CHAPTER 1

# An Introduction to Solar Electricity

The world is in the midst of a global renewable energy revolution. With installations of new solar and wind energy systems climbing rapidly, nearly 50 countries have pledged to be 100% dependent on renewable energy by 2050. That's no pipe dream. It's highly doable. In fact, researchers at Stanford University project that the world could be 100% reliant on renewables in 20 to 40 years. The technologies and know-how are here, and in many parts of the world, so is the commitment.

Although the United States and Canada are not leading the race to a renewable energy future, significant progress is being made in both countries. In the US, for instance, solar, wind, biomass, hydroelectricity, and geothermal now produce about 17% of the nation's electricity—up from 7 to 8 percent at the beginning of the millennium.

One reason why renewable energy production has increased in recent years in the US is declining cost. Because of this, solar electric systems now consistently generate electricity at or below the cost of power from conventional sources like nuclear power and coal. With federal tax credits that have been in place for over a decade, solar electric systems on homes and businesses consistently produce electricity much cheaper than utilities. Declining costs and rising popularity have led many utilities to install solar and wind farms.

In this book, we will explore solar electric systems, technically known as *photovoltaic systems* or *PV systems,* for short. I will primarily present information on residential-scale PV systems—systems suitable for homes and small businesses. These systems generally fall in the range of 1,000 watts for very small, energy-efficient cabins or cottages to 5,000 to 15,000 watts for typical suburban homes. All-electric homes could require even larger systems (on the order of 25,000 watts). Small businesses typically require much larger systems. Before we move on, though, what does it mean when I (or a solar installer) refer to a 10,000-watt system?

## Sizing Solar Systems: Understanding Rated Power

Solar electric systems are sized by their wattage. As just noted, a home might require a 10,000-watt system. The wattage rating is known as the *rated power* of a system. Rated power is also known as *rated capacity*.

The rated power of a system is the rated power of the modules (frequently, but improperly, referred to as *panels*) multiplied by the number of modules in the system. If your system contains ten 300-watt solar modules, its rated power, or capacity, is 3,000 watts. A system with twenty 300-watt modules is rated at 6,000 watts. To simplify matters, installers and other professionals convert watts to kilowatts. So, a 10,000-watt system is a 10-kilowatt (or kW) system. That's a shorthand measure based on the fact that kilo in scientific jargon means 1,000.

But what does it mean when I say a *module's* rated power is 300 watts?

The rated power of a solar module is the instantaneous output of the module measured in watts under an industry-established set of conditions known as *standard test conditions (STC)*. By carefully controlling the temperature of the modules and the intensity of the light they are exposed to, all manufacturers rate their modules similarly. That way, buyers like you know what they're getting—as do installers and system designers. But what does it really mean that a module is rated at 300 watts?

Of course, most of us are familiar with the term *watts*. When shopping for light bulbs, for instance, we select them based on wattage. The higher the wattage, the brighter the bulb. We also compare microwave ovens and hair dryers by their wattage. The higher the wattage, the more energy these devices consume. In these and other electronic devices, wattage is a measure of power consumption.

Technically speaking, though, wattage is the rate of the flow of energy. The higher the wattage, the greater the flow. So, a 100-watt incandescent light bulb will use a lot more power each second it operates than a 12-watt LED light.

*Watts* is also used to rate technologies that *produce* electricity, such as solar modules or power plants. For example, most solar modules installed these days are rated at 275 to 300 watts. Power plants are rated in millions of watts, or megawatts; a typical coal-fired power plant produces 500 to 1,000 megawatts of power.

To test a solar module to determine its rated power, workers set it up in a room that is maintained at 77°F (25°C). A light is flashed on the module at an intensity of 1,000 watts per square meter. That's equivalent to full sun on a cloudless day in most parts of the world. The module is arranged so that light rays strike it at a 90° angle, that is, perpendicularly. (Light rays striking the module perpendicular to its surface result in the greatest absorption of the light.) A 300-watt module will produce 300 watts of energy under such conditions.

To size a solar electric system, solar installers first determine the size of the system (in watts) a customer needs to meet his or her needs. (I'll explain that process later.) They then divide that number—the rated power of the system—by the rated power of the modules they're going to use. This simple math reveals the number of modules they will need to install. If a customer needs a 9,000-watt system, for instance, he or she would require thirty 300-watt modules.

## An Overview of Solar Electric Systems

Now that you understand a little bit about solar system sizing, let's take a look at solar electric systems.

Solar electric systems capture sunlight energy and convert it into electrical energy. This conversion takes place in the solar modules, more commonly referred to as *solar panels.* A solar module consists of numerous *solar cells.* Most solar modules contain 60 or 72 solar cells.

Solar cells are made from one of the most abundant chemical substances on Earth: silicon dioxide. It makes up 26% of the Earth's crust. Silicon dioxide is found in quartz and a type of sand that contains quartz particles. Silicon for module construction is extracted from sand.

Solar cells are wired to one another in a module. The modules are encased in glass (on the front) and usually a thin layer of plastic sheeting (on the back) to protect the cells from the elements, especially moisture. Most modules have silver or black aluminum frames, although there are some frameless modules on the market, which were introduced for aesthetics and to simplify installation and reduce cost.

Two or more modules are typically mounted on a rack and wired together. Together, the rack and modules are known as a *solar array.*

**Figure 1.1.** *These solar modules being installed by several students at The Evergreen Institute consist of numerous square solar cells. Each solar cell has a voltage of around 0.6 volts. The cells are wired in series to produce higher voltage, which helps move the electrons from cell to cell. Modules are also wired in series to increase voltage.* Credit: Dan Chiras.

Ground-mounted arrays are usually anchored to the earth by a steel-reinforced concrete foundation. In such cases, the foundation is also considered part of the array.

### *How Solar Cells and Modules Are Wired*

Inside a solar module, solar cells are "wired" together in series. The modules in an array are then also wired in series. What does all this mean?

Series wiring is a technique commonly used in electrical devices. Batteries in a flashlight, for instance, are placed so that the positive end of one battery contacts the negative end of the next one. That's series wiring. It's done to increase the voltage. When you place two 1.5-volt batteries in series in a flashlight, you increase the voltage to 3 volts. Place four 1.5-volt batteries in series, and the voltage is 6.

So, what's voltage?

Voltage is the somewhat mysterious force that moves electrons in wires and electrical devices. The higher the voltage, the greater the force.

In solar modules, each solar cell has a positive and a negative lead (wire). When manufacturing solar cells, the positive lead of one solar cell is soldered to the negative of the next, and so on and so on.

Most solar cells in use today are square and measure 5 × 5 inches (125 × 125 mm) or 6 × 6 inches (156 × 156 mm) and have a voltage of about 0.6 volts. When manufacturers wire (actually, solder) 60 solar cells together in series in a module, the voltage increases to 36. Seventy-two cells wired in series creates a 43-volt solar module.

Solar modules are themselves wired in series to further increase voltage. Ten 36-volt modules wired in series results in an array voltage of 360. Two more modules added to the series brings the voltage to 432 volts. Higher voltages allow us to transmit electricity more efficiently over greater distances.

A group of modules wired in series is known as a *series string.* Most residential solar arrays consist of one or more series strings, each containing 10 to 12 modules. String sizes in commercial PV arrays are larger.

### *Converting DC Electricity into AC Electricity*

Solar modules produce direct current (DC) electricity. That's the kind of electricity released by all batteries.

DC electricity is one of two types of electricity in use today. It consists of a flow of tiny subatomic particles called *electrons* through conductors, usually copper wires. In DC electricity, electrons flow in one direction (Figure 1.2). As illustrated, energized electrons stored in a charged battery flow out of the battery along a wire through a metal filament in a light bulb. Here, the energy of those electrons is used to create light and heat. The de-energized electrons then flow back into the battery.

In a solar system, DC electricity produced in the solar modules flows (via wires) to a device known as an *inverter.* Its job is to convert DC electricity produced by solar cells into alternating current (AC) electricity, the type of electricity used in homes and businesses throughout most of the world. In wires and devices that are powered by AC electricity, electrons flow back and forth—that is, they *alternate* direction very rapidly.

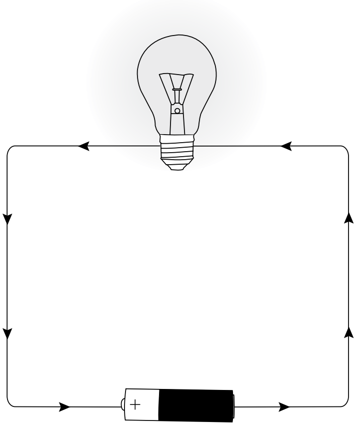


**Figure 1.2.** *Solar electric systems produce direct current (DC) electricity just like batteries. As shown here, in DC circuits the electrons flow in one direction. The energy the electrons carry is used to power loads like light bulbs, heaters, and electronics.* Credit: Forrest Chiras.

You may have noticed that the solar electric system I've just described has no batteries. Many people erroneously think that all solar systems include batteries. While that was true in earlier times, battery-based solar electric systems are extremely rare these days; they aren't much needed anymore. The vast majority of systems in more developed countries are connected to the electrical grid—the wires that feed electricity to our communities. When a solar electric system is generating electricity, it powers the home or business. Any surplus electricity it produces is fed onto the grid, where it is consumed by one's neighbors. However, the utility keeps track of that surplus and gives it back to the producer—you or me—free of charge whenever we need it. Although it's a bit more complicated than this, you can think of the grid as a very large battery. (More on this later.)

### *Applications*

Once a curiosity, solar electric systems are becoming commonplace throughout the world. Besides being installed on homes, they are now powering schools, small businesses, factories, and office buildings. Microsoft, Toyota, and Google are powered by large solar electric systems. More and more electric utilities are installing large PV arrays. In fact, utility-scale solar systems make up a large portion of the industry today.

Even colleges are getting in on the act. Colorado College (where I once taught courses on renewable energy) installed a large solar system on one of its dormitories. A local middle school hired me to install an array on its grounds (Figure 1.3). Several airports, notably those in Sacramento,

**Figure 1.3.** *This solar array was installed at the Owensville Middle School in Owensville, Missouri, by the author and his business partner, Tom Bruns, and numerous hard-working students. The array is small for a school of this size, which uses almost 1,000 kilowatt-hours per day; the array only provides about 12 days' worth of electricity to the school. The array is also used for science and math education.* Credit: Dan Chiras.

Denver, and Indianapolis, are partially powered by large solar arrays, making use of the vast amounts of open space that surround them.

Farmers and ranchers install solar electric systems to power electric fences or to pump water for their livestock, saving huge amounts of money on installation. My wife and I power our farm and our home entirely with solar and wind energy. We even installed a solar pond aerator to reduce sludge buildup, lengthen the lifespan of our pond, and keep it open during the winter (Figure 1.4).


**Figure 1.4.** (a) *Aerating my half-acre farm pond reduces bottom sludge and helps create a healthier environment for the fish.* (b) *To prevent the pond from icing over completely in the winter (so our ducks can swim), I designed and installed a solar pond aerator in conjunction with a St. Louis company, Outdoor Water Solutions. They are currently selling a design like this online.* Credit: Dan Chiras.

Solar electric systems are used on sailboats and other watercraft to power lights, fans, radio communications, GPS systems, and refrigerators. Many recreational vehicles (RVs) are equipped with small PV systems as well.

Bus stops, parking lots, and highways are now often illuminated by superefficient lights powered by solar electricity, as are many portable information signs used at highway construction sites (Figure 1.5). Numerous police departments now set up solar-powered radar units in neighborhoods. These units display the speed of cars passing by and warn drivers if they're exceeding the speed limit.

You'll find solar-powered trash compactors at the Kennedy Space Center and in at least 1,500 cities in the US. In downtown Colorado Springs, sidewalk parking meter pay stations are similarly powered. In Denver, you'll find solar-powered credit card payment centers for city bikes that people can rent for the day (Figure 1.6).

Backpackers and river runners can take small solar chargers or larger lightweight fold-up solar modules with them on their ventures into the


**Figure 1.5.** *This electronic road sign is powered by a small solar array.*
Credit: Dan Chiras.

**Figure 1.6.** *These bikes in downtown Denver, Colorado, can be rented by the hour. The payment system (left) is powered by solar electricity.* Credit: Dan Chiras.

wild to power small electronic devices like cell phones. Military personnel have access to similar products, and there are numerous portable devices available for charging cell phones and tablets in our daily lives. Some are even sewn into backpacks, sports bags, or briefcases. There are also a number of cart and trailer-mounted PV systems on the market that can supply emergency power after disasters.

Solar electric systems are well suited for remote cottages, cabins, and homes where it is often cost prohibitive to run power lines. In France, the government paid to install solar electric systems and wind turbines on farms at the base of the Pyrenees Mountains rather than running electric lines to these distant operations.

PV systems are becoming very popular in less-developed countries. They are, for instance, being installed in remote villages to power lights and computers as well as refrigerators and freezers that store vaccines and other medicine. They're also used to power water pumps.

Solar electricity is also used to power remote monitoring stations that collect data on rainfall, stream flow, temperature, and seismic activity, and PVs allow scientists to transmit data back to their labs from such sites.

Solar electric modules often power lights on buoys, vital for nighttime navigation on large rivers like the Saint Lawrence River. Railroad signals and aircraft warning beacons are also often solar-powered.

The ultimate in remote and mobile applications, however, has to be the satellite. Virtually all military and telecommunications satellites are powered by solar electricity, as is the International Space Station.

## World Solar Energy Resources

Solar electricity is rapidly growing in popularity, which is fortunate for all of us because global supplies of the fossil fuels we have long used to generate electricity such as coal, natural gas, and oil are on the decline. As supplies wane, and as efforts to address global climate change increase, solar electric systems—along with small and large wind systems and other forms of renewable energy farms—could very well become a major source of electricity throughout the world. Frankly, I think it is inevitable. But is there enough solar energy to meet our needs?

Although solar energy is unevenly distributed over the Earth's surface, significant resources are found on every continent. "Solar energy's potential is off the chart," write energy experts Ken Zweibel, James Mason, and Vasilis Fthenakis in a December 2007 article, "A Solar Grand Plan," published in *Scientific American*. Less than one billionth of the Sun's energy strikes the Earth, but, as they point out, the solar energy striking the Earth in a 40-minute period is equal to all the energy human society consumes in a year. That is, 40 minutes of solar energy is equivalent to all the coal, oil, natural gas, oil shale, tars sands, hydropower, and wood we consume in an entire year. What is more, we'd only need to capture about 0.01% of the solar energy striking the Earth to meet *all* of our energy demands. Clearly, solar electric systems mounted on our homes and businesses or in giant commercial solar arrays could tap into the Sun's generous supply of energy, providing us with an abundance of electricity.

Most renewable energy experts envision a system that consists of dramatic improvements in efficiency and a mix of renewable energy technologies. Large-scale wind farms will very likely provide a large percentage of the world's electricity. (The world currently produces three times as much electricity from wind as it does from solar.) Geothermal and biomass resources will contribute to the world's energy supply. *Biomass* is plant matter that can be burned to produce heat or to generate steam that's used to power turbines that generate electricity. Biomass can also be converted to liquid or gaseous fuels that can be burned to produce electricity or heat or power vehicles. Hydropower currently contributes a significant amount of electricity throughout the world, and it will continue to add to the energy mix in our future.

What will happen to conventional fuels such as oil, natural gas, coal, and nuclear energy? Although their role will diminish over time, these fuels will probably contribute to the energy mix for many years to come. In the future, however, they will very likely take a back seat to renewables. They could eventually become pinch hitters to renewable energy, supplying backup electricity to an otherwise renewable energy-powered system.

Despite what some ill-informed critics say, renewable energy is splendidly abundant. What is more, the technologies needed to efficiently capture and convert solar energy to useful forms of energy like heat, light, and electricity are available now and, for the most part, they are quite affordable.

And don't lose track of this fact: While nuclear and fossil fuels are on the decline, the Sun will enjoy a long future. The Sun, say scientists, will continue to shine for at least five billion more years. The full truth, however, is that scientists predict the Sun's output will increase by about 10% in one billion years, making planet Earth too hot to sustain life. So, we won't be enjoying five billion more years of sunshine; we have less than a billion years before we'll have to check out. But that's a bit more than the 30 to 50 years of oil we have left.

## What the Critics Say

Proponents of a solar-powered future view solar energy as an ideal fuel source. It's clean, and it's relatively inexpensive because the fuel is free. Solar is also abundant and will be available for a long, long time. Moreover, its use could ease many of the world's most pressing problems, such as global climate change.

Like all fuels, solar energy is not perfect. Critics like to point out that, unlike conventional resources such as coal, the Sun is not available 24 hours a day. Some people don't like the looks of solar electric systems. And, many uninformedly argue that solar is too expensive. Let's take a look at the most common arguments and respond to the criticisms.

### *Availability and Variability*

Although the Sun shines 24 hours a day and beams down on the Earth at all times, half the planet is always blanketed in darkness. This poses a problem for humankind, especially those of us in the more developed countries, as we consume electricity 24 hours a day, 365 days a year.

Another problem is the daily variability of solar energy. That is, even during daylight hours, clouds can block the sun, sometimes for days on end. At night, PVs produce no energy at all. If solar electric systems are unable to generate electricity 24 hours a day like coal-fired and natural-gas-fired power plants, how can we use them to meet our 24-hour-per-day demand for electricity?

Some solar homeowners who live off grid (that is, not connected to the electrical grid) solve the problem by using batteries to store the electricity needed to meet nighttime and cloudy-day demand. I lived off grid for 14 years, and had electricity 24 hours a day, 365 days a year—almost entirely supplied by my PV system. I met nighttime and cloudy-day demand thanks to my batteries. I rarely ran out of electricity, and when I did, I fired up my backup generator.

Although efforts are being made to build large storage facilities, I doubt that batteries could serve as a backup for modern society. We use—and waste—way too much electricity. But don't dismay. Solar's less-than-24-hour-per-day availability can also be offset by coupling solar electric systems with other renewable energy sources, for example, wind-electric systems or hydroelectric systems.

Wind systems in good locations often generate electricity day and night (Figure 1.7). It can be transported by the national electrical grid to regions hundreds of miles away, making up for times when solar energy is reduced by clouds or eliminated by nightfall. Figure 1.8 shows how Denver, Colorado, can be supplied by wind and solar from neighboring areas.

Hydropower, generating electricity from flowing water, can also be used to provide a steady supply of electricity in a renewable energy future. In Canada, for example, hydroelectric facilities are treated as a *dispatchable energy resource,* much like natural gas is today in the United States. That is, they can be turned on and off as needed to meet demand. In a finely tuned power system, wind, solar, hydropower, and other renewables could be used to provide a steady supply of electricity day and night. Coal and natural gas could provide backup.

**Figure 1.7.** *The author's boys, Skyler and Forrest, check out a large wind turbine at a wind farm in Canastota, New York. Wind farms like this one are popping up across the nation—indeed, across the world—producing clean, renewable electricity to power our future.* Credit: Dan Chiras.

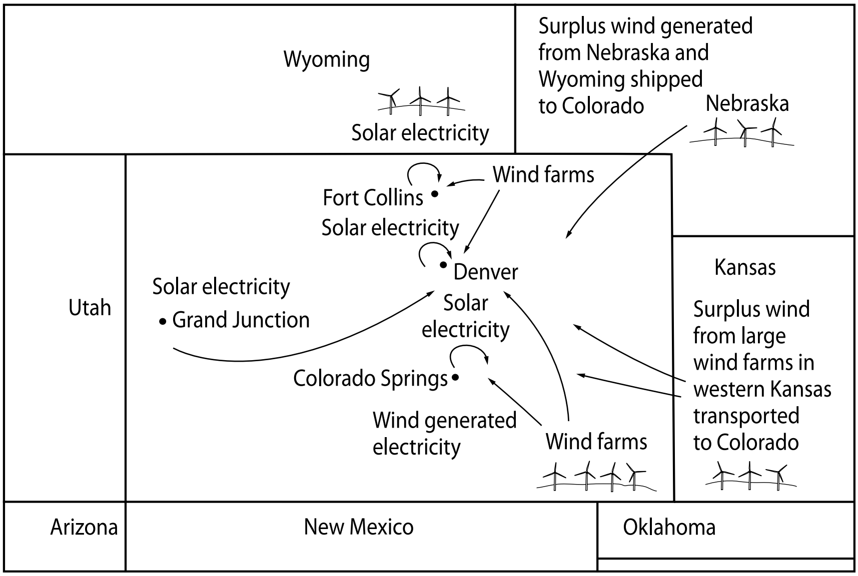


**Figure 1.8.** *Electricity can be transported from one state or province to another via the electrical grid, a network of high-voltage transmission lines. As illustrated here, surplus electricity from solar and wind energy systems can be imported from neighboring states or from nearby areas, helping to create a steady supply of electricity through rain and shine.* Credit: Forrest Chiras.

With smart planning, forecasting, and careful design, we can meet a good portion of our electrical needs from renewables with the remainder coming from our pinch hitters, the nonrenewables. European nations such as Denmark, Germany, and Spain are already successfully integrating renewable energy into their electrical grids on a large scale.

### *Aesthetics*

While many of us view a solar electric array as a thing of great value, even beauty, some don't. Your neighbors, for instance, might think that PV systems detract from the beauty of their neighborhood.

Ironically, those who object to solar electric systems rarely complain about visual blights like cell phone towers, electric transmission lines, and billboards. One reason that these common eyesores draw little attention is that they have been present in our communities for decades. We've grown used to ubiquitous electric lines and cell phone towers. But PV arrays are relatively new, and people aren't used to them yet.

Fortunately, there are ways to mount a solar array so that it blends with a roof. As you'll learn in Chapter 8, solar modules can be mounted 6 inches (15 cm) or so off, and parallel to, the roof surfaces (Figure 1.9). Manufacturers are also producing much-less-conspicuous modules with black frames or no frames at all, as noted earlier. There's also a solar product called PV laminate that is applied directly to the type of metal roof

Figure 1.9. *Solar arrays can be mounted close to the roof to reduce their visibility. Like the arrangement shown here, arrays can be supported by aluminum rails, usually about 6 inches (15 cm) above the surface of the roof (the gap helps cool them in the summer). While attractive, arrays installed this way tend to produce less electricity than pole-mounted or ground-mounted PV arrays, which stay much cooler on hot summer days.* Credit: Rochester Solar Technologies.

known as *standing seam metal roofing.* This results in an even lower-profile array (Figure 1.10). Solar arrays can sometimes be mounted on poles or racks anchored to the ground that can be placed in sunny backyards—out of a neighbor's line of sight (Figure 1.11).

**Figure 1.10.** *This product, known as PV laminate, is a plastic-coated flexible material that adheres to standing seam metal roofs. It's best applied to new roof panels before they are installed on the building. PV laminate is not as sensitive to high temperatures as conventional silicon-crystal modules used in most solar systems.* Credit: Uni-Solar.

**Figure 1.11.** *Ground-mounted solar arrays like this one accommodate numerous modules and can be oriented and angled to maximize production. Because they allow air to circulate freely around the modules, systems such as these stay cooler than many roof-mounted arrays and thus tend to have a higher output.* Credit: Dan Chiras.

### *Cost*

For years, the biggest disadvantage of solar electric systems has been the cost. Those of us who advocated for solar electricity in the 1970s through the 1990s had to appeal to people's sense of right and wrong and their understanding of the external economic costs—that is, the environmental costs—of conventional power. Thankfully, those days are over. As noted earlier, solar electricity is now cost competitive—and frequently cheaper—over the long haul than electricity from conventional sources, even in rural areas. I'll show you the proof of this assertion in Chapter 4.

Solar electricity makes sense in most areas with a decent amount of sunshine. In those areas with abundant sunshine and high electricity costs, like southern California or Hawaii, it makes even more sense. Solar electricity may also make sense for those who are building homes in remote locations a long way from power lines. In such instances, utilities often charge customers gargantuan fees to connect to their power lines. A homeowner, for instance, could pay $20,000 to connect, even when building a home only 0.2 miles from a line.

PV systems produce electricity far cheaper than power companies, but here's the rub: there's a rather large upfront cost. This is what makes solar electricity seem so expensive. When buying a solar electric system, you are paying for the technology that will produce all of the electricity you'll consume over the next 30 to 50 years. That said, this investment often earns a return on investment ranging from 5% to 7% per year.

To avoid the high cost, some individuals lease solar electric systems. Many companies will install solar systems for free, then charge a monthly fee. Individuals can also buy into community solar systems—that is, solar electric systems installed in other locations, like nearby solar farms. Homeowners and business owners purchase solar modules from the farm. The output of the modules a customer pays for at these sites is then credited to his or her electric bill. More on this later.

## The Advantages of Solar Electric Systems

Although solar electricity—like any fuel source or technology—has some downsides, they're not insurmountable, and they are outweighed by the many advantages. One of the most important advantages is that solar energy is an abundant, renewable resource—one that will be with us for hundreds of thousands of years. While natural gas, oil, coal, and nuclear fuels are limited and on the decline, solar energy will be available to us for at least one billion years.

Solar energy is a clean resource, too. By reducing the world's reliance on coal-fired power plants, solar electricity could help us reduce our contribution to a host of environmental problems, among them acid rain, global climate disruption, habitat destruction, species extinction, cropland loss caused by desertification, and mercury contamination of surface waters (caused by the release of mercury from coal-fired power plants). Solar electricity could even replace costly nuclear power plants.

Solar energy could help us decrease our reliance on declining and costly supplies of fossil fuels like coal, natural gas, and oil. Although very little electricity in the US comes from oil, electricity generated by solar electric systems could someday be used to power electric vehicles like the Tesla, Chevy Bolt, or Nissan Leaf—and the dozen or so other models being produced by the world's auto manufacturers. In such cases, solar will serve as a clean replacement for oil, the source of gasoline.

Without a doubt, the production of solar electric systems does have its impacts, but it is a relatively benign technology compared to fossil-fuel and nuclear power plants.

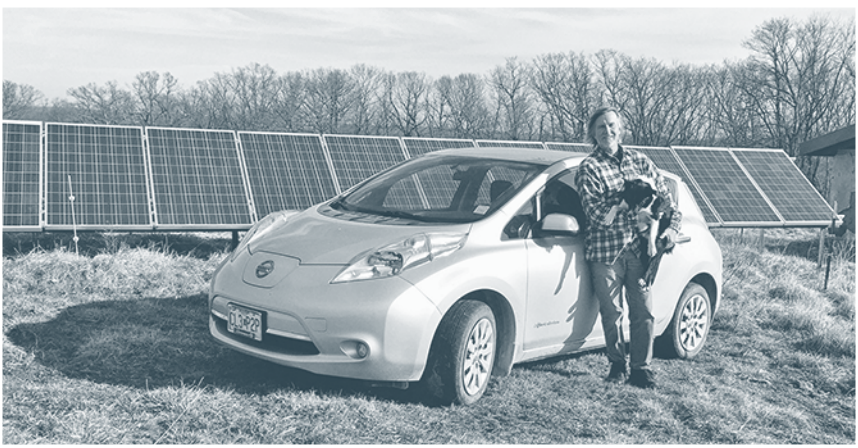

**Figure 1.12.** *Dan with His Electric Car. The author's all-electric 2013 Nissan Leaf, which he powers entirely with solar and wind energy. Folks interested in buying a used all-electric car can get some killer deals on slightly used vehicles. This car costs over $35,000 new. He got it in January 2016 for under $9,000, and it was in perfect condition.* Credit: Linda Stuart-Chiras.

Another benefit of solar electricity is that, unlike oil, coal, natural gas, and nuclear energy, the fuel is free. Moreover, solar energy is not owned or controlled by hostile foreign states or one of the dozen or so major energy companies that strongly influence global energy policy. Because the fuel is free, solar energy can provide a hedge against inflation, which is fueled in part by ever-increasing fuel costs. That's why solar is popular among many businesses and some school districts. Put another way, solar is an investment for a lifetime of inexpensive electricity not subject to annual price hikes.

An increasing reliance on solar and wind energy could also ease political tensions worldwide. Solar and other renewable energy resources could alleviate the perceived need for costly military operations aimed at stabilizing (controlling the politics of) the Mideast, a region where the largest oil reserves reside. Not a drop of human blood will be shed to ensure the steady supply of solar energy to fuel our economy.

Yet another advantage of solar-generated electricity is that it uses existing infrastructure (the electrical grid). A transition to solar electricity and wind energy could occur fairly seamlessly.

Solar electricity is also modular. (That's one reason why solar "panels" are called "modules.") That is, you can build a system over time. If you can initially only afford a small system, you can start small and expand your system as money becomes available. Expandability has been made easier by the invention of *microinverters,* small inverters that are wired to each solar module in a PV system. (For years, most solar systems were designed with one inverter, known as a *string inverter.* If you wanted to add modules, you'd almost always have to buy a larger, more expensive inverter. With microinverters, a homeowner can add one module and one microinverter at a time. It is much more economical to expand this way.)

Solar electricity does not require extensive use of water, as do coal, nuclear, and gas-fired power plants.

On a personal level, solar electric systems offer considerable economic savings over their lifetime, a topic discussed in Chapter 4. They also create a sense of pride and accomplishment, and they generate tremendous personal satisfaction.

A 2015 report by the Lawrence Berkeley National Laboratory on home sales in eight states from 2002 to 2013 showed that solar electric systems boosted selling prices. Sales prices on homes with PV systems were about $4.17 per watt higher than comparable "solarless" homes. If you had a 10-kW PV array on your home, you would have made an additional $41,700. That's amazing, especially when you take into account that the cost of a PV system nationwide at the time of the study was about $3.46 per watt, installed. That system would have cost $34,600 up front. Had you availed yourself to the 30% federal tax credit, the cost would have been $24,200. So not only would you have almost doubled your money, the system would have generated a ton of electricity free of charge.

## Purpose of This Book

This book focuses primarily on solar electric systems for homes and small businesses. It is written for individuals who aren't well versed in electricity. I'll teach you what you need to know about electricity as we go along, so you won't need a master's degree in electrical engineering to understand the material on solar systems.

When you finish reading and studying the material in this book, you will have the knowledge required to assess your electrical consumption and the solar resource at your site. You will also be able to determine if a solar electric system will meet your needs and if it makes sense for you. You will know what kind of system you should install, and you'll have a good working knowledge of the key components of PV systems. You'll also know how PV systems are installed and what their maintenance requirements are.

This book will help you know what to look for when shopping for a PV system to install yourself or when talking to a professional installer. If you choose to hire a professional to install a system, you'll be thankful you've read and studied the material in this book. The more you know, the more informed input you can provide into your system design, components, siting, and installation—and the more likely you'll be happy with your purchase.

I should point out, however, that this book is not an installation manual. Reading it won't qualify you to install a solar electric system. It is a good start, however.

## Organization of This Book

We'll begin our exploration of solar electricity in the next chapter by studying the Sun and solar energy. I will discuss important terms and concepts such as average peak sun hours. You'll learn why solar energy varies during the year, and how to calculate the proper orientation and tilt angle of a solar array to achieve optimal performance.

In Chapter 3, we'll explore solar electricity—the types of solar cells on the market today, their efficiencies, and how they generate electricity. I will also introduce you to some new solar electric technologies that are currently being developed.

In Chapter 4, we will explore the feasibility of tapping into solar energy to produce electricity at your site. I'll show you how to assess your electrical energy needs and determine the size of the solar system you'll need to meet them. You'll also learn why it is so important to make your home as energy efficient as possible before you install a solar electric system.

In Chapter 5, we'll examine the types of residential solar electric systems and hybrid systems—for example, wind and PV systems. You will also learn about connecting a PV system to the electric grid and how utilities handle surpluses you may produce, a process called *net metering*. We'll explore ways to expand a solar electric system and ways to add batteries to a grid-tied system.

Chapter 6 introduces inverters, string inverters, microinverters, and optimizers. You'll learn about your options.

In Chapter 7, I'll tackle batteries and the associated equipment required in battery-based solar systems, including charge controllers and backup generators. You will learn about the types of batteries you can install, how to install them correctly, battery maintenance, ways to reduce maintenance, and safety. You will also learn a little bit about sizing a battery bank for a PV system.

In Chapter 8, I'll describe mounting options so you can make the best decisions for your site.

In Chapter 9, we'll explore a range of issues such as permits, covenants, and utility interconnection. I'll discuss whether you should install a system yourself or hire a professional and, if you choose the latter, how to locate a competent installer.