying up-front. It cannot be easy to track all the different organizations, but North Carolina State University maintains a good resource, the Database of State Incentives for Renewables & Efficiency® (DSIRE). This information is available online at https://www.dsireusa.org/

If you are using a reputable solar installation company, they should also be able to provide you with available incentives in your area.

Getting Solar Loans, like a home improvement loan, is also possible. The payments are often lower than the average energy bill. In some places, the local or state government subsidizes, so the loan is available at interest rates below market rates (Homeowner's Guide to Going Solar, 2022).

Another guide to solar financing is available from the Clean Energy States Alliance from

https://www.cesa.org/resource-library/resource/a-homeowners-guide-to-solar-financing-leases-loans-and-ppas/

How Solar Panels Increase Home Value

Studies have shown that solar homes have lower energy costs and higher resale values, on average about $15,000 more in 2015, or about $4/watt (Hoen et al., 2015). As a result, people see a home with solar generating capacity as something they are willing to pay a premium. Therefore, it makes more sense for some people to sell their house and buy one with an existing solar energy system than add one yourself.

If you find yourself face to face with an opportunity to buy a house that already has solar power, treat it as you would with any other important part of a house. Remember that the age and condition of the system will not necessarily be brand new. Check that the panels have been regularly maintained and aren't weather damaged. Inspect and test any batteries and electronics. Consult with professionals, and look at any production records, electric bills (including net Metering) if the seller will allow it, and service history.

But you're probably like me and want to add Solar to your existing house. So take comfort that putting money into the system is a good investment, even if you have to sell before you've paid off the installation.

Community or Shared Solar

If you aren't in a position to have your solar system set up, you can take part in a community system. This program is still a developing area, so people are coming up with new and different approaches. Still, the general idea is that people who can't put their independent system can go in and buy shares in a system that contributes to the local power grid.

In some places, owning a lot and just installing Solar on it. In some ways, this is like an electrical cooperative or a club. They make the most sense, where solar energy can be generated cheaper than traditional methods (Community Solar Basics, 2020).

The critical thing to remember is that this is a privately owned system. Therefore, the members holding it will still have to deal with all the regulations, permits, maintenance, and installation. The other thing to remember is that community solar is not eligible for the federal ITC. However, it would help if you talked to the utility company and other local or state governments to ensure you have received all their incentive and rebate programs.

Solar Leases

Some people prefer to lease their cars than buy them. You can do the same thing with solar power systems in some areas. In this situation, you get the power from the solar system, but someone else—a solar leasing company—owns the equipment (Planning a Home Solar Electric System, 2019). The advantage of doing this is that the leasing company will pay for all the upfront costs and do the maintenance.

There are a couple of negative aspects for you, though. First, you don't get long-term savings—you will get cheap electricity and cut your carbon footprint, but you may not profit from selling electricity back to the utility. You don't own the system, so you won't qualify for the federal tax credit. Finally, even though people like to buy a house with solar panels, selling your home with a lease may be more challenging. For example, the home buyer must agree to accept a 20-year contract, which can be off-putting (Lane, 2022).

For some people, leasing makes sense and can be a way to get into solar power even if you need to be in the financial position to buy a system outright.

Power Purchase Agreements (PPA)

Like a lease agreement, a power purchase agreement is where someone else pays to build a solar energy system on someone's property. Still, this has become a micro-utility company because they sell power to the landowner (SEIA, 2022). The electricity is sold cheaper than grid power—or there would be no reason to do it!

Other advantages are similar to leased Solar: the customer does not have to do maintenance, there are no upfront costs that the customer pays, and their electricity prices are fixed and predictable (SEIA, 2022). The utility company still provides electrical services and benefits from reducing the load on their grid and increasing generating capacity with the developer ties into the grid.

The developer takes all the financial risks, does the legwork for permits, and files for incentives and credits. Developers have an easier time of this since they employ people to chase forms and applications all day. The developer usually asks for a long-term contract, anywhere from 10 to 25 years.

WORKING WITH YOUR UTILITY AND INSTALLER

Finding Installers, Site Assessments, and Bids

You don't have to be a hardcore DIY to get your house running on solar power. The solar power industry is growing, including companies that will design and install a system for you. Finding one can be challenging, but no more difficult than finding other contractors.

Turnkey Systems

One extreme is to find someone who will do a turnkey installation. In this case, you write the check, and your installer will design the system, get all necessary permits, provide all the materials and parts, do the physical work, and help you file for all the incentives and credits that are available (Thompson, 2020a).

Contracted Systems

The other extreme is where you do all the work yourself, but there is a middle road that can save you money if you have some skills and the time to invest in "sweat equity." Here you will find a solar contractor. You can work out arrangements with them to do whatever parts of the process you don't want to do. So, for example, you could get their help with designs and permits, specialized roofing, or electrical work but still, do some of it yourself.

What to Watch For

When looking for a solar installer, you want to be sure you are getting a reputable business/person to work for you. A face-to-face meeting is essential to ensure you and your contractor get along. You also want to check references and reviews. You also want to check into whether they are licensed and certified. A North American Board of Certified Energy Practitioners (NABCEP) certificate indicates that they are well-trained and will use best practices (Allen, 2022). You can also check with the local Better Business Bureau.

Site and Roof Assessment

Once you've narrowed the field to two or three front runners, get site assessments and bids from them. Even if you have to pay a fee for a complete site assessment, it's worth it because if you use only one site assessment, they may miss something another contractor caught.

If you are considering installing your roof, you need to get the roof checked before you build things on it. The shingles and roofing materials need to be in good condition, and you want to ensure that no areas are rotting through. Whether you have this done by a separate roofing company or as part of the solar assessment process will depend on the contractors you are talking to. Some may work in partnership with roofing companies, but other solar companies may do the roofing themselves. It may be tempting to cut corners on this step, but it is less expensive to do all the roofing in the long run, so you can forget about it for decades after you put the solar panels up.

Remember that communication is the key to a successful working relationship. You should be able to contact your installer reasonably but remember that the contractor should also be able to contact you if issues arise. A good plan is to agree on milestones or to have regular progress reports.

Another approach that can keep everyone working in harmony is paying in installments, such as half up front, another 10% at the first milestone, 10% when the electrical inspection is passed, and the rest on completion. That's an example, but you and your contractor can agree to whatever makes sense. And be sure to get a written contract (Hiring a Contractor, n.d.). As the old proverb says, "Don't do business with anyone if you can't do it on a handshake, and then don't do business on a handshake."

WORKING WITH YOUR UTILITY COMPANY

If you have decided that you are going to use a grid-tied system, then you are going to have another relationship to maintain. You will need equipment that makes your system compatible with the local grid, you will have to follow the policies, and you will want to know whom to contact and how to contact them if there are issues.

Equipment for Grid Connections

In the next chapter, I will explain the specific equipment requirements and grid connections in more detail, but you need an inverter to connect your panels to the grid. But first, you must talk to your local power company to ensure you get equipment compatible with their system.

Addressing Safety and Power Quality for Grid Connections

If you are tied to the grid, as I mentioned, you will have to have a way to disconnect from the system if there is a power outage. In some places, you can cut the grid connection and still generate power for your house. In other areas, that may not be allowed so that electrical workers don't have to worry about coming into contact with lines that your solar system might be energizing. Be sure to find out their regulations.

Net Metering and Rate Arrangements for Grid-Connected Systems

Net Metering may be the most important thing to understand about working with your utility company. The idea is simple—if you're using electricity from the grid, you pay for it. If you're producing more energy than you use, it goes back to the grid, and you're selling it.

In practice, net Metering can be more complicated. First, you must be sure you have an electric meter compatible with net Metering. Secondly, you have to understand the way your utility pays you. Sometimes, they look at the meter's total and bill you or credit that amount, which shows up as kilowatt-hours they owe you—like a store credit. If you want them to write you a check, they will do that, but they may use the wholesale rate per kWh, not the rate you pay when you buy it. This can shock you and make you think you're getting a bad deal, so it's better to know about it upfront, especially if you're paying for your solar equipment yourself. But that's not always the case.

Feed-in Tariff

It is the name of a system where there is one meter for the energy you use and another for the energy you generate. So, for example, when the government subsidizes solar power, you might sell your power for $0.20 per kWh but buy it for only $0.10 (Taylor-Parker, 2020b).

Net Purchase and Sale

Based on this system, where you buy it for more than the utility company does, only it uses a separate meter for each direction. This is also known as net billing, but a separate meter is optional.

Aggregate Net Metering

Aggregate net Metering is for people with multiple electrical services at the same address. An example might be someone who has a workshop on their property. Another example might be a landlord who wants to put Solar on an apartment building. Because they have a business, they got a separate electric meter for the workshop. Under aggregate net Metering, the utility company adds up all the meters for usage. Solar panels are still the only thing offsetting the use.

Virtual Net Metering

This system is like a power purchase agreement in that several customers may share a single solar power system to offset their electric bills.

Net Billing vs. Net Metering

Not all utility companies use net Metering. Some use a system known as net billing. The difference between the two is that net Metering usually pays the same rate for electricity, whether it is going into your meter or coming out of it. The energy you export is bought as a credit. If you export 50kWh, you can draw 50kWh because you have already “paid” for it.

With net billing, the utility company writes you a check. But net billing usually pays a much lower rate for the energy you export. The power is bought at the wholesale power rate (McDevitt, 2022). The wholesale rate is usually ½ to ⅓ the retail power you pay.

Be sure to understand the kind of net Metering before you commit to building anything. For example, if you budget a system that could cost tens of thousands of dollars based on being paid one rate for your electricity only to find that the utility buys it at half of what you figured,

it could be a natural disaster. Your system will take twice as long to pay for itself!

It's easy to avoid by checking everything before you pull the trigger. And if you have questions, don't be afraid to ask installers, utilities, and solar development agencies—they're all willing to help.

TAKING CARE OF BUSINESS

You're probably excited about installing solar panels, figuring out how and where they go, and what you'll do with all the money you save by going solar. It seems like Solar is the greatest, and everyone will applaud you for doing your part in fixing the problems with the electric grid and fighting in a tangible way against climate change.

Nothing makes you feel like you've stubbed your toe more than running into a problem with an inspector or finding that your neighbor has filed a complaint with the city. Likewise, finding out that you missed out on grant money or a tax credit because you forgot to apply can be upsetting, so here are a few considerations you should be aware of.

DIY Solar Permits

Suppose you're doing a turnkey or contractor-assisted installation. In that case, you will have help on this front, but if you're doing it yourself (or acting as the general contractor), you will need to be aware of the following steps (Solar Permitting, Services & Inspections 2021 Guide, 2021). Remember, even if you do a stand-alone installation on a remote property, you will have building codes to follow. In addition, all installations have to follow electrical codes, so don't think permits and inspections are just for city folk.

Permits aren't free, so when calculating the installation cost, expect to spend a few hundred dollars on the permits. It may cost extra if

you hire someone to help with the applications, which can run 10 to 15 pages—there are a lot of details you have to include.

Permits take time, too. Don't think you'll drop off your application, run and pick up some solar panels, and install everything that afternoon! It can take days or even a few weeks for permit applications to be processed, depending on where you live and how much construction is going on. The best advice is to ask the planning office well before you build so that your paperwork can be all settled and your project will not be delayed.

Design

You must know what you want to do when you begin the process. So, a thorough design is necessary. You need to do your solar assessments and determine precisely what pieces and parts you wish to install and where they will go. Building and electrical inspectors will only approve one specific thing and not generally permit you. You may have to revise your design once you get approval, but you must have something concrete. (This is an excellent reason to get help from a professional and does labor yourself rather than the other way around.)

Utility Permits

For any grid-tie system, right from the hop, you will want to talk to the utility company as soon as you have your design. First, you must apply for an "interconnection permit," where the utility lets you connect your equipment to the grid. You will also want to ensure that your connection allows you the power rates you planned.

The power company will ensure that your equipment and wiring diagram comply with local and national electric codes. They will need to see a diagram of your property showing the location of your house and buildings, your electric meter, power lines, and significant obstacles. In addition, they will need to know how many panels they will have, where they will go, the number of inverters they will use, and the make and model of the inverters.

Building Permit

You will want to be on good terms with the folks at your local planning office because they will make your life easy if you have done your homework. If you haven't, they can make your life difficult. You have control over how the situation unfolds, though.

Again, they will want to see complete plans for your actions. For example, if you're doing a roof-mounted installation, they may wish to prove, like an engineer's report, that your roof will support your solar panels. The planning office will tell you if there are rules you must follow—like maintaining setbacks from the edge of your property for ground-mounted solar panels, having limitations on height, or similar things.

I can't tell you what your particular location will require, so it's best to get it straight from the horse's mouth. Ask about both general building requirements and if they have any special needs for solar installation. The more you show you are trying to play by the rules, the more accommodating you will find them.

Electrical Permit

In some places, you may apply for an electrical permit as part of the building permit. In other areas, it may need to be done separately with the city, and in other places, it may be done with the utility company. Make sure to ask how to do it in the jurisdiction you live in. A licensed electrician is a great person to consult with, even if you are going to do the work yourself. The National Electric Code is a complex document, and many little details can cause you to fail an inspection for minor issues. It's cheaper in the long run than to correct them—and busy inspectors don't like having to re-inspect the same property repeatedly!

Approval and Inspections

It will be a happy day when you have all your permits in hand; however, don't be tempted to build anything until you receive the

permit because if you are found to have made anything without a permit (even if it's been applied for), you could be required to remove it. That gets ugly and expensive, especially if you are taken to court, so don't go there. Also, you will have to pay for the inspection, so don't be surprised.

But once you have all your permits, it's time to celebrate and get busy. There are still a few hurdles before you can put your system online. First, you will have to pass inspections. You may have to pass a building inspection and almost certainly have to pass an electrical inspection. Most jurisdictions make you do one check for roughing things in and then a final review. But, again, the people who issued you the permit can tell you your requirements.

Life being what it is, once you have proudly completed your solar power installation and passed your final inspection, you will be eager to throw the switch and generate your energy. But, unfortunately, it will be the cloudiest, rainiest day of the year. So I will leave that disagreement to you and Mother Nature to settle!

Federal Tax Credit

The United States has made a Federal Tax Credit available to encourage the development of solar power by homeowners. It is not money paid to you, but it allows you to take a third of the cost of your solar installation off the tax you owe. If you live in another country, check and see if your government offers incentives or rebates to people installing solar power. If you are a business, there is a similar program, which is appropriately called the Investment Tax Credit. The homeowners' tax credit is sometimes called an ITC, which can be confusing. Just make sure you are looking at the appropriate forms and information.

The US Department of Energy has a guide available at https://www.energy.gov/eere/solar/homeowners-guide-federal-tax-credit-solar-photovoltaics, which is full of information.

The key points, according to Solar Energy Technologies Office (2022), are:

- Claim up to 30% of the installation until 2032, no maximum.
- Located at a residence in the US.
- You own the system or a shared-solar (community) interest.
- It has to be a new system—not buying a house that has solar already. Includes:

    ◦ PV Panels/cells
    ◦ Contractor labor and preparation costs (permit and inspection fees)
    ◦ Wiring, inverters, mounting equipment
    ◦ Storage devices (battery systems)
    ◦ Sales tax

- The installation has to be completed during the tax year claimed.

You can claim this using Form 5696, available from the IRS at

https://www.irs.gov/forms-pubs/about-form-5695.

There can be an interplay between the Federal Tax Credit and other rebates and incentives. You can consult with your installer or even a Certified Public Accountant. Some jurisdictions make it easier than others. And as mentioned earlier, remember to use the Database of State Incentives for Renewables & Efficiency® (n.d.) at https://www.dsireusa.org to see what other options might be in play.

SOLAR RETURN ON INVESTMENT:

Is it? These are the questions you've been waiting for. How much money will I save or make? How much will I spend? How soon will the system pay for itself? These are all facets of what is known as "return on investment." again, it can be complex, but there are people to help. For example, your bank or credit union can help, as can your installation company.

There are a lot of numbers to crunch and a lot of variables. It will depend on which payment options and usage options you go with. If you take out a loan, your interest rate will affect how quickly the system pays for itself, and your finances (credit score) might affect the interest rates you can get. It would help if you determined your percentage for more complex agreements, like community-shared Solar.

Basic Method

The primary method is to take the monthly savings and divide the cost of the system by that amount to get the number of months until you've broken even. Here are two examples. Both say you start with a relatively typical installation of $16,000 in a place where the monthly energy bill is about $90/mo. (To give you a rough idea, this is about 725 kWh per month, and the system is around 7 kW.)

Since this is a simple grid-tie system, it is a place where there is a surplus of the sun during the day, which offsets the power used at night; so in the first case, this is what happens if you can eliminate your electric bill and come out even. Then, in less than 15 years, you will pay for the system and still have no more electric bills.

In the second case, you can see that if you can generate ⅓ more energy than you use, an extra $30 a month reduces the time by five years!

	No buyback	$30 / month sold
Total Cost of System	$16,000	$16,000
Old energy bill per month	$90	$90
New energy bill per month	$0	$0
Savings per month	$90	$120
Number of months to break even	$16,000 / $90 = 178 mo.	$16,000 / $120 = 133 mo
Number of years to break even	178 / 12 = 14.8 years	133 / 12 = 11 years

Other factors

This simple system needs to account for a couple of things. First, if you have maintenance costs, including repairing panels damaged by the weather, it could be deducted from the monthly savings. If you have a loan, you must account for monthly interest charges.

If you take advantage of the federal tax credit, you could save $4,800. That would reduce the installation cost to $11,200, so the break-even period in the first case is more than ten years, but in the second case is less than eight years!

It is also possible to get a loan where the payments are less than your electric bill so that the analysis will be similar, but the savings will be lower, and the payback time will be longer.

CHAPTER TAKEAWAY

Even if you will be off-grid in a remote location, solar energy is a pursuit you are doing only partially. It would help if you interfaced with suppliers, professionals (probably), utilities, and your local government. Having good relationships can make your project more successful.

Search the internet, starting with the Department of Energy (https://www.energy.gov/), state and local government websites, bank or credit unions, utility companies, and local installers. You will be able to find lots of information about your energy needs, your equipment needs, and your financing options.

You want your system to last long, so shopping around is essential. This action applies to every project stage, whether choosing materials or expert help. Don't be tempted to do something quickly when it would only take a little longer to do it well. Remember, if the equipment is supposed to last 20 years or more, it would not matter for a delay of a week or even a month, but fixing something because it was done poorly will be remembered forever.

Now that you understand that the project will go from planning to permitting to construction, inspection, and approval phases, it's time to look into the nuts-and-bolts details of building your system.

PART III

THE LITTLE THINGS

Great things are not done by impulse, but by a series of small things brought together.

— VINCENT VAN GOGH

5

PANELS AND MOUNTS

It's time to talk about solar panels. In Chapter 1, you learned a bit about how they work, but now it's time to discuss them from the point of view of someone who will make a purchase. It's time to shift from theory to the practical reality of putting them to work.

TYPES OF PANELS

There are currently three main types of solar panels: Monocrystalline, Polycrystalline, and Thin-film. While much research is going into improving PV cells, those are the main types.

Monocrystalline panels are made from one single, large silicon crystal. They are the most efficient cell type but are also more expensive up-front (Taylor-Parker, 2020a). There is a new variation on monocrystalline cells called Passivated Emitter and Rear Cells (PERC).

PERC panels derive more energy from the light that hits them by having the back layer of the cell treated chemically ("passivated") so that they reflect light into the cell, work more efficiently with electrons

in the cell, and make use of a broader spectrum of the light hitting the panel. This results in a 5% increase in efficiency over older monocrystalline panels (Boylan, 2021).

Polycrystalline panels have a distinctive bluish color because they comprise many different crystal fragments instead of having one crystal lattice through. In addition, they are less wasteful to produce than monocrystalline panels because virtually all crystal material is well-spent during manufacture. As a result, they are cheaper than monocrystalline panels, but they are also less efficient.

Thin-film solar panels are not pure silicon; they have different chemical compositions. As a result, they are about half as efficient as silicon panels (Marsh, 2021) but don't weigh as much. For this reason, someone with a large, flat roof that can't support much weight might choose these, but a "large roof" means something like a commercial building here. Thin-film panels can also have uses off-grid or in portable applications, but you need to balance the need for lightweight and lots of power.

Two-Sided Panels

There are a few other variations in panels you should be aware of. For example, bifacial panels are two-sided, meaning both sides work. "How do both sides work when only one side can point at the sun at a time?" you ask. It's all done with mirrors! Joking aside, most solar panels have a back plate to reflect light into the cells. However, if you replace it with a transparent material, as the light passes through it, it does not convert to electricity. With a light color or reflective surface, the PV cells on the back of the panel can convert the reflected energy (Marsh, 2021).

Solar Shingles

There is a lot of interest in making roofing shingles that include photovoltaic cells right in them. This innovation will be an excellent option, but as of 2023, they have yet to quit there because they are expensive and need to put out more energy to make economic sense

in the long run (Gambone, 2022). Some people consider them better looking, but they are about five times more expensive than full-size panels.

How Many Cells

Another variation you will worry about is how many cells are in a panel. According to Marsh (2021), the most common number of cells available in a panel is 60, 72, or 96. But some solar panel makers cut the cells in half, giving the panel twice as many cells, which could provide minimal increases in efficiency and lifespan.

N-Type or P-Type

When they make your solar panels, the manufacturer takes silicon crystals and adds something to them. If they add phosphorus, it has a negative charge and is called an N-type cell. If they add boron, the silicon takes on a positive charge and is called a P-type cell (Taylor-Parker, 2020a).

12V or 24V

You make a solar panel out of PV cells. Each cell produces a voltage of about 0.5V. When they are connected in panels, they connect them in an array. By putting them end to end, or in “series,” we can raise the voltage to something easier to use. The most common choices are 12V and 24V (Beginners Guide to 12 Volt Solar Panels, 2020).

Increasing the voltage does not mean more significant power. The power is measured in watts. Watts is calculated by multiplying the number of volts by the number of amps, so a 300W panel at 24V would have to supply half as many amps, or it might have to have twice as many PV cells as a 300W panel at 12V. (Sorry—there’s no free lunch!)

SOLAR PANEL EFFICIENCY

The maximum efficiency of single-junction solar panels is 33% (Planète Énergies, 2019), and PERC panels are getting pretty close to that with about 25% (Boylan, 2021). Regular monocrystalline panels are about 20% efficient, and polycrystalline panels range from 15% to 17%.

Thin-film panels are the least efficient, but there's a lot of variation depending on their chemical makeup. The best are made of Copper Indium Gallium Selenide (CIGS) and can be up to 15% efficient, while amorphous silicon (a-SI) is only 6% to 8% efficient. Cadmium Telluride (CdTe) is between the extremes of the other two types, with 9% to 11% efficiency.

Efficiency is not always the most crucial factor in a solar panel, like if you need a lightweight panel, but it is essential. It will enable you to generate power in the smallest area or take the shortest time to pay for your system.

COST AND SIZE

Here you will determine how many panels you'll need and how large the array will have to be, and then you can decide on the cost. First, you will need your monthly energy usage in kWh from your electric bill. Then, divide this number by 365 to get your daily energy usage. The average US household uses about 11,000 kWh/year, so dividing by 365 says you use roughly 30 kWh / day.

Find Your Peak Sun Hours

You may get anywhere from 8 to 16 hours of daylight during the year, but not all of those hours will give you maximum output from your

solar panels. Dawn and dusk, for example. You can find your peak sun hours on a map in several places. One good source in the US is:

https://unboundsolar.com/solar-information/sun-hours-us-map

For example, if you live in Omaha, Nebraska, you will find that your average peak sun-hours figure is 4.9. Divide your 30-kWh daily usage by your average peak sun hours number; in this case, 30 kWh / 4.9 sun hours = 6.15 kW.

Efficiency

There is an efficiency rating for solar panels, which is a fudge factor to account for when the panels heat up and lose a bit of generating capacity, as well as conversion from DC to AC. You will want to redo this calculation when looking at actual solar panel models. Still, a typical value is around .87 or .90. Divide your kilowatt rating by this efficiency factor to get the kilowatts you need for your system. In this example, take the 6.15 kW / .87 = 7.07, so this means you would need a system with a size of 7 kW, or 7,000 watts.

How Many Panels

Once you know how many watts you need to generate, you can start looking at different models of solar panels. Panels are usually around 300W per panel, varying from 275W to 350W (Taylor-Parker, 2018a). Using an average figure of 300W, you can work out that 7,000/300 = 23.3 solar panels. You'd instead round up to 24, then round down to 23.

Pricing

Now you have done enough homework to be able to start talking to solar panel vendors about prices. You know how many panels you'll need, and more importantly, you have an idea of how much power you're trying to generate. If you go to thin-film panels, you'll have to use more panels to generate the same amount of electricity, likewise with polycrystalline. But you'll be able to make rational comparisons.

LIFESPAN AND RELIABILITY FACTORS

Lifespan

Before you start writing checks or taking out loans, you want to determine that you're getting good value thoroughly. Most solar panels have a 20-30 year lifespan, but you need to consider that. If you're retiring, at 65 years old, you'll have a different idea about the panels than if you're 35 and might have to replace the panels again in your lifetime. Then, it would help if you looked at the rated lifetime and the manufacturer's warranty.

Fire and Electrical Ratings

Solar panels must have the same fire safety rating as the roof installed on, and in California, that includes the racking (Boylan, 2021). Three classes, A, B, and C, determine how far the flame spread can be.

Class A is the highest level of Safety, and it is not just city houses that need to be concerned about it. If you are installing an off-grid system in an area with a risk of wildfires, you may be required to have a Class A system. Solar panels cannot withstand the high heat of a forest fire, as they can melt the crystal structure, though. If you have the misfortune of a fire, you will want to be sure that your insurance covers your solar panels.

You should ensure that you buy panels tested and approved by Underwriter Laboratories. Look for a sticker saying, "UL approved." You want to know that they meet the requirement of UL 1703, the Standard for Flat Plate Photovoltaic Modules, and UL 61730, the Standard for Safety.

Extreme Conditions

No matter where you live, Mother Nature occasionally throws you a curveball. Big storms, winds, and heat waves are all things that can

cause trouble with solar panels. Solar panels are tested for hail impacts, and the Department of Energy is making its list of recommendations to manufacturers more robust so that panels will be made to be hurricane-resistant (Boylan, 2021).

Light-Induced and Age-Related Degradation

In crystalline silicon panels, oxygen molecules left over from manufacturing react with sunlight after installing the panels. This results in an initial drop in efficiency, between 1% and 3%, according to Boylan (2021). This shouldn't be a concern as the reputable manufacturer will rate the panels' efficiency after the initial Light Induced Degradation.

Over time, the panels will also lose efficiency. Usually, this is about 0.5% to 1.0% of their rated output (Best Efficient Solar Panels of 2021, 2019). It does not mean that if your panel is 20% efficient when it's new and loses 1% of its output, it will only be 19% efficient. It will lose 1% of 20% every year, or .01 * 20 = .2 loss of efficiency. The results for this case look like

Year	Loss	Efficiency (in %)
		20.0
1	.2	19.8
2	.2	19.6
3	.2	19.4
5	.2	19.0
10	.2	18.0
15	.2	17.0
20	.2	16.0

Some manufacturers will guarantee that the degradation is linear, like in this example. You can make a warranty claim if the panel's

generating capacity decreases faster than this. However, verification is necessary to ensure the problem is with the solar panel. When comparing two solar panels, you will want to choose the one with the lowest degradation rate over time unless you have a reason to make a trade-off.

Recycling

What has yet to be discussed is what happens to solar panels after they reach the end of life. Recycling e-waste is a problem that still needs a solution from manufacturers and in dealing with end-of-life panels (Bakhiyi et al., 2018). Manufacturing solar panels use chemicals in large quantities, some of which can be harmful.

The point here isn't to say that Solar is environmentally harmful. On the contrary, the net benefit of cutting greenhouse gas emissions is currently more important than the other problems created by manufacturing solar panels and equipment, even if it does generate e-waste. But the point is to share that everything you do will have pros and cons. For example, when they reach the end of life, solar panels can create hazardous waste and health issues for those who process them.

Your solar panels are going to work for 25 years, though. In a quarter of a century, the work being done toward recycling e-waste and solar panels will have made progress. As someone interested in solar benefits, look for ways to support sustainable solar energy.

BEST PANELS ON THE MARKET

Here's the big question: What are the best solar panels on the market? There's no single right answer to that question. You will want to discuss it with your dealer and installer and look at the internet. There are three sources:

- https://news.energysage.com/best-solar-panels-complete-ranking/
- https://www.ecowatch.com/solar/best-companies/panels-for-homes
- https://unboundsolar.com/blog/best-solar-panels

The first two pick SunPower (Maxeon) as the most efficient brand, with EcoWatch and EnergySage being current as of 2023.

Brands

The following is a list of some of the major manufacturers. Consult with your local dealer and installer regarding pricing and availability.

- SunPower
- REC
- Panasonic
- Q Cells
- Silfab
- AXITEC
- Canadian Solar
- Jinko Solar
- Trina Solar
- Mission Solar
- Astronergy
- Heliene
- LG

MOUNTING AND RACKING

Solar panels can't just be thrown out on your roof; they must be mounted firmly. In high winds, there can be a significant amount of force trying to turn them into a sail. Almost as important, you need to

mount them to be at the optimum angle to the sun for your location. At higher latitudes, usually, the panels are mounted at higher angles, say 40 degrees, than the 20-degree angle typical in the southern US.

You can choose racks that follow the sun so that the panels face the sun as long as possible during the day, but most installations use fixed racks. Because the complicated tracking equipment cost is usually less than the little extra power generated, it is cheaper to install a few more panels (Solar Racking: Best Solar Panel Mounts in 2021, 2021).

Pay attention to mounting and racking just because it's not glamorous. If your solar panel isn't well supported and is ripped loose during a storm, you will not be happy! Likewise, positioning is crucial for you to get the maximum production out of your system, which makes it more expensive in the long run. The overall cost of racking is about 10% of the total system cost (Almerini, 2019). So, it's an important part and not one you should scrimp on.

Roof-Mounting Basics

Most solar installations are roof mounted. If someone says they are installing solar, many assume it is on the roof. There are a lot of positive aspects to rooftop installations, according to Schell (2020). These are a few of them:

Rooftop installations make use of space that otherwise goes unused, and it doesn't require land. That makes it perfect for people with small, urban lots. On the other hand, people don't have easy access to panels on a roof, which deters vandals and protects the panels from damage that might be related to traffic. They are also cheaper to install.

Rooftop solar systems protect your roof and prolong its life by shielding it from UV light and other weather conditions (Taylor-Parker, 2020c). In addition, it can offer another beneficial energy side-effect by helping to hold in heat, as if your roof were better insulated.

On the other hand, there are a few downsides to placing your panels on the roof. If you have a shingle roof, you must be careful during installation because anchor screws will have to screw into the roof (Schell, 2020). Flashing and grommets are ways to seal around the mounting screws, but you want to be sure that your installers are not cutting corners. If you're installing yourself, make sure that your roof remains watertight.

If you have to repair a roof with a solar system, it can make it hard to access and more expensive—so you may have to do roof repairs before you mount solar panels. And even if you don't need repairs now, you should check whether or not installing solar will make a difference if you have a warranty on your existing roof.

With a roof-mounted system, once the roof is covered with panels, you will be out of space, and the size of your system will be at maximum. (Yes, you can add more ground-mounted panels if you have room.) And the other thing to consider is that roofs are hot, which can reduce your panels' efficiency, so you need to consider leaving space for cooling. Finally, if you live in an area with a Homeowners' Association, you should be sure you are within the terms of the agreement you signed (Schell, 2020).

Racking Components

The most typical installation is still roof-mounted on a sloping shingle roof. In this case, you will need some roof attachments to support mounting rails, usually a few inches above the roof. Those mounting rails have slots so that clamps can be installed to hold the panels down.

Some systems mount the solar panels directly to the roof attachment hardware, and some railless systems make it easier to angle the panels as necessary. They also have lower shipping costs and can be faster to install, but they don't supply the same degree of rigidity to the panel (Pickerel, 2017). Some systems will use three rails to support two rows of panels, which makes for fewer attachment points, and reduces the chance of leaks.

Your roof attachments might be more straightforward if you have a metal roof. On corrugated roofs, some brackets are designed to fit the curve of the corrugated metal. You must use grommets and sealers to ensure the roof won't leak.

If you have the type of roof known as a "standing seam" metal roof, there is a vertical piece at the seam between roof panels. A U-shaped clamp is made that will fit over the seam and can be attached without penetrating the roof (Gambone, 2022). These clamps then support the rest of the system.

If you have a shallow slope on your roof or need to mount your panels at a greater angle, install tilt legs to angle your panels the right amount. Calculating the right elevation angle (usually just called "angle") is something you'll learn about in Part IV. We'll also talk about the azimuth angle (usually just "azimuth") or which compass direction your panels point (Taylor-Parker, 2018b).

For flat roofs, there is another type of roof-mounting system known as a ballast-mounted system. In this case, the mounting rails are not attached to the roof but are held down by concrete blocks (Gambone, 2022). Again, the weight of the solar panels holds the system down, but concrete ballast blocks are added to stand up to high winds.

The advantage to a ballast mount system is that it won't increase the chance of leaking since there are no fasteners that have to screw through the roofing materials, but it's not suitable for every room. Again, the roof has to support the weight of the system, including the heavy ballast block.

Some new approaches to non-penetrating mounts attempt to bring the advantages of ballast mount systems to roofs with a steeper pitch. One such uses the weight of the panels on one side of a roof, with straps that connect to either more panels or a counterweight on the other side of the roof's peak, with the combined weight holding the panels onto the roof. These systems are rare, so you'll want to discuss the specifics with the dealer.

GROUND-MOUNTING BASICS

What if your roof isn't an option? It could be too small for the size system you need. It might not face the right direction—panels must face south in the northern hemisphere. There may be other factors, such as the complexity of your existing roof. You can always look at mounting your system on the ground. There are pros and cons to this choice, as with anything.

The first factor to consider is how much land you have. Is it open? Is it accessible? Does it have trees or other obstructions that will shade the solar panels? If you have a lot of lands available, installing an extensive ground-mounted system might be a good choice. The panels will not be installed at great heights, so there is more excellent Safety when you install them and when you have to do maintenance or clean them. Ground-mounted panels are more accessible, but while that's good for you, it can also be harmful. A ground-mounted system is usually more efficient because you don't have the heat radiating off the roof. However, they are also slightly more exposed to air circulation and cooling.

A ground-mounted system is usually more expensive per watt when it's done being installed (Wolf, 2022a). The reason is that all the other components cost the same, but using an existing roof can't eliminate the cost of the frames or poles that support the panels. But, this is an upfront cost you only have to pay once, so if your ongoing savings are higher, it may be worth it (Taylor-Parker, 2020c).

Fixed Mounts

Two basic ground-mounting systems exist: fixed ground mounts and pole mounts. An improved ground mount comprises supporting posts that hold an array of solar panels, which looks like a roof-mounted system with no house under it. The posts are often set into the ground using a post-pounder (Wolf, 2022a), or they can be placed in concrete.

Systems that use fixed ground mounts can be ballast mounted and are also popular. The panels are held down by the weight of the panels (Almerini, 2019) and, if necessary, concrete blocks. So you won't have to worry about ensuring that your roof is solid for a ballast mounted, and there is no drilling or digging into the ground. You will want to choose your site carefully, though. Some places with wet or soft ground might not be suitable.

Pole Mounts

The other primary type of ground mounting is called pole mount. You need one large rectangular array of solar panels in a pole mount system. You have larger poles, and on the top, you have several solar panels. Where a fixed mount system may have one edge of the panels very close to the ground, often pole-mounted systems are higher.

Pole-mounted systems lend themselves to being used with a tracking system that will rotate to follow the sun as it travels east to west and a tilting system to change the angle of the panels depending on how high in the sky the sun is (Wolf, 2022a). However, even without a tracking system, a pole mount can be an excellent way to mount panels.

When installing the concrete base, it is much less work to set up one more extensive base than many small bases, for example. It's challenging to consider ballast mounting a pole-mounted array, as the unit tends to be top-heavy and unstable. But who knows what a clever engineer might come up with in the future—maybe a sort of tripod could be created offering the advantages of reasonably portable pole mounts.

Distance and Land

If you are going to be using ground-mounted solar panels, you're going to need a larger piece of land. It will have to have good sun exposure from the south. It shouldn't be too hilly, though the more the slope of any hills faces south, the more you can use it to aim your

solar array. North-facing hills are generally a poor choice (in the northern hemisphere).

If you have a large property, you won't necessarily be able to use that land for anything else. For farmers, this means that they might lose money because the income from crops that could be grown on that land is higher than the energy savings. You must consider your long-term plans for that land, as moving a solar installation will be costly!

It would help if you also dealt with vegetation that grows from under the solar panels. Trimming may be necessary occasionally, depending on where you live.

A solar array doesn't have to be right next to your house, but the further away you place it, the more expensive it gets. The cost of running suitable cable can be costly in the long run. Burying the cable is often a good idea, but there is the expense of trenching; you have to use appropriate cable for burial, follow all applicable electrical codes, and make sure to "Call Before You Dig" so that you don't damage any existing utilities.

Whether your solar array is close to or nearby where you use power will make a difference when choosing inverters—more about that in Chapter 7.

Carports

There is a third way to mount solar panels: a cross between roof-mounted and ground-mounted. You can build a roof—usually a carport—out of solar panels and use the space underneath it for parking cars or storage. But since there is no existing roof under it, this is a very tall ground-mounted system.

You can install carports in places you might have yet to consider, such as over a driveway, but you must ensure that local zoning and building codes permit this. The solar panels might not make a difference, but the fact that you want to build a larger structure may

create hurdles. Make sure you check with your local authorities and contractors before you commit to a carport project.

PUTTING IT TOGETHER

Racking and mounting hardware is pretty simple stuff. Three manufacturers that are known for high-quality mounting products are Ironridge, Quick Mount PV, and Unirac (Almerini, 2019). SunModo and DynoRaxx are other suitable suppliers, while General Specialties and MT Solar are well-known for pole mount systems (Solar Racking: Best Solar Panel Mounts in 2021, 2021).

You are putting the rack components well within the scope of most DIY-oriented people. The hardest part is doing the roof attachments or foundations for ground mounts. Beyond that, the hardware is usually straightforward, and the most challenging part is working on a roof or at heights. But if you don't feel safe or comfortable, don't risk it—there are many qualified solar installers.

Ready, Aim…

How you aim your panels will be important in how much money you save or generate. You may find that you can't make the perfect alignment—perhaps your house faces southwest, so you'll always get more light in the afternoon, but you'd like to face directly south. That's not a deal breaker, but it may affect your payback period. You might also be able to overcome alignment with different mounting solutions.

With this in mind, the best situation is to aim your panels due south. (If you're in the southern hemisphere, it would be due north.) It's best to use a GPS device to determine which direction is south because a compass has an error called "magnetic declination," which varies depending on where you live (Taylor-Parker, 2018b). If you use a GPS, you won't have to concern yourself with this.

The tilt of your solar panels will vary with how far you live from the equator. If you lived right on the equator, you would have no tilt—your panels would lie flat so that the sun passed directly overhead. If you lived at the North Pole, you would stand your PV array vertically, like a wall—but you wouldn't get sunshine for part of the year either! (That's okay—I know you don't live there.)

The rule of thumb for anyone between the equator and the pole is to set your panel to an angle equal to your latitude (Taylor-Parker, 2018b). For example, if you live in Minnesota at 45° N latitude, you'd tilt your panel 45°. If you live in Dallas at about 33° N latitude, you will tilt your panels at 33°. By doing this, you will get the best year-round production of electricity.

In the winter, the sun moves further south, so if you prefer to produce more electricity during that time of year, you can give up a little summertime production and tilt the panels another few degrees, even up to 15°. If you want to lean toward producing more electricity in the summer, you can lean the panels back so they get more direct light overhead during the long summer days, but you'll make less electricity in the winter.

If you're fussy, you could adjust the tilt angle thrice a year. But, according to Phil Taylor-Parker (2018b), most people don't do this. Instead, they are just at 5-10% of the size of their system. And taking this approach to the extreme, you would look at a tracking system to get the most out of the sun daily. Again, great idea, but the added complexity of the moving parts is expensive.

CHAPTER TAKEAWAYS

In this chapter, you learned that you want to choose the panels that make the most sense, given your assessment of your energy needs and your particular building site. There's room for creativity in installing on the roof, on the ground, or even a system that combines both if you want.

Now you are familiar with different types of panels, what to look for when buying, and some companies that make them. You know some of the different ways you can mount panels and what's involved so you can avoid problems by not building on a rotting roof or staying compliant with local building codes. And you know how to aim them, so you can choose a good spot to put them.

Once you have energy pouring in from your panels, it's time to start looking at what happens next. First, we'll look into connecting your panels, converting energy, and storing it.

6

POWER CONVERSION

Your solar panels give you electricity from the sunlight, but it's not ready to use. For one thing, there will be variation in the output, like if the sun goes behind a cloud, for example. If you had a light connected to this directly, the light would get brighter and dimmer. So, we need to regulate the voltage.

More than just regulating the voltage is going to be required, though. That would work for some simple off-grid systems, but you would be limited to 12V (Direct Current) DC appliances that you can plug into your cigarette lighter. In North America, the power that comes from the grid is alternating current or (Alternate Current) AC, and it is converted to 120VAC to enter our houses. (Europe and other countries use 240V, but the principle is the same.)

So to both run regular household appliances and connect to the grid, you will need something to convert DC power to AC power and change it to the correct voltage. That is what an inverter does. You may be familiar with power inverters that you can plug into the cigarette lighter of your car to make AC power. A solar power inverter does the same thing, but instead of using your car battery as the source, it uses solar panels.

TYPES OF SOLAR INVERTERS

String Inverters

There are three different approaches to solar inverters. The most basic is what is known as “string inverters.” String inverters got their name because they take several solar panels connected in series one after another, like a set of Christmas lights.

The advantage of string inverters is that they offer centralized power control, and you usually have only one inverter. They are sometimes called “central inverters” (Matasci, 2021). In addition, you can hook up more than one string of solar panels to an inverter, which can make for a lower initial cost.

The downside to string inverters isn’t with the inverters themselves. Because the solar panels are connected in series, the circuit runs from one to the next until it has passed through the entire string. It means that if any of the panels has a problem, it will cause a problem in the whole system. For example, if one of the connections between panels gets broken, the system will not work at all. Another drawback is that if you want to install ground-mounted panels far from your electrical panel, DC suffers what is known as “resistive losses,” so by trying to carry the DC power a long distance from the panel to the inverter, a lot of power is lost in the wiring.

Micro-Inverters

Going to the far end of the scale is using what is known as “micro-inverters.” These units mount on each solar panel, and they only control the power from that panel. If one panel has a problem, the rest of the system still works. They give the highest degree of control and offer the best performance. In addition, the inverter can monitor each panel, regulating problems on a fine-tuned, individual basis.

Because the power is converted to AC right at the panel, it doesn't suffer resistive losses and can be mounted further away from the house. You can also monitor each panel's performance; some micro-inverters can provide reporting and monitoring. This allows you to address problems surgically. For example, micro-inverters can compensate for installations where you might have trouble with occasional shade or complex roofs that don't allow panels to be aligned perfectly (Matasci, 2021).

The downside to micro-inverters is that they are more expensive because you must buy an inverter for each panel.

Power Optimizers

There is a middle ground between string inverters and micro-inverters. For example, you can benefit from isolating panels and regulating the DC output but keep the cost savings of having one central inverter. Systems that do this are known as "string inverters with power optimizers."

Power optimizers, like micro-inverters, are module-level power electronics (MLPE) that work at the level of individual solar panels (Understanding Power Optimizers, 2021). They ensure that each panel produces the most DC it can under the given circumstances, and they are even out the power on the string.

When shade falls on one panel but not others, it affects the output of the entire string. Power optimizers are a way to allow the other panels to provide their full output still. In addition, having a steady, more significant input allows for greater conversion efficiency when the DC reaches the inverter.

The term you will run into that describes how optimizers work is maximum power point tracking or MPPT. This allows the system to identify which panels are operating at a higher output than others and conditions the power on the way to the inverter, increasing efficiency (Hahn, 2020).

If you're using power optimizers in a system with battery storage, connect them to the battery charge controller. This save converting DC to AC and back to DC again. There will be more about this in the next chapter when we get to batteries.

Battery, Hybrid, and Grid-Tie Inverters

If you are only concerned with getting solar power into your house and using it immediately, then a simple DC-AC inverter would take care of your needs. But since the sun sets at night, you must be tied to the grid, have battery backup, or both.

If you will be off-grid, one way to arrange your system is to have an inverter that generates power from your batteries while the solar panels recharge the battery. I'll talk more about batteries in the next chapter.

In a hybrid system, the inverter plays a significant role in coordinating your energy sources. For example, it can control the rate batteries are charged and draw power from them to supplement the panels when needed or draw power entirely from batteries in an outage—or if you have to disconnect from the grid because of a power outage. In addition, a grid-tie inverter has to sync its AC output to match the grid's frequency (60 Hz in N. America) and ensure that the power is in phase—meaning that the AC is moving in the same direction at the same time as the current on the grid.

Size

You will need to have an inverter that can supply all the energy that is asked for. The way to compare is measured in watts. The size of your panels in watts is a good starting point. If your inverter isn't rated for as many watts as you calculated when sizing your solar panels, you will walk away while leaving the energy you collected on the table.

But two things can happen if you set your capacity equal to the panel output. First, when you turn on large motors or other appliances, they

have what is known as “inrush current,” meaning they take extra power to get started. If your inverter can’t handle peaks greater than standard usage, it will trip the protection circuit—similar to blowing a fuse. (If you get an inverter with poor protection circuitry, it can damage the inverter!)

You will need to check the continuous rating—the amount of steady power in watts the inverter can provide—and the surge rating. The surge rating is the number of watts that can be supplied quickly. A suitable inverter will have a surge rating of up to 300% of its standard output. Smaller, cheaper units will only have surge ratings of 25% to 50% over max (Inverter Basics and Selecting the Right Model, 2019).

If you’re working with a string inverter, you also want a little excess capacity to add panels down the line. One recommendation is to get an inverter 30% larger than you need (Metaye, 2021). So if you were looking at a 6kW system, you would want 6kW * 1.3 = 7.8 kW, or you’d be looking for an 8,000-watt inverter—or larger!

Some advice you to buy the largest inverter you can afford. However, if you’re going with micro-inverters, you can add more as part of an expansion, which is another advantage to making that choice.

COMPARING SOLAR INVERTER TECHNOLOGIES

While you don’t need to know all the electronics to build an inverter to use them, you will want to know a little about how they work. There are three main types; you want to make the best choice since all your power will come through them. If you tie your system to the grid, your utility company will be very strict about specifications and make and Model, making your task easier. You will only have to choose from their list.

Pure Sine Inverters

The best type of inverter, and the most expensive, is known as a pure-sine inverter. Pure sine means that the output wave is a smooth sine curve with no jumps or breaks. This looks exactly like the power that a utility company promises to provide to your house.

Power stations naturally generate sine waves because they use rotating motion to create electricity (Inverter Basics and Selecting the Right Model, 2019). However, doing the same thing electronically takes a little effort and more complicated circuitry. The best pure-sine inverters have low-frequency switching and transformers, adding weight, size, and cost.

Anything you plug into a pure sine wave inverter will work efficiently as if you were running from house current. A pure sine wave replicates your household electric supply, and you don't have to give it a second thought. The only problem is that you have to pay for the privilege.

Modified Sine Wave Inverters

Instead of turning DC into perfectly smooth waves, a modified sine wave inverter makes a waveform that looks roughly like a sine wave but jumps and looks blocky. This is because using on-off switches is cheaper than making complicated analog circuits. In addition, waveforms like this contain frequencies besides the pure 60Hz sine wave, which can cause heating in motors and other loads.

The efficiency of modified sine wave inverters is less than pure sine inverters, and some things will perform better using a modified sine wave. According to Inverter Basics and Selecting the Right Model (2019), powering most motors takes 20% more energy input. The extra frequencies in modified sine waves can cause trouble with clocks and appliances that use the power line frequency as a time reference. Variable units, like light dimmers or electric drills, may have only on and off settings.

Square Wave Inverters

Square wave inverters are inexpensive but only made a little now. You do not want one. Very few things run well from them, and they can damage complicated electronics like computers. The odds of finding one in a solar electric system are very low, but if you do see one, avoid it.

BUYING INVERTERS AND OPTIMIZERS

Like anything else, you want to make sure you get the best value for your inverter dollar, and you want to be sure that you get something reliable. So look for UL Listings and warranty, and ensure you size the inverter correctly. While inverters are efficient, every drop of efficiency you can hang onto while meeting your other targets is essential.

You will have to coordinate the budget process for your whole system. Choosing an excellent inverter at the expense of panels is silly. But buying panels and tracking systems is only good if you can turn the power you collect into energy to use or sell. You must take a whole-system approach to balance your needs and constraints across the project.

Warranties are an essential consideration. You want something that will last, and while nobody can guarantee perfection, you want to know that the manufacturer will be there to help if you have problems. Most solar panels have 25-year warranties, as do most power optimizers (Understanding Power Optimizers, 2021).

Ensure that the inverters you buy have overload, surge protection, and low-voltage shutoff. Problems can occur if there is insufficient power from the solar cells. It is better to shut the system down

safely, even if that causes a local blackout than to damage your devices by trying to operate when insufficient power is available (The Role of an Inverter in a Solar Electric System - DIY Solar Resources, 2020).

CHAPTER TAKEAWAYS

Once your panels convert your sunlight to DC power, you must convert that energy to AC. You can do that all at the receiving end, your central electrical service panel, or you can do it at the sending end. Your other choices will determine what sort of conversion technology you should use. Whether you are going to be tied to the grid, whether you are going to have batteries, how far from the house your panels will be located, and whether you are ever going to add panels in the future are the keys, in addition to optimizing cost and performance, are the keys to choosing the right kind of inverters.

Using that AC power once you have it is easy enough. You have plenty of ways to do that. But, as we move on to the next chapter, it's time to think about what you want to do with the power you generate when you can't use it.

7

STORING THE SUN'S POTENTIAL

Solar energy is something you can only harvest during the day. So even the most efficient systems can't provide energy 24 hours a day. So you need to be like the ant in the fable of the ant and the grasshopper and store away some energy for when it's not available. Currently, the best way of storing electrical energy is by converting it to chemical energy and keeping it in batteries.

Batteries have been undergoing a tremendous amount of development in the 21st century. Between smartphones, electric vehicles, and even solar energy, new chemical formulations that last longer and store more energy in smaller spaces are becoming available and becoming more affordable. Here are some critical things about using batteries in solar energy systems.

BATTERIES

For an off-grid system, it's challenging to build a system that doesn't use batteries. However, even if you are using a grid tie, the security of having batteries is worth the expense. A battery is a chemical

reaction, using different elements in reaction with electricity, and there are several ways of doing the same job using different chemicals. Each has strengths and weaknesses, so here are the major types you can choose from.

Battery Types

Four chemistries are commonly used for solar power: lead-acid, nickel-based, lithium-ion, and flow batteries. Every battery needs to try and get the best energy density, which is how much power it can hold in space. Cost and depth of discharge will also be important, as is the number of charge-discharge cycles a battery will give before it reaches the end of its life. Something else to pay attention to is the surge current, which is like cold-cranking amps for car batteries. Again, it's how well the battery can handle a robust temporary demand.

Lead-acid

Traditionally, Lead-acid batteries are the kind of battery used in cars. They are an ancient technology dating back to the mid-1800s (Lane, 2020). There are several variations of the lead-acid battery. Wet cells, also known as flooded lead-acid (FLA) cells, contain lead plates in hydrochloric acid. Lead and acid are hazardous substances, but battery recycling is well managed. When charging, a lead-acid battery creates flammable hydrogen gas (the product of electrolysis), so they need to be kept in a ventilated area.

On the other hand, as batteries go, they are the least expensive option and are very well established. There are reports of people building large systems using old, discarded batteries, but I wouldn't recommend this because batteries near the end of their life will only last for a while, and you'll be looking for new ones all the time.

In addition to flooded cells, there are sealed lead acid (SLA) batteries, sometimes called gel cells. These batteries are not prone to spilling and are not hazardous. In addition, there is no off-gassing of hydrogen, and you don't need to add water over time (Thompson,

2020b). They also sit unused for longer, so SLA batteries are a wise choice if you're considering an off-grid system for a cottage that you only use a few times a year.

For regular lead-acid batteries, the depth of discharge is about 30% to 50% daily. It does not mean the voltage should be half—a 12V battery that gets down to 6V is probably toast! The deeper you discharge a battery, the fewer charge and recharge cycles you will get, but deep-discharge batteries are designed to deal with this better than ordinary lead-acid batteries. Even so, you will get between 500 and 1,200 charge/discharge cycles from a battery (Types of Solar Batteries: Pros & Cons and How to Choose? 2021). If you charge them daily, a conservative estimate on lifetime is 2-4 years.

Lead-acid batteries have a low energy density, which is large and heavy. Typically, they are rated at 80-90 watt-hours per liter (Wh/L). In addition, they have good surge current capacity (Types of Solar Batteries: Pros & Cons and How to Choose? 2021).

Nickel-Based Batteries

One battery chemistry with nickel is known as Nickel-Cadmium (Ni-Cad) batteries. These were some of the early consumer rechargeable batteries used in the aviation industry (Lane, 2020) because they withstand a wide range of temperatures.

They are currently a less popular choice for two main reasons. First, cadmium fumes are highly hazardous, and cadmium in solid form is also dangerous. In some countries, they banned cadmium entirely. It does not mean you can't use it or are taking your life into your hands, but a large installation would have to consider this.

There is a persistent notion that Ni-Cad batteries have a "memory" effect; even though they haven't fully discharged, they will act like they need charging when they hit a certain point. This information came from specific satellite cases in the 1960s (The Nickel Cadmium Memory Effect — Fact or Fiction? 2019). Still, the batteries had to

follow the same pattern daily for thousands of days. Then, a paper published by two scientists at GE started the recurring myth.

Ni-Cad batteries are a good choice if you need to withstand extreme temperatures or have a large installation. They can have an energy density of up to 150 Wh/L, almost twice that of lead-acid batteries, and a lifespan of up to 2,000 charge/discharge cycles (Types of Solar Batteries: Pros & Cons and How to Choose? 2021).

Lithium-Ion

The current area of development in battery technology is lithium-ion batteries. They are everywhere, from cell phones to laptops to electric cars. They have a high energy density from 100 to 265 Wh/L. Their lifespan is also up to 2,000 cycles, and they are deep discharge batteries, with a depth of discharge averaging a little better than 90% (Types of Solar Batteries: Pros & Cons and How to Choose? 2021).

They are cheaper than other batteries, but their cost is decreasing. However, improperly charged batteries could be a fire risk. For example, in New York, there were 200 fires caused by lithium-ion batteries (Rubin, 2022), but as long as they use the proper charger, the battery is UL Listed, and not allowed to get too hot, they are safe.

Lithium-ion batteries come in two variations, nickel-manganese-cobalt oxide (NMC), which has a higher energy, and Lithium Iron Phosphate (LFP), which is a little safer and has a longer charge/discharge life (Types of Batteries for Your Home, 2021). Either way, they are beautiful.

There is some controversy about mining and the environmental impact of lithium batteries. Whether it will be a permanent solution or other energy storage systems will be invented remains to be seen. However, taking the win of reducing carbon is pragmatic.

Flow Batteries

Even though the flow batteries are prepared for prime time, they are a new technology showing great potential! They are entirely different from typical batteries. They work by having two tanks of liquid electrolytes. The electrolytes store electrons, and when pumped past an electrode—think of a metal plate separating two liquids—it creates an electric potential. To charge the batteries, the generation source, such as solar panels, charges the electrolytes as they flow past the electrode (Service, 2018).

People are still sorting out the best materials to make flow batteries. Metals like vanadium and zinc-bromine (Service, 2018) are popular. Unfortunately, they are large and thus aren't suitable for small houses, but at least one company manufactures a flow battery for residential use (Lane, 2020). So, keep your eyes open for new ideas and products in this area.

CALCULATING SIZING AND NEEDS

Most of the work you need to do to judge the size of your battery system is done when you assess how much energy you use, but there are a few questions you want to answer specifically regarding storage. What goal you are trying to achieve is important and affects the choice of solution. If you're going off-grid, your needs will be very different than someone who needs to make it through the night.

Kilowatts vs. Amps and Amp Hours

Up to this point, I've talked about energy use in watts or kilowatts, but many batteries will give you their rating in amps and amp hours. There's a relationship, and conversion is not a complex calculation. The power of an electrical current is shown as P = I x E. So the letters are P for power in watts, I for current in Amps, and E for voltage in Volts. (We use I because it comes from the French

intensité de courant (Why I?, 2023), or intensity of current, and E is for electromotive force, which is the physics term for voltage.)

Plug in pieces you know, and it's easy to solve for the other. So, if you have a 100-watt light bulb that runs on 120VAC, you take 100 = I x 120, or 100/120 = I and find that you will have 0.83 amps of current. Likewise, if you have something that runs on 120VAC, it says that it will draw 15 amps of current, P = 15 X 120 = 1,800 watts, or 1.8 kilowatts.

The DC works the same way. If you have a 12V battery and want to run your 100w load, you have 100 = I x 12, or 100/12 = I, which is 8.3 Amps. It makes sense that the current got ten times bigger because the voltage got ten times more minor, but you're still generating the same 100w of power. And likewise, if you have a 12V battery and a 15-amp load, you will make P = 12 x 15 = 180 watts. Yes, it's ten times smaller because the current is the same as before, but the voltage changed.

So for another example, you have a car battery. Most car batteries have about 50 amp-hours of energy, 12V batteries. The battery's life will depend on the amount of current you draw. If you draw 1A, it will last 50 hours—1A x 50 hours = 50 Amp hours. If you draw 2A, it will last 25 hours. 2A x ? = 50, or 50/2 = 25. If you draw 10A, it will be 50/10 = 5 hours.

You have to do this bit of arithmetic because your house uses AC, which is not exactly equal to the DC going into the inverter. It's easiest to know how many watts you have in usage, which you figured out before, and then once you have watts, you can work out amps depending on how many volts your batteries and panels are. Of course, if this is too much before you've had coffee, you can always have an installer or dealer do it, or there are online calculators.

The last thing to know is that you can always trade off voltage against the current. So if you have 24kWh from 12V batteries, you'd need 2,000 amp hours of battery life if you wired your batteries into a 24V system, 24 kWh / 24V = 1000 amp-hours or half as many

batteries. And if you want a 48V battery system, you will only need 500 amp-hours of storage.

System Goals

Saving Money

If you're going solar to cut down your bills but still use gid-tie, one approach is to use your power when it's most expensive from the grid to avoid paying peak-power premiums. If there's a flat-rate plan, avoid using the grid except when necessary (Taylor-Parker, 2018a). In a scenario like this, you may only need a few batteries because you're not trying to have a lot of battery capacity on hand, maybe just a few hours.

Reliability and Self-Sufficiency

Reliability is your goal when you want power when the grid goes down. Self-sufficiency is your goal when you want to go off-grid. The only difference is how long you can go before you run out of power. The key is the number of batteries and how fast you can charge them from your panels.

It will take more batteries to be completely off-grid for the same power use because you have to have enough capacity to last the planned maximum number of days without power.

Another thing to remember is that you have some control over how long the batteries last by controlling how much of your house you keep powered by them. For example, you use them like a backup generator. In that case, it's possible to do electrical wiring so that the key systems—refrigerator and freezer, heating unit, and water pumps maybe—keep running. Still, you choose not to use the electric dryer because you can hang clothes outside.

Calculating the Number of Batteries

The number of batteries should be straightforward now. Figure out how many kilowatt-hours you use per day and how many days you

want to be able to go without power. If you have to deal with low temperatures, you'll need to consider that because all batteries have less power when it's cold.

So if you use 11,000 kWh a year, that's about 900 kWh per month, and if you divide it by 30 days, it is about 31 kWh per day. So if you want to go seven days without power, you need 31 kWh x 7 = 217 kWh.

Now, if you use lead-acid batteries with a 50% depth of discharge, you account for it here. Divide by 50% = 0.5, so you need 217 kWh / 0.5 = 434 kWh of storage.

Let's say you want to wire your system up at 24V, using P /E = I, and we get 434 kWh / 24V = I (in amp-hours). But you have to use watts, not kilowatts, so that it would be 434,000Wh / 24V = 18083 amp-hours; call it 18,100.

How many car batteries would give you 18,100 amp-hours in a 24V setup? The answer isn't pretty—it would take about 362 batteries since car batteries have a 50 amp-hour average charge. If you can go to a 48V system, you can cut that in half immediately, but it's still over 180 batteries! If a car battery is $100 a pop, you're talking $15,000 or more, hoping you get a discount for buying so many!

Looking at the same thing using lithium-ion batteries, we jump where we'd still need 217 kWh to go seven days without power. Instead of dividing by 50% depth of discharge, we can divide by a 90% depth of discharge, so we get 217/0.9 = 241 kWh of storage, almost half as much. You can already see why lithium-ion batteries are selling well!

If we need 241,000W and one lithium-ion battery is rated at 3.8kWh at 48V, it will take about 63 batteries. Those batteries sell for around $3,300, so buying them would cost over $200,00 (Lithium Batteries, 2023)!

Suppose that's just silly. In that case, the point of these examples is to show that it's impossible to have a single best battery and that

batteries are a significant investment in your solar energy system. As you learned early on, reducing your energy use means shrinking the size of your generating, but it also reduces the size and cost of your storage system.

Instead of looking for an extensive system like this, why look at a little more modest one? For example, if all you wanted to do were run the same house for one day instead of 7, you would reduce the required storage to 31 kWh / day or even call it 50 kWh to round up to an even number.

For the lead-acid batteries, divide by 50% discharge depth and get 100 kWh storage. 100 kWh / 24V = 4,166Ah. That would still be 80 batteries. Going to 48V brings it down to 40 batteries, or about $4,000. That's a lot more reasonable!

For the lithium-ion batteries and allowing 50 kWh, or about a day and a half of storage, you would get 50 / .90 = 56 kWh of storage you want. For those same lithium-ion batteries, you would need 15 of them, and 15 x $3,300 is about $48,600.

You should figure out how much power you need by giving a few examples, but you may need some advice. There are many variations and choices on the market, so developing a good relationship with dealers is worthwhile if you decide you don't need to hire an installer.

CHARGE CONTROLLERS

If you have batteries, you may need a charge controller. This unit controls the charging of your batteries, ensuring that charging is as efficient as possible. For example, if there is a surge or the batteries get full, a charge controller won't overcharge them, but once they are full, it will maintain a small charge to keep the batteries topped up.

You don’t need a charge controller if your system is grid-tied. In that case, once the batteries are full, the excess energy is diverted to the grid (Mooney, 2022). Like everything, you must ensure that a charge controller can handle the maximum number of amps your panels will put out (watts divided by voltage), plus a safety margin of about 25% (Zientara, 2022). Of course, you must be sure it is the same voltage as your panels and batteries.

When you charge a battery, there are a few different stages: “bulk” charging, when the battery is very low, “absorption” charging, which is a lower charging current as the battery gets near full capacity; and “float” or “trickle” charging, where a small current keeps the battery maintained at full charge. These stages are ideal for lead-acid batteries, but if you have lithium-ion batteries, they don’t need a full absorption stage (Zientara, 2022).

MPPT Charge Controllers

There are two main types of charge controllers to consider. The first type is Mean Power Point Tracking, the same MPPT used for power optimizers. Yes, your power-optimizing system automatically makes charging work better by providing a consistent power output to feed the system and the batteries.

Remember, solar panels don’t like to get hot, but this means that when it’s cold out, they will put out more than they are rated conservatively. And if it’s hot and cloudy, their output might drop. It happens because an MPPT uses transistor switching to convert from a varying DC input voltage to a steady DC output.

PWM Charge Controllers

Pulse-width modulation (PWM) is a more straightforward way of controlling the charging rate of batteries. You get full voltage if you turn a switch on at any time. If you switch it off simultaneously, you get zero volts. But if you switch it on and off quickly, you get a voltage between zero and full. It could happen because each short pulse of

power has a portion where it is on and a portion where it is off. The longer the portions where it is off, the lower the voltage.

These voltage variations are related to the switching in the MPPT, but an MPPT can create a higher or lower voltage, whereas a PWM controller can only make a lower voltage. Therefore, with a PWM controller, you don't want your panels to have a voltage much more significant than your battery voltage, or you lose a lot of energy because you will have long off-periods during PWM switching (Zientara, 2022).

Comparing MPPT and PWM Charge Controllers

PWM controllers are less expensive, often less than $50-$60, and better for simple, minor installations and off-grid systems. However, they can only pull the voltage down and waste the rest of the energy.

MPPT controllers cost between $100 and $200, are better for more complicated systems, and are 20% to 25% more efficient than PWM controllers because they balance voltage and current to allow panels to provide their maximum power (Bruce, 2022).

MONITORING SYSTEMS

Having a system that allows you to monitor the status of your solar energy system can give you some real benefits. They can monitor the entire system or separate components and even let you know if you have trouble with a particular PV panel. You can access this information, or some designs can even put it on the web or send you messages on your smartphone.

If you gather data on your usage and when the solar output is the highest, not just in theory but in the case of the actual system after installation, you can adjust it for peak performance. Moreover, you

can share the data with other apps, like energy monitoring programs or financial analysis tools (Kuchta, 2022).

With remote monitoring, you can know what your system is doing, even if you are on vacation. If you have one panel that starts to misbehave, you can identify and localize the problem, reducing repair costs.

You can be sure that your system is safe. It provides extra Safety and security to know immediately if the system starts performing differently or if batteries get hot. If there are changes in your electric bill on a grid-tied system, you can dig into the data to see why.

The inverter is a key stage to monitor, and some inverters have monitoring built into them, like Enphase, Sun Power, Tesla, and SolarEdge. You can also buy add-on monitoring systems from separate companies. For example, sense, Curb, and Emporia are three companies that sell systems that will attach to your house wiring, whether you have solar energy or not (Zientara, 2023).

CHAPTER TAKEAWAYS

Batteries are a significant addition to the budget of a solar power system, but the self-sufficiency or increased reliability that they give you may be worth the extra cost. If you look at batteries, also be sure to explore the advantages in efficiency and battery longevity gained by using charge controllers. And once you have developed a sophisticated system, new monitoring tools help monitor it and wring every drop of performance and efficiency possible out of your solar input.

PART IV

BUILDING YOUR OWN SOLAR POWER SYSTEM

I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that.

— THOMAS ALVA EDISON

8

SAFETY FIRST

Anything you do is going to include risk. You are betting that you will be able to save money in the long run by installing solar, but the risk is that you want. That's not a significant risk to take in comparison with risking your health or your life. It's effortless to make a mistake or have an accident, so it's worth having a quick discussion of some of the risks and hazards you will want to avoid, whether you're doing all the work building your system or having someone else do it.

ELECTRICAL HAZARDS: DATA AND FACT

Solar power means electrical energy, so you must know the dangers to avoid them. The adage you want to follow here is "an ounce of prevention beats a pound of cure."

According to Mike Anderson, the Safety Director for Nickel Electrical Companies (2015), there are about 80 deaths from electrocution in the US per year and 4,000 injuries. In 2018, the number of fatalities

had doubled to 160 by 2018. Of all electrical injuries, 9% were fatal, from electric shock, not burns, and 36% happened at private residences (Tsonis, 2022).

The point of bringing up all these facts is not to discourage or scare you but to make you aware that you risk injuring or killing yourself or possibly even somebody else. But you can successfully avoid problems by remembering safety tips (Solar Energy Safety Tips, 2022).

- Call a licensed electrician if you have questions. Not for free advice, but getting a professional involved is better if you don't know how to be safe if you don't understand what you're trying to do. It's more important to be safe and comply with electrical codes than to save a few bucks.
- Stop working in bad weather. Wind can blow and grab panels and could knock you off a roof. You also risk being hit by unpredictable lightning, which can strike anywhere. (Forget old wives' tales about only hitting the tallest object or never striking twice.) Don't work on a wet roof or with wet tools that could fall and injure someone.
- Don't work at heights alone, and use appropriate fall restraints. If you don't have any or don't know about harnesses, lanyards, and appropriate tie-off points, ask. You can die from falling as low as 6 feet—less if you're unlucky!
- Use ladders safely. Please ensure they are no less than a 1:4 ratio of the distance from the wall to the base compared to the height. Make sure you are clear of power lines and obstructions. Don't work to the side, and always maintain three points of contact. Someone should always hold the ladder. Scaffolds are better.
- Make sure you have your roof strength checked before installing. An engineering inspection is well worth the peace of mind, and fixing things is easier before you get a lot of equipment on the roof.

- Don’t wear rings or jewelry when working on electrical systems.
- Cover your solar panels with something opaque when wiring them.
- Don’t lean, sit, stand, or walk on PV panels.
- Be sure to properly ground your entire system and be sure all grounds are bonded. You should consult an electrician to ensure you are safe and compliant with all electrical codes.
- Wear eye protection, protective clothing, and other personal protective equipment (PPE) as necessary. Even though stripping wires might seem harmless, it’s easy to get a sharp fragment of wire or insulation caught in your eye.
- If you work on an off-grid system in a remote location, let someone know where you plan to be and when to return.
- Be careful using power tools. Wear appropriate PPE, ensure they are in good working order and you are comfortable using them.

The above list is a partial list. Common sense will be of great value to you, but the best advice is, “If you’re not sure, stop.” Once you have a plan and know how you’re going to carry it out, then good luck!

SOLAR SAFETY

Even after all that, there are a couple of things to add specific to safety requirements for solar systems. First, you must be ready because a solar panel can go from light output to maximum very quickly if the sun comes out from behind a cloud. To avoid this situation, you should cover panels when working on them.

The National Electrical Code (NEC) requires that solar energy systems have a rapid shutdown capability, both in the panel array area and outside it. Micro inverters have slightly different rules.

(Ginsberg, 2019). Consult with your electrician and equipment dealer to ensure you comply with this requirement.

You will probably not be using a high-voltage solar system for a residential system, but if you do, some special rules change because these are more suited to large commercial installations. Any system over 80VDC will require Arc Flash Circuit Interrupters (Ginsberg, 2019). This high-voltage solar system approaches areas outside the homeowner's DIY project's level.

Whenever you work on wiring or inside a panel, you should ensure to turn off the circuit breaker. Please don't rely on light switches alone because it's possible to have power in the circuit. Always check with a voltmeter that the course is live after you work on it. Never work inside a live electrical panel.

Something that always bears repeating is that you should never short-circuit a battery. The damage can range from changing your underwear to having a lead-acid battery explode. So, it is never okay, and it doesn't matter what kind of battery.

CHAPTER TAKEAWAYS

Safety first! It's not worth cutting corners if you fall off a roof and break your back because you got zapped trying to reach an energized cable before it came into contact with a poorly grounded solar panel frame!

Be constantly aware of your situation, and don't rush; if you're unsure, uncomfortable, or in terrible weather, it's better to "run away and live to fight another day." Use your head!

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INSTALLING THE COMPONENTS

Now that you know about all the significant parts of a solar installation, it's time to discuss some details when you do the work. You will have done all your design work before you get to this point. You'll know what kind of system you want, how many panels you will need, what kind, how you will mount them, and where you will mount them.

If you want battery storage, you will already know how many batteries, what kind, and where they will live. If you had them do some of the work, you should have been in touch with your electric utility, an electrician, and some solar installers. You will have your permits from the city and utility, have your materials on hand, or have a delivery scheduled for the appropriate time. What else will you need?

TOOLS AND LABOR

You will need tools to do the job. If you don't own everything, you can always buy them, but for some that are more specialized or that you

don’t think you’ll use again, you might prefer to rent them. That’s up to you. These lists aren’t complete, but by the end of your project, you will know what you wished you’d had at the start!

Still, you need a starting point, and this is a good one, compiled from experience, Unbound Solar (10 Essential Tools for DIY Solar Installation, 2021), Kerry Armour (2008), and Northern Arizona Wind and Sun (How to Install an Off-Grid Solar System, 2023).

Tools

Common Tools

Many of the tools you will need are standard DIY tools. Part of the installation, like roof mounting panels, is like any construction project, so here is an essential list of tools to get you started.

- Hammer
- Screwdriver and fastener tools: Phillips, straight head, Allen keys, and any specialty fasteners (Torx, etc.)
- Pliers
- Wrenches—combination wrenches, sockets, and adjustable
- Tape measure
- Chalk line
- Framing square
- Level
- Caulk gun
- Flat pry bar
- Hacksaw or Sawzall
- Cordless drill motor and drills
- Ladders (fiberglass non-conductive preferred) and or scaffolding
- PPE: safety glasses, earplugs, gloves, fall restraints, etc.
- Shovels, picks for digging
- Tarps
- Trash cans or bins, trash bags

- Five-gallon pails, useful for storing parts and carrying supplies up and down

Again, you may think of other things you need, but these should get you started.

Electrical Tools

Since the other installation portion is the electrical work, you will need tools for wiring and conduits. Here's a sample list:

- Wire cutters / diagonal cutters
- Wire strippers
- Lineman's pliers
- Crimping tool
- Needle nose pliers
- Steel fish tape
- Electrical tape
- Wire nuts
- Zip ties and cable staples
- Multimeter for measuring AC and DC voltage and resistance. Multimeters that measure amps are not very useful, but clamp-on ammeters that electricians use are probably more expensive than you want unless you include them in the budget.
- Conduit bender
- Label maker for labeling wires at both ends or marker and tape.

Optional and Specialized Tools

Some of these tools will either be necessary if you're working off-grid or might make your life easier, but they are optional. Consider renting them as another option.

- Soldering iron

- Scaffolding
- Solar panel hangers: these serve the same function as a drywall lift—they make holding large solar panels easier so you can focus on attaching them to the rails.
- Generator: A generator can be worthwhile if you work off the grid or need electric tools while the power is off.
- Genie lifts may be a luxury, but an electric bucket or hoist can significantly speed up installation. Be sure to use it safely, don't overload it, don't use it on uneven ground, and follow all the safety procedures and manual instructions.
- Trencher: if you have to bury cables, this can save more than enough time to make up for the expense of renting it. Ensure you follow codes about the burial depth, conduit, and inspections, especially call before digging!

Labor

Given the size of solar panels, it is likely that you will need some help. The bigger your crew, the faster the installation will go. You may have family members that can help or friends that will assist. If not, you might need help from nearby handy people or construction companies.

The cost of labor is something you will want to be sure to think about when you are planning the cost of your system. Still, it can range from making a deal with your kids to buying pizza and beer for your buddies—waiting until everyone is done working at heights to open the bar—hiring a couple of laborers or contracting all the workouts.

OFF-GRID SOLAR SYSTEM INSTALLATION

There is little difference between installing an off-grid system and any other, except that you may be in a remote location. Working on an undeveloped site adds a bit of logistical complexity and, in some ways, makes it a bit like camping, not just for people but for getting materials and equipment out to the site efficiently, plus you have to make sure that basic human needs like food, shelter, water, and sanitation are met.

Planning is key. It's expensive in both time and gasoline to drive back to town because you forgot one bolt. Making checklists to keep supplies organized is essential. If you need a crew, ensure you have allowed enough time to finish the work so that you only need to return the next day with enough people available.

The same applies when you are going up on a roof. Ensure you have everything you need to avoid expensive trips up and down chasing after supplies. For example, if you are going to climb a ladder and need to carry something, put it in a five-gallon pail, and slip the handle over your arm in the crook of the ladder. This way, you can climb with both hands and feet safely.

If you need to camp at your work site, that's up to you, but also remember that if the weather should come up before you have finished the project, you will also need to cover some of the supplies. Tarps are a good idea if you have no buildings on the site. But be careful if you leave materials on the site unattended. Theft of construction supplies is a problem, even in rural settings.

Otherwise, installing an off-grid will be much the same as any other, and almost everything in the following sections will apply to your situation.

MOUNTING RACKS AND PANELS

Before you put the panels up, you must install the racks to hold them up. You want to ensure this step is done carefully because you want to do it only once. On roof mounts, you only want to make the holes in the roof as you have to, and on ground mounts, pouring concrete bases is challenging to fix. So don't rush it!

Roof Mounts

I assume that you have had your roof evaluated by a professional engineer and that it will support the weight of the installation and crew! The roof doesn't need any repairs because it was in good shape, or you have already done them.

Lay out all your materials and plan an attack (9 Steps to Mount Solar Panels on Roof, 2021). You could work in stages, from the furthest end of the roof to the closest. Doing things in sections lets you keep yourself organized and have less extra material lying on the roof while you're working—nothing has ever fallen off the ground!

You will want to mark out the locations for the mount anchors using the tape measure and chalk line. Remember to follow the old maxim, "measure twice, cut once," but don't give yourself a panic attack—most mount systems have room for adjustment. If possible, you might even have the best results if you can lay out the rail mounts so that you know that the measurements are correct; that is an excellent way to be sure you haven't made any arithmetic errors.

Again, working in sections keeps you from making a mistake that carries through many other holes. It's also a good idea to work from the top down, so you aren't liable to try and sit on a panel. Plus, facing up on the roof is safer than facing down.

You will want to drill the holes for your panels and attach any flashing with the rail kits. Be sure to use grommets if they are included in your kit, and sealing with silicone is a good idea when you attach the mounting stanchions. You can't overdo it with silicone because it's easy to remove. If you install a ballast-mounted system, you can skip the drilling and install the stanchions with the ballasted feet. Be

careful carrying heavy ballast up and down ladders, though—this is where a lift might be convenient, but don't forget that they, too, have weight limitations.

Next, you will attach the rails to the stanchions, ensuring correct spacing between the wires. If you have micro-inverters or power optimizers that need to be wired to the panel, those may need to be mounted before the panels are installed and cover the electronics up.

You will need to wire the panels as you go because you may only be able to access the connections at the back if they are mounted at a steep angle. If it is a very sunny day, remember that it might be necessary to cover the panels while wiring them. If it's too windy, delay your panel installation until you can find a day with better conditions. A gust of wind acts on the large surface area of a solar panel like a sail and can rip it out of your hands.

You will have to have an idea of how the wiring is going to run and how it is going to get to your electrical panels or wherever it attaches to the inverter. You want to "dress" the cable as you go to tie things neatly. Don't forget to leave a "service loop" at each panel so there is enough slack you can do while it is still connected if you have to remove the panel for service.

Ground Mounts

For ground-mounted systems, you will have to prepare the site first. Which could involve clearing trees and brush or whatever you have. To reduce maintenance, clearing the area and putting down gravel is tempting, which is undoubtedly an option. However, it's expensive, and it is only desirable to eliminate vegetation partially. One of the criticisms of solar arrays is that they eliminate biodiversity. This doesn't have to be the case, but it's something to consider. Pole mounts are easy to trim around.

As part of the site preparation, you will want to trench any cables you must run before you assemble the panel mounting system so that you don't have to maneuver a trencher around obstacles. Again, ensure

you have arranged all your permits before you start digging, follow the rules about depth, and provide you will avoid hitting any existing utilities.

If installing concrete footings, you will want to measure their locations carefully. Most good footing systems and tilt legs will again have a range that can be adjusted. If you need more than that, you can modify the mounting hardware by grinding the mounting holes into slots, but hopefully, you won't find that necessary.

When installing the rails, it's necessary to put things in place with nuts and bolts kept loose so that everything can be roughed in before tightening everything up. For example, if you put the first bolt in and tighten it to the final torque, you may need help to get all the last pieces to line up.

You may find yourself working on ladders when installing a ground-mounted system, so be careful that your ladder is well-braced and that you're not trying to work to your side at the end of your reach, which is the best way to keep from tipping the ladder over while at the top.

Once you assemble the footings, support legs, and panel rails, you are ready to mount the panels. Make sure you have an excellent way to support the panels, whether it is a panel hoist or just a couple of helpers. Working in sections is a good approach here as well. If you're doing a pole-mounted system, each pole is an independent section anyway!

Accessing the back of the panels on a ground-mounted system is usually easier. However, depending on the hardware and components you are using, you may still need to install micro-inverters and power optimizers before putting the panels up—the same rules about routing cables and leaving service loops apply. Not only will this make your life easier in the future but securing the cables on the array will make them less prone to damage by animals, weather, and other hazards.

SYSTEM WIRING

The wiring work is pretty straightforward, but a couple of “gotchas” can get you. So first, I’ll repeat it: make sure you aren’t working inside a live panel, so flip off the breaker for any circuit you are working on.

Battery Wiring

Because batteries are DC, you will want to keep them close to the inverters. Remember that DC loses a lot of energy to heat, so you want to use cables that are as short as possible and as thick as practical. Sure, you can buy super heavy welding cables, but they will be costly, and it may not be possible to put the right kind of connectors on them to attach them to your inverter and batteries. So, bigger is better for battery cables, but only up to a point.

General Wiring Tips

To ensure you have a clean installation at the panel end, you must keep the wiring tidy. Use cable ties, leave service loops where necessary, and dress cables neatly with cable ties. Likewise, routing in a panel should be tidy, with wires running around the outside of the box, separated into hot (black) and neutral (white) wire runs.

Doing a neat job may make the system slightly more efficient, but even if it doesn’t, you will save a lot of time and hassle if you ever have to service anything. As reliable as electronics are, you will, sooner or later!

Following the wiring diagrams given in the installation manual for equipment is very important. If you deviate from the recommended installation, you may lose any chance at warranty claims or legal protection, in addition to an increased risk of shock or equipment failure. If changes are necessary, they should be done in consultation

with a licensed electrician, so you are sure that they meet all electrical codes.

Also, important when doing AC wiring to use the wire size specified by the NEC for the circuit size in amps. See “National Electrical Code Allowable Ampacities of Insulated Conductors Rated 0-2000 Volts” (2019) at

https://www.usawire-cable.com/pdfs/nec%20ampacities.pdf

for a chart. You will see that the correct wire size depends on whether you are using copper or aluminum wire, how many amps of current you need, and what the temperature is expected to be where the wiring is run. While it’s simple to say that for copper wire, you want 12-gauge wire for standard house wiring, solar power wiring still needs to be standardized. It would be best to have someone check your work to be sure you’ve navigated the tables correctly.

And if it’s necessary to cut power at the entrance, you must do something other than that. Instead, it usually requires that you schedule an appointment with the power company to have your power shut off while you are working on it. But, again, try to plan these things to coincide with inspections, though inspectors will not do the shutoff and reconnection.

Back feed Breaker

A back feed breaker is like a circuit breaker in your service panel, but it lets your system feed power back into the grid (Thompson, 2020b). It is installed in your service panel, takes the leverage from your inverter, and connects it to your service. Usually, circuit breakers are the loads that draw on the power at the panel. Still, since the solar inverters put energy onto the busbars, the circuit breaker can be considered to face the other direction. (This is different from how it works, but it’s a good way to picture it without getting technical.) Therefore, you may have to rearrange the circuit breakers.

The details of choosing the right size and location for your back feed breaker depend on the size of your existing load and main breaker. There are different methods for calculating, but to comply with the electrical code, you must figure out the total amount of current the panel is rated for, and the placement of the back feed breaker must follow different rules depending on where you place it (Gittens, 2020).

The most important rule you must remember is the “120% rule.” This means the current running through your main electrical panel (including all subpanels because they tap off it) can be at most 120% of your electrical service. So, if you have a 200A service, you can only have a total of 240A in the panel, whether running into your house or back onto the grid.

You should consult with your electrician in this matter. That’s good news because, as you’ve read more than once, you want someone to ensure your work is safe and that you pass inspections with flying colors.

POWER CENTER

Installing your batteries and inverters will be the next phase after the panels are up. Your location will be near your house’s service panel, but you might have additional sub-panels depending on your configuration. Getting a licensed electrician to review your plans and check your work is a good idea, even if you do it yourself. They may catch mistakes you miss or offer more manageable ways to do things.

Again, because you may be attaching to the leading electrical service of your house, you may need to have the utility company shut the power off for the final installment stage. They may also have tests to verify that your emergency cutoff equipment works as required.

Make sure that if you have racks or shelving to install the batteries, they are securely fastened to the wall and floor, so they are not tipped over. Of course, since batteries are hefty, you need to ensure the floor can support their weight! Securely holding them is super important if you use flooded lead-acid batteries as they can break or leak if they fall, flooding your house with sulphuric acid.

You should install batteries over a spill containment tray if you have trouble with a single battery leaking. You should also keep a spill kit or a large container of baking soda, which could use during an acid spill. A fire extinguisher is rated for electrical fires, and a smoke detector is suitable in the battery room, as it records maintenance dates and activities, like replacing or refilling batteries (Thompson, 2020c).

Ventilation and temperature are essential for all types of batteries as well. Ensure lead-acid batteries are ventilated to dissipate hydrogen gas and not get too cold, whether SLA- or FLA-type. Lithium-ion batteries are also sensitive to cold. Too much heat also increases fire risk, so no matter what battery chemistry you choose, ensure that your battery room keeps the batteries within their recommended operating range.

Final Inspection

After you get everything hooked up, you will have a chance to make sure all the pieces are working, but you will have to have the final electrical inspection before turning everything on all at once. Passing that inspection is your last hurdle; whether you're on the grid or not, it's a moment to celebrate. After the inspector gives you the all-clear, you can turn everything on and let there be solar power!

CHAPTER TAKEAWAYS

Solar installation is straightforward DIY work. Assembling rails, mounting panels, running cables, and installing batteries or inverters is something you will easily be able to do. However, to ensure that your installation goes as well as it can, ensure you have the tools and help you need. For the critical parts of the installation—meters, wiring inside electrical panels, grounding, and utility connections—ensure you get the experts (often required anyway) involved.

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KEEPING THINGS RUNNING

Once you have everything running and have finished cleaning up all the little pieces of stripped insulation, packing materials, and excess cutoffs of wire and building materials, you're in the maintenance phase. An old saying among tradespeople is that "You can schedule the maintenance, or the machines will schedule it for you." So, to keep your system working reliably and without unexpected problems—that seem to come at the worst possible time—you'll get great results by being a stickler for maintenance.

INSPECTION AND MONITORING

The first part of maintaining anything is inspecting it regularly. Monitoring systems are a big help in this regard. You get a complete record of each panel's performance; some systems automatically update the computer with those measurements and generate charts and graphs for you. If you are casual, you can monitor things by hand and keep records.

Either way, the important thing is that you have to read the records. For example, suppose the system generates messages telling you that a panel is about to fail. In that case, it's like the radio operator on the Titanic who found that nobody was listening to him!

You are reading records regularly, whether once a week or once a month, is essential. The best thing to do is to check data more frequently, say every day when the system is new, but after you have been through an entire year, you will know that every week or ten days is more reasonable.

And fancy monitoring systems are no substitute for taking a tour and looking at the system with your own eyes. During your regular check, you should ensure no obstruction in the panels and that they are secure. So that wiring is in place and not showing signs of heat or being eaten by squirrels (who, for some reason, love some plastic insulation) or birds.

If you have a ground-mount system and live in an area with frost in the soil, you should inspect the panels and racking every spring. If the ground heaves unexpectedly, it can stress or break panels. Catching things early, no matter the cause saves money and reduces damage.

SOLAR PANEL MAINTENANCE

Solar panels don't require a lot of maintenance. Therefore, inspecting and monitoring will only find panels that need to be replaced sometimes, if ever. In addition, it will show you that some of your panels might have become shaded.

Trees and shrubs always grow bigger, but they don't grow smaller, so one of the crucial parts of maintaining your panels is gardening and trimming trees and bushes. As usual, be careful when climbing or using power tools, and be mindful that neither you, your tools, nor the branches you cut fall onto the panel array!

The main thing that you will find when you inspect your panels is that they accumulate dirt and grime. How often will depend on where you live. In a desert, you might have dust and sand that are blown about in the wind and collected on your panels. If you have a ground-mounted system that is too low to the ground, rain can spatter mud up onto the panels.

When you clean solar panels, there are a couple of points to remember. First, of course, and as always, safety comes first. If you're on the roof, make sure you are stable and not unbalanced. All the standard rules of ladders and working at heights apply. You always want to avoid standing on the panels, so long extension handles with soft mops are helpful to reach the middle of a solar array but avoid contact with power lines (Colfelt, 2022).

You want to wash as gently as possible. Using water from a hose—not—a pressure washer is the first thing to do. It may wash all the dirt off if you do it often, and if not, it will soften anything on the panel so that it comes off easily (Cleaning and Maintenance Tips for Solar Panels, 2022).

If a rinse isn't enough, use a soft rag or mop. You must use something that is not abrasive, or you will scratch the outer layer of the panel, and scratches reduce the panel's efficiency. Don't use harsh chemicals if you have filmy deposits or sticky substances. Regular soap is usually delicate, but you'll want to see what the manufacturer recommends before trying anything harsher and more aggressive.

If you find that your panels are cracked, don't wash them. Good panels will have a warranty of 20 to 25 years, so you will want to contact your installer, dealer, or manufacturer to see how to get them taken care of. They may repair the panel, but it's also likely that they will replace it (and this is where those service loops you put in will seem like a good idea!) Even if you should have a panel that, for some reason, doesn't have a warranty, you should contact a dealer

or the manufacturer to see what options are available for that particular panel.

And finally, if you find that your panels are showing up as inefficient, inspect and clean them before going any further. Four times a year is often enough to keep a system working well, but you might be surprised at the difference it makes if you let it go too long.

BATTERY MAINTENANCE

You learned earlier that each kind of battery has a rating known as Depth of Discharge. The State of Charge is the other way of looking at it (maybe a more positive approach!). Depth of discharge is how much of the battery is empty, and the state of charge is how full it is (How to Maintain an Off-Grid Solar System, 2018).

Lead-Acid Batteries

You can get an electronic readout of the state of charge, but for FLA batteries, you can also measure it using a tool known as a hydrometer. You can still buy these at auto parts stores, but your solar dealer might have one or include it with a whole battery installation.

To use a hydrometer, you draw some of the electrolytes into the tube and read the number per the directions. That number is called the specific gravity, which changes with the battery's charge.

A fully charged 12V battery will measure 12.7VDC and have a specific gravity of 1.26. A battery that is 75% charged will measure 12.4 volts and have a specific gravity of 1.22 (Solar Battery Care, Maintenance, and Safety: Don't Touch the Terminals! 2019). The hydrometer should come with a chart showing the appropriate charge levels.

When measuring the specific gravity, you should consider the fluid level because water evaporates over time as the battery charges (How to Maintain an Off-Grid Solar System, 2018). If you have a charger malfunction or overcharge the batteries, it's possible to boil the electrolyte away.

Follow the instructions with the battery, but if you need to add water, use distilled water, and clean the top of the battery before opening the caps. In a car, batteries are more likely to get dirty than if sitting in a room, but you don't want to drop any contaminants into the battery and short out a cell.

Remember that a lead-acid battery should not be discharged below 50%. Also, it's important to note that a completely discharged battery should measure about 11.9V but have a specific gravity of 1.12. So even though it measures close to 12V, you can't use that voltage measurement to tell how amps of current it will supply.

It is essential to equalize your batteries. It is one way of making sure that all batteries are charged evenly. Depending on the batteries' connection, some may be charged first and others less. Some inverters and power optimizers will do this automatically if you program them too. If you don't have one of those systems, compare specific gravity readings—all batteries should be very close.

It's a good idea to have a spare battery if you need to remove it from the array, but batteries have a limited shelf life without being kept on a trickle charger. On the other hand, you have an entire solar array that could power one extra battery on a float at no additional cost for electricity!

You want to avoid having a mixed collection of old and new batteries. So, you should keep them in shape and replace a bank at a time (How to Maintain an Off-Grid Solar System, 2018).

Other Batteries

You won’t have to fill SLA batteries, gel cells, lithium-ion batteries, and other types of test-specific gravity. You should check the state of charge, but instead of using a hydrometer, you will have to use a voltmeter and use the table that your manufacturer should supply. Lithium-ion batteries may come with a management tool, or you can purchase one, but each battery manufacturer requires their own (Curran, 2020).

Just checking the inverters to ensure you only have green lights is a good thing to do daily. After that, you can look into details more every week or monthly. It’s okay to let the inspection interval get longer as you get more comfortable with your system, but regularly checking without forgetting is essential.

CHAPTER TAKEAWAYS

Most solar energy systems are low maintenance; it's usually effortless even when they require attention. However, regular inspection is the key to catching problems before they spiral out of control.

FLA batteries require the highest level of maintenance, but that's the price you pay for the lower installation cost. If you want your system to be more "set it and forget it," you will get closer with SLA batteries or lithium-ion—but the key word is "closer." Of course, you will never get rid of the need for maintenance, but if you're smart about it, it doesn't have to be a burden and will give you optimum performance from the system for the maximum number of years.

CONCLUSION

There you have it. You have enough information under your belt that no matter why you want to install a solar-generating system, you have a good idea of what you need to do if you don't have the answer to every question, you know where to look the answers by this point.

I've shown you what's involved in the planning process and what homework you have to do regarding knowing what your energy needs are, what your energy goals are, and how to decide what kind of system will meet them. You've seen how you will have to work with different people and organizations if you want to bring the project to fruition.

There may be money to help you subsidize the project and where to look for additional funding sources. You know something about the different ways solar projects are connected to the grid and that you can buy the equipment outright, but there are options for financing, leasing, or going in on it with a group.

And finally, you've got many nuts and bolts for dealing with the hardware. You know how to evaluate the sun in your area with the aid of online tools, you know how to calculate the placement and angle of the panels, and you know about racking and mounting systems. Installation is not a massive project after you've done all the planning and gotten all the necessary permits, and you know how to make things happen.

We have yet to discuss other solar energy methods, like passive solar heating and solar hot water. Those are topics for another day and another book, but you should have more than enough here to keep you busy. If you do a good job, you will get a good return on your investment, reduce your carbon footprint, or become less reliant on the power grid for your energy security—and hopefully, all three!

GLOSSARY

Absorption charging: The stage of charging a *lead-acid battery* at a lower current than initially when it is nearly full.

Age-Related Degradation: The drop in performance over time of a solar panel, used to define the terms of a warranty.

Aggregate Net Metering: *Net metering* when there is more than one electrical service at the same address.

AGM battery: A kind of *Sealed Lead-Acid battery*, AGM stands for Absorbent Glass Mat. They are maintenance-free and cannot spill.

Alternating Current: electricity that flows in alternately increasing and decreasing amounts, most often changing direction many times a second.

Ampacity: The amount of current a wire or cable is rated to carry safely.

Amp-hour: The number of amperes used in an hour, abbreviated Ah.

Azimuth: The compass direction that a solar panel faces.

Backfeed breaker: A circuit breaker that will allow electricity to feed into a service panel instead of out of it and that has overload protection.

Ballast mount: A way of mounting solar panels where they are held in place by ballast or weights.

Battery: A device for storing electricity as chemical energy, made up of *cells*.

Boron oxide: a chemical released by some solar panels during the first 1000 hours of use which slightly limits their efficiency.

Breakeven period: the length of time it takes for a system to pay for itself either in savings or income.

Bulk charging: Charging a battery at the maximum charge rate, is done when the *battery* is at its full *depth of discharg*e.

Cell: A single unit for generating or storing an electrical charge of a given voltage.

Charge controller: Electronics that adjust the charging of batteries to prevent damage and optimize the life and performance of the *battery*.

Community solar: Also called *shared solar*, this is a cooperative approach to installing a solar power system for several houses.

Contracted system: A system that is partially built using hired labor.

Depth of discharge: The lowest level of charge a battery should be run down to without damaging it.

Direct Current: Electricity that flows continuously in one direction.

Elevation angle: The angle at one edge of a *solar panel* is raised from the ground.

Energy audit: A careful analysis of the use and loss of energy in a home or business.

Energy density: The amount of electricity a *battery* can hold in a given volume of space.

Energy Guide: A system informing consumers of the energy used by new appliances, as tested.

Federal Investment Tax Credit: A tax incentive for installing solar power.

Federal Tax Credit: A tax incentive only for homeowners who install solar energy systems.

Feed-in tariff: Similar to net billing, a solar billing system with two meters.

Fixed mount: A type of ground mount that supports solar panels on a structure that is not adjustable.

Flashing: Roofing material used to prevent leaks at joints and around mounting bolts.

Float charging: Keeping the charge of a *battery* topped up with a small current. See *trickle charging*.

Flooded Lead-Acid battery: A *lead-acid battery* with lead plates and sulphuric acid electrolyte in liquid form, abbreviated FLA.

Flow battery: A *battery* currently in development that uses tanks of electrolytes and pumps to create and store energy.

Gel cell: A form of *Sealed Lead-Acid battery*.

Grid-tie Inverter: An *inverter* that is capable of syncing the frequency of its output to the grid frequency and that is able to disconnect if the grid fails.

Grid-tied: Being connected to an external electrical distribution grid.

Grommet: a flexible washer, used to provide a seal at a screw or bolt.

Hybrid solar system: A system that is able to operate as both a *grid-tied* system or an *off-grid* system.

Hydrometer: A device for measuring the specific gravity of a battery's electrolyte, and thus the batteries *state of charge*.

Inverter: An electronic device that converts DC current to AC current at the right voltage to be compatible with household use and utility grids.

kilowatt: 1,000 watts, abbreviated kW.

Lead-acid battery: A *battery* chemistry that comes in several varieties, see *Flooded Lead-Acid battery*, *Sealed Lead-Acid battery*, *gel cell*, and *AGM battery*.

LED: Light Emitting Diode, widely used for energy-efficient lighting.

Light-Induced Degradation: Initial drop in efficiency of a solar panel, see *boron oxide*.

Lithium-ion battery: A modern *battery* chemistry with a high *energy density* and long life.

Maximum Power Point Tracking: A way that *power optimizers* keep track of the panels that are putting out the greatest power and use it to provide maximum energy to the system, abbreviated MPPT.

Micro-inverter: A small power *inverter* that attaches to an individual solar panel and converts DC electricity to AC power at the source.

Modified sine wave inverter: A slightly less expensive *inverter* than a *pure sine wave inverter* that has a blocky waveform with higher harmonics.

Module-level Power Electronics: Electronics, like power optimizers and micro-inverters that work at the level of an individual panel, abbreviated MLPE.

Monocrystalline: A crystal structure made from one single, continuous crystal lattice.

NABCEP: North American Board of Certified Energy Practitioners, an organization that offers a listing of installers and dealers who have completed training and been examined to be qualified.

National Electrical Code: A set of regulations that govern all electrical wiring, installation, and practices and from which local regulations derive. Abbreviated NEC.

Net billing: A system where you are billed for your electrical usage and paid cash for solar energy sent to the grid at different rates.

Net metering: A system where you are billed for your electrical usage and credited for solar energy sent to the grid at the same rate.

Ni-Cad battery: A *battery* chemistry using nickel and cadmium.

Off-grid: Not being connected to any utility company's distribution grid.

Passivated Emitter and Rear Cells: a recent type of solar cell, 5% more efficient than *monocrystalline* cells, abbreviated PERC cells.

Peak sun hours: the number of hours per day that solar panels will produce maximum output.

Photovoltaic Cell: An object employing the *photovoltaic effect* to generate electric energy, also called a *solar cell*.

Photovoltaic Effect: The way that certain materials generate electricity when exposed to light.

P-N junction: the boundary between a positive and negative layer inside a semiconductor that allows it to change behavior in useful ways. Can also be reversed in N-P junction transistors.

Pole mount: a type of rack for ground-mounted solar installations where an array is mounted above the ground on a pole.

Polycrystalline: a crystal structure made up of multiple crystals that are fragmented at the lattice level.

Power optimizer: A power regulating device that isolates each solar panel and regulates DC for better system efficiency.

Power Purchase Agreements: an agreement to buy power from a solar generating entity, abbreviated PPA.

PPE: Personal Protective Equipment. General term for safety devices and clothing, like safety goggles, earplugs, etc.

Pulse Width Modulation: A way to control the amount of energy in a system by changing the relative amount of time a switch is on or off, abbreviated PWM.

Pure sine inverter: An *inverter* that creates an output that is a pure sine wave, exactly like that provided by the utility company.

PV: Abbreviation for Photovoltaic.

Racking: The term for systems of rails and supports used to hold solar panels in place.

Return on Investment: the amount of money you will save or make as compared with the cost of installing solar.

Sealed Lead-Acid battery: A *lead-acid battery* that is not vented, usually with a gel electrolyte. Abbreviated SLA.

Shared solar: see *Community solar*.

Silicon: An element used to make semiconductors, including transistors, computer chips, and solar cells.

Smart meter: An electrical meter that can report usage to the utility company remotely.

Solar cell: Another name for *Photovoltaic Cells*.

Solar efficiency: The output of a solar panel under Standard Test Conditions as a ratio over 1000W expressed as a percentage, e.g., 200W / 1000W = 20%.

Solar hours: The number of hours per day that a given location gets that are useful for generating electricity.

Solar loan: A loan, sometimes at reduced interest rates, specifically for installing a solar power system.

Solar shingles: Solar cells that take the form of traditional roofing shingles.

Solar tracker: machinery that tilts and rotates panels to face the sun as it moves through the sky throughout the day and year.

Specific gravity: A measure of the density of a liquid, which increases with the amount of electrical charge in a *battery*.

Square wave inverter: An inexpensive *inverter* that is not compatible with all electronic devices.

Standard Test Conditions: The parameters under which the performance of a photovoltaic cell, panel, or array is measured: the output at 25°C, when exposed to 1000W per square meter.

State of charge: The amount of charge, usually expressed as a percentage, that a *battery* contains.

String inverter: A power *inverter* that works on a number of solar panels connected together in a string.

Surge rating: A measure of the amount of energy over the normal maximum that an *inverter* or *battery* can provide for a short time.

Thin-film solar cell: A lightweight type of *photovoltaic cell* made from a material that is less efficient but easier to install in some locations.

Tilt legs: support members used to set solar panel racks at the desired angle to the mounting surface.

Trickle charging: Keeping the charge of a *battery* topped up with a small current. See *float charging*.

Turnkey system: a system where all planning, components, and installation are done by a contractor. All the owner has to do is “turn the key.”

Two-sided panels: Solar panels that can generate electricity from light exposure on either or both sides of the panel.

Usage monitor: a *watt-hour* meter that can measure the energy usage of an individual appliance or one that can measure a whole circuit or house.

Watt: A unit of power, which is given by Volts x Amps, abbreviated W.

Watt-hour: the number of *watts* used in an hour, abbreviated Wh.

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