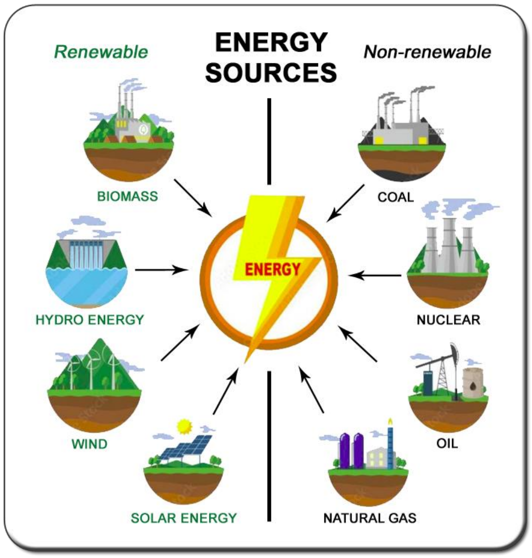
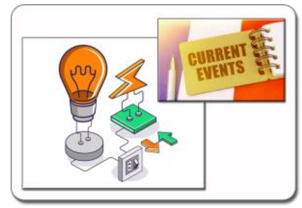


Renewable Energy Sources – Biomass, Hydro, Wind, & Solar

Vortex Energy Group LLC
www.VortexEnergyGroup.com

Renewable Energy in the US



Renewable energy refers to energy derived from natural sources that are replenished constantly and sustainably over time. Unlike fossil fuels (coal, oil, natural gas), renewable sources do not deplete and produce little to no greenhouse gas emissions during operation, making them environmentally friendly and essential for combating climate change. Following are statistics, comparisons, and projections for the US renewable energy market:

The Most Prevalent Renewable Energy Sources in the U.S. (as of recent data):

1. **Wind Energy**
    - **Leading source** of renewable electricity in the U.S.
    - Utilizes wind turbines to convert kinetic energy from wind into electricity.
    - Most prominent in states like Texas, Iowa, Oklahoma, and Kansas.
2. **Hydropower (Hydroelectricity)**
    - **Second-largest** source of renewable electricity.
    - Uses the flow of water (typically from dams) to spin turbines and generate electricity.
    - Key contributor in the Pacific Northwest (e.g., Washington, Oregon).
3. **Solar Energy**
    - Gaining rapidly in market share.
    - Converts sunlight directly into electricity using photovoltaic (PV) panels or concentrated solar power systems.
    - Popular in sunny states like California, Arizona, and Nevada.
4. **Biomass Energy**
    - Derived from organic materials (wood, agricultural waste, landfill gases).
    - Can be burned directly for heat or converted into biofuels (e.g., ethanol, biodiesel).
    - Used in both electricity generation and transportation.
5. **Geothermal Energy**
    - Uses heat from beneath the Earth's surface to generate electricity or provide direct heating.
    - Mainly used in western states like California, Nevada, and Utah.

Quick Snapshot (Approximate electricity generation share from renewables in the U.S.):

- Wind: ~11%
- Hydropower: ~6%
- Solar: ~5%
- Biomass: ~1.3%
- Geothermal: ~0.4%

U.S. Renewable Energy Snapshot (2023–2024)

In 2023, renewable energy sources accounted for approximately **21.4%** of total U.S. electricity generation, with the following breakdown:

- **Wind**: 10.2%
- **Hydropower**: 5.7%
- **Solar**: 3.9%
- **Biomass**: 1.1%
- **Geothermal**: 0.4%

By 2024, renewables' share increased to **24.2%**, driven by significant growth in wind and solar generation .Wolf Street

📈 Projections Through 2030 and Beyond

🔆 Solar Energy

- Solar power generation is projected to grow by **75%** from 2023 to 2025, reaching **286 billion kWh** .
- The U.S. Department of Energy's SunShot Initiative aims to reduce solar energy costs by 50% by 2030, potentially leading to solar meeting **33%** of U.S. electricity demand .U.S. Energy Information AdministrationCenter for Sustainable Systems

🌬️ Wind Energy

- Wind power generation is expected to grow by **11%** from 2023 to 2025, reaching **476 billion kWh** .
- The U.S. aims to deploy **30 GW** of offshore wind capacity by 2030, with potential to supply up to **25%** of U.S. electricity by 2050 .

🌊 Hydropower

- Hydropower generation remains relatively stable, contributing around **5.7%** of total electricity generation in 2023 .U.S. Energy Information Administration

🌱 Biomass and 🌋 Geothermal

- Biomass contributed **1.1%** and geothermal **0.4%** to electricity generation in 2023 .
- Geothermal energy is gaining attention for its potential to meet up to two-thirds of growing energy demands by the early 2030s, especially with advancements in drilling technologies .Business Council for Sustainable Energy+1U.S. Energy Information Administration+1New York Post

🔮 Looking Ahead

The U.S. Energy Information Administration projects that renewables will supply 44% of U.S. electricity by 2050, with solar and wind leading the growth . However, achieving these projections depends on continued policy support, technological advancements, and infrastructure development.

Basics of Biomass Energy

Biomass Energy is energy generated by burning plant or animal material like, for example, wood. Humans have been burning wood to create heat and light for hundreds of thousands of years(1), and today biomass energy is still a vital part of our energy mix.

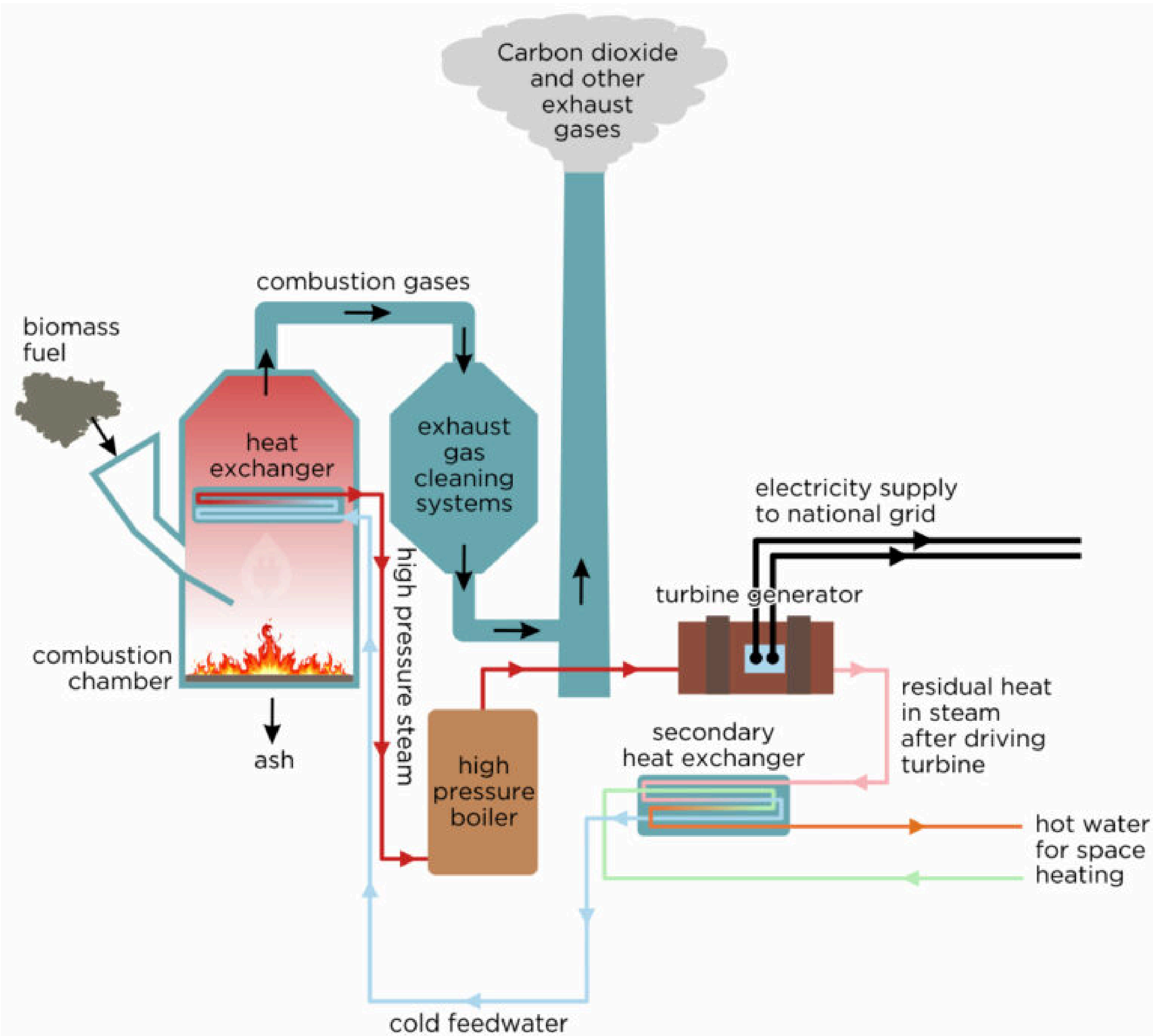
Small Scale Biomass

Using biomass energy can be as simple as heating a camping kettle over a burning pile of twigs. In the home, a log burning can be used to heat a room. Small-scale biomass boilers are available that can centrally heat a whole house and provide hot water. These systems are larger than a gas- or oil-fired boiler, but they are more environmentally friendly since they do not use fossil fuels. They are also cheaper to run than electric fires or immersion heaters. Larger systems like this can be used to heat an entire office block or apartments.

As the earth rotates from morning to noon to evening, sunlight hits every part of the surface at different angles depending on the time of day and time of year. The nearer to the earth's equator, the higher the concentration of Solar Energy falls on the surface. You can find out how much Solar Energy falls on any location on earth using the Global Solar Atlas website(2).

Industrial Scale Biomass

At the other end of the scale, Industrial biomass electricity generation plants use exactly the same principle as the kettle on a fire, but at a much larger scale. The biomass fuel is burned in a combustion chamber, and the hot gases heat a heat exchanger, where cold feedwater is boiled to high pressure steam. This steam is fed into a high pressure boiler, and on into a turbine generator to generate electricity that is sent to the national grid. After the electricity has been generated, the exhaust steam from the turbine is fed into a secondary heat exchanger so the residual heat can be used to provide space heating.



This is called 'Co-generation' or 'Combined Heat and Power' (CHP), and it makes the biomass plant more efficient because the same steam is being used twice to do two different jobs.

Burning biomass fuels creates poisonous combustion gases and particles, and a modern biomass plant includes various systems to reduce or remove some of these by-products from the exhaust gas before it is vented back into the atmosphere.

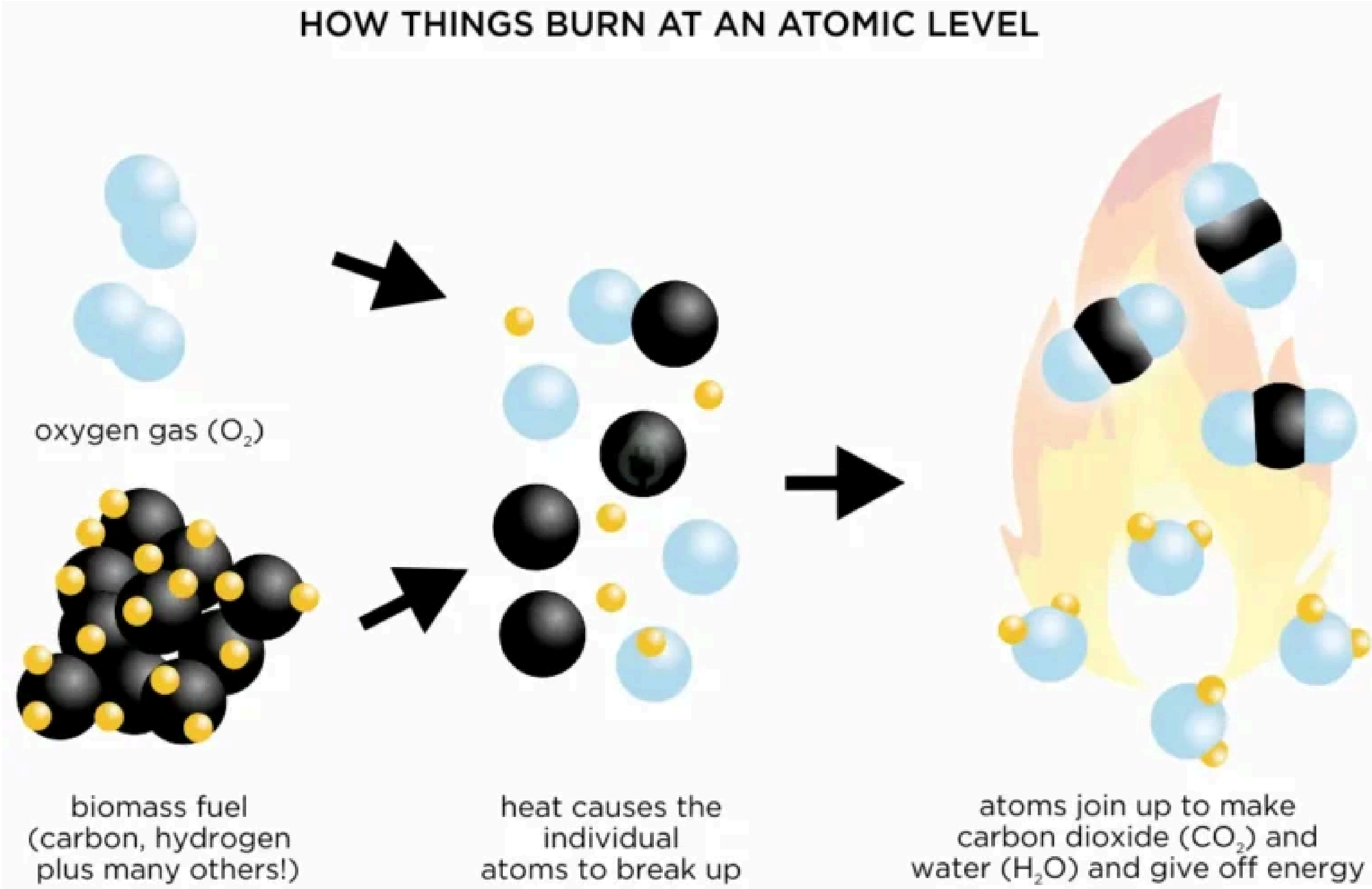
There are many different kinds of plant and animal materials that can be used for biomass fuels, for example:

- Wood pellets
- Straw pellets
- Peanut shell husks
- Rape or corn meal
- Sunflower pellets
- Poultry litter and other animal waste

Burning Things Makes Carbon Dioxide Gas

All biomass fuels contain a chemical element called carbon, and it is this carbon within the fuel that releases energy when burned. Once the biomass fuel has been heated up sufficiently, carbon reacts with oxygen gas that is naturally present in the air, and this reaction gives off energy in the form of heat and light. Biomass fuel will not burn without oxygen.

As well as giving off energy, this carbon-oxygen reaction also creates water vapour and a gas called carbon dioxide (CO2).



Controversy Over the Sustainability of Biomass

There is controversy about whether or not biomass should be called a renewable/sustainable source of energy, due to the fact that it releases CO2 into the atmosphere.

CO2 is a gas that occurs naturally in the air. There has always been CO2 in the air, but the amount has been rising significantly since the start of the industrial revolution, and it is now higher than it has ever been during the last 800,000 years(2). For over a decade, the vast majority of climate scientists around the world have been convinced about the overwhelming evidence that human activity is driving this rise in CO2 levels(3).

CO2 is called a 'greenhouse gas' because it acts like a greenhouse around the earth, trapping the sun's heat and causing the average land and sea temperatures to rise. The more CO2 there is in the atmosphere, the more of the sun's heat gets trapped, and temperatures rise faster.

Left unchecked, rising surface temperatures will have catastrophic knock-on consequences for all life on earth. As the ice caps melt, this causes sea levels to rise, which will flood all low-lying coastal regions around the globe, where many cities are located. In an attempt to slow down the rate of global warming, governments across the world are implementing policies to reduce the amount of CO_2 that humans release into the atmosphere.

Managed Woodland for Carbon Neutral Business

All trees and plants constantly soak up CO_2 out of the atmosphere all the time they are growing, storing it in themselves in the form of carbon. When a tree is cut down and burned, all the carbon stored inside it turns into CO_2 and is released back into the atmosphere. In effect, burning a tree is carbon neutral over the lifespan of that tree – it only releases as much CO_2 as it absorbed while growing.

Coppicing hard woods from a managed woodland over a short term (15 year) rotation allows for sustainable, carbon neutral biomass fuel production. 1 hectare (10,000 square metres) of 15-year old chestnut will produce 4 tonnes (3.6 US tons) of oven-dry hardwood biomass fuel. With 1 hectare for each year of the 15 years of rotation, felling once per year, this means 15 hectares of land will produce a sustainable supply of 3.6 tons of fuel per year(4).

The lag between burning the wood, and waiting for trees to grow to capture the released CO_2, has been described as 'carbon debt', placing the burden on future generations to plant enough trees to compensate for the wood being burned today(5).

In February 2021, a group of more than 500 scientists signed a letter to the European Union, arguing that "burning of wood will increase warming for decades to centuries. That is true even when the wood replaces coal, oil or natural gas"(6).

Deforesting ancient woodland or rainforest for biomass fuel is never sustainable nor renewable, since those forests cannot be replaced like-for-like over a short-term time frame.

Land Required for Biomass Fuel Consumption

On average, a small to medium scale biomass generation plant (between 5-20 megawatts) burns approximately 1 US ton of dry wood per hour for each megawatt (MW) of generation capacity(7). So a 20 MW plant would burn 20 tons per hour. This equates to 480 tons per day, or 175,200 tons per year.

Over 2,800 square miles of 15-year rotation managed woodland is required to sustainably produce enough hardwood fuel to run one 20MW biomass generation plant 24 hours a day, 365 days a year. This amount of land requirement for carbon-neutral, sustainable biomass fuel production is a significant issue that stands against the argument for "renewable" biomass.

The largest biomass electricity generation plant in the world, Drax in the UK, has a generation capacity of 2595 MW across 4 units(8). According to Drax's own annual report, the plant consumed 7.37 million tonnes of wood pellets in 2020(9). To make this many pellets requires at least 14 million tonnes of felled wood. There is not enough land in the UK to sustainably provide this much wood, so the vast majority of Drax's biomass fuel is shipped over the Atlantic ocean from the US, Canada and Brazil. The additional environmental cost of shipping biomass fuels around the world is another consideration in weighing up the sustainability of biomass electricity generation.

The Difference Between Biomass Fuels and Fossil Fuels

Fossil fuels (coal, oil and gas) also were once living things, but these are not counted as biomass. CO2 trapped in fossil fuels becomes highly concentrated during the fossilization process, and burning it releases CO2 that has been locked away underground for millions of years. It is not possible to plant sufficient trees at a fast enough rate to absorb all the ancient CO2that is released when burning fossil fuels.

References

1. https://en.wikipedia.org/
2. https://www.ametsoc.org/
3. https://www.ucsusa.org/
4. https://www.forestresearch.gov.uk/
5. https://easac.eu/
6. https://www.dropbox.com/
7. http://www.nacdnet.org/
8. http://www.draxpower-remit.com/
9. https://www.drax.com/

© 2025 Copyright Energy Follower

Hydropower explained

Hydropower is energy in moving water

People have a long history of using the force of water flowing in streams and rivers to produce mechanical energy. Hydropower was one of the first sources of energy used for electricity generation, and until 2019, hydropower was the leading source of total annual U.S. renewable electricity generation.

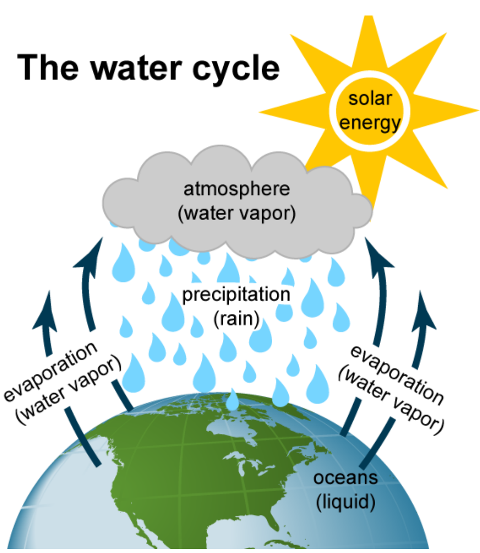
In 2022, hydroelectricity accounted for about 6.2% of total U.S. utility-scale[1] electricity generation and 28.7% of total utility-scale renewable electricity generation. Hydroelectricity generation varies annually, and it's share of total U.S. electricity generation generally decreased from the 1950's through 2020, mainly because of increases in electricity generation from other sources. Hydroelectricity's percentage share of total annual U.S. electricity generation in 2001 through 2022 averaged about 6.7%.

Hydropower relies on the water cycle

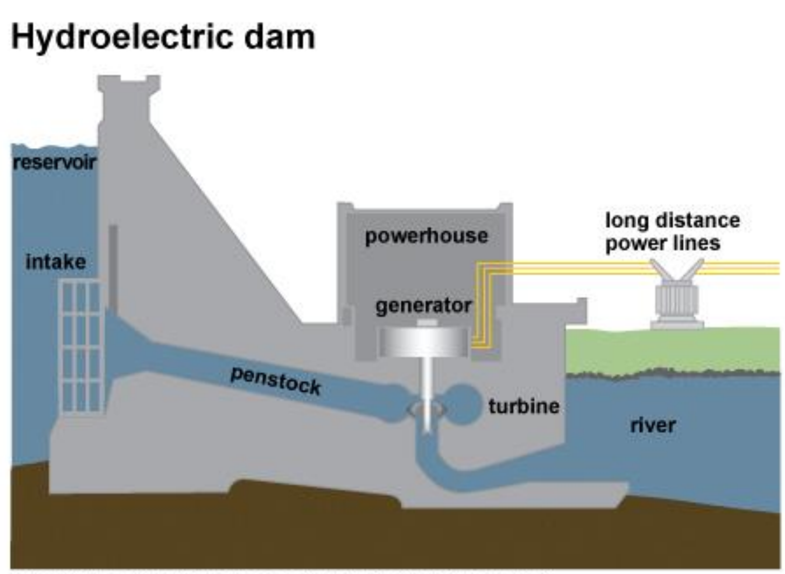
Understanding the water cycle is important to understanding hydropower. The water cycle has three steps:

- Solar energy heats water on the surface of rivers, lakes, and oceans, which causes the water to evaporate.
- Water vapor condenses into clouds and falls as precipitation—rain and snow.
- Precipitation collects in streams and rivers, which empty into oceans and lakes, where it evaporates and begins the cycle again.

The amount of precipitation that drains into rivers and streams in a geographic area determines the amount of water available for producing hydropower. Seasonal variations in precipitation and long-term changes in precipitation patterns, such as droughts, can have significant effects on the availability of hydropower production.



Source: Adapted from National Energy Education Development Project (public domain)



Source: Adapted from the Tennessee Valley Authority (public domain)

Hydroelectric power is produced with moving water

Because the source of hydroelectric power is water, hydroelectric power plants are usually located on or near a water source. The volume of the water flow and the change in elevation—or fall, and often referred to as *head*—from one point to another determine the amount of available energy in moving water. In general, the greater the water flow and the higher the head, the more electricity a hydropower plant can produce.

At hydropower plants water flows through a pipe, or *penstock*, then pushes against and turns blades in a turbine that spin to power a generator to produce electricity.

Conventional hydroelectric facilities include:

- *Run-of-the-river systems*, where the force of the river's current applies pressure on a turbine. The facilities may have a *weir* in the water course to divert water flow to hydro turbines.
- *Storage systems*, where water accumulates in reservoirs created by dams on streams and rivers and is released through hydro turbines as needed to generate electricity. Most U.S. hydropower facilities have dams and storage reservoirs.

Pumped-storage hydropower facilities are a type of hydroelectric storage system where water is pumped from a water source up to a storage reservoir at a higher elevation. The water is released from the upper reservoir to power hydro turbines located below the upper reservoir. They usually pump water to storage when electricity demand and generation costs, or when wholesale electricity prices are relatively low, and release the stored water to generate electricity during peak electricity demand periods when wholesale electricity prices are relatively high. Pumped-storage hydroelectric systems generally use more electricity to pump water to the upper water storage reservoirs than they produce with the stored water. Therefore, pumped-storage facilities have net negative electricity generation balances.

Hydropower has a long history

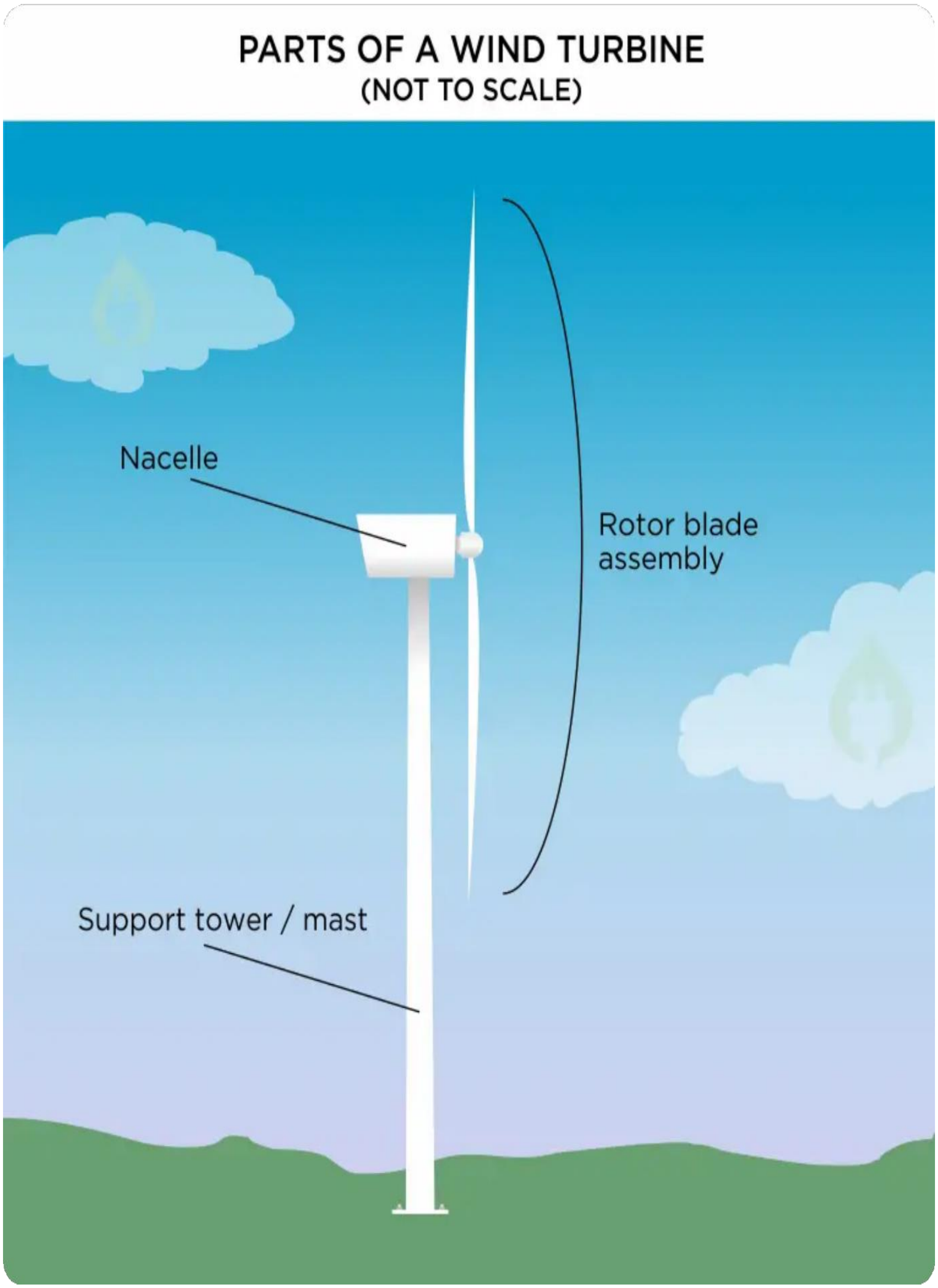
Hydropower is one of the oldest sources of energy for producing mechanical and electrical energy, and up until 2019, it was the largest source of total annual U.S. renewable electricity generation. Thousands of years ago, people used hydropower to turn paddle wheels on rivers to grind grain. Before steam power and electricity were available in the United States, grain and lumber mills were powered directly with hydropower. The first industrial use of hydropower to generate electricity in the United States was in 1880 to power 16 brush-arc lamps at the Wolverine Chair Factory in Grand Rapids, Michigan. The first U.S. hydroelectric power plant to sell electricity opened on the Fox River near Appleton, Wisconsin, on September 30, 1882.

There are about 1,450 conventional and 40 pumped-storage hydropower plants operating in the United States. The oldest operating U.S. hydropower facility is the Whiting plant in Whiting, Wisconsin, which started operating in 1891 and has a total generation capacity of about 4 megawatts (MW). Most U.S. hydroelectricity is produced at large dams on major rivers, and most of these hydroelectric dams were built before the mid-1970s by federal government agencies. The largest U.S. hydropower facility, and the largest U.S. electric power plant in electric generation capacity, is the Grand Coulee hydro dam on the Columbia River in Washington State, with 6,765 MW total generation capacity.

Utility-scale power plants have at least 1 MW (or 1,000 kilowatts) of total net electric generation capacity.

The Parts of a Wind Turbine: Major Components Explained

By John Gill February 6, 2025



1. *Support Tower / Mast*

The main support tower is made of steel, finished in a number of layers of protective paint to shield it against the elements. The tower must be tall enough to ensure the rotor blade does not interfere with normal day-to-day operations at ground level (for instance with turbine shadow flicker).

A smaller, on-shore 2MW wind turbine has a support tower 256 feet tall, with rotor blades 143 feet long. This means that the lowest point of the sweep of the rotor blades is 113 feet from the ground – a safe distance up.

To ensure the tower is securely attached to the ground, first a 15 to 20 foot deep concrete foundation pad is poured, requiring approximately 30,000 tons of cement. The anchor bolts for the tower are embedded deep into the concrete pad itself.

The tower is then securely bolted onto this concrete foundation pad. The tower itself must also be strong enough to hold up the nacelle and the rotor blades in all weathers. The weight of the steel support pillar alone for a 2MW wind turbine is 220 tons.

2. *Nacelle*

The nacelle is the 'head' of the wind turbine, and it is mounted on top of the support tower. The rotor blade assembly is attached to the front of the nacelle.

The nacelle of a standard 2MW onshore wind turbine assembly weighs approximately 72 tons.

Housed inside the nacelle are five major components (see diagram):

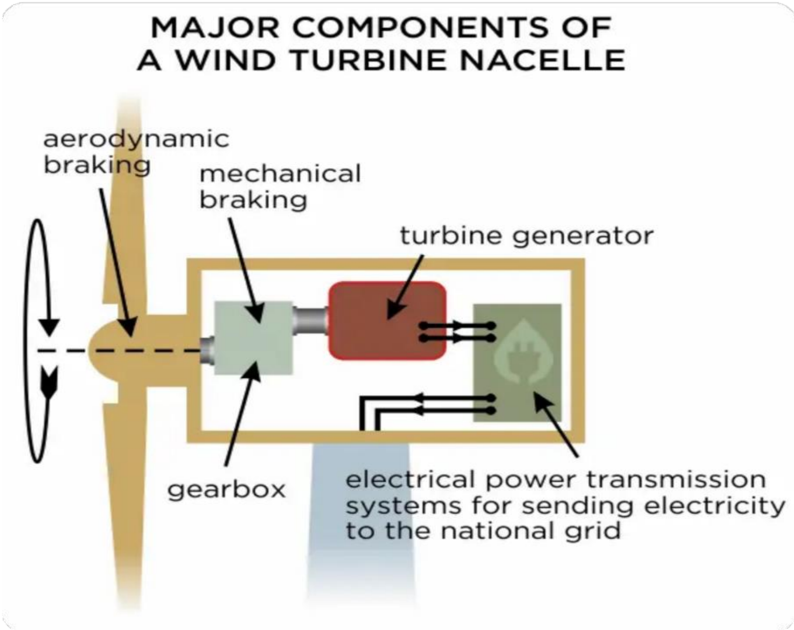
a. Gearbox assembly

b. Aerodynamic braking system

c. Mechanical braking system

d. Turbine generator

e. Electrical power transmission systems



a. Gearbox Assembly

The gearbox assembly receives the rotating input shaft from the centre of the rotor blade assembly, and using a system of gears, speeds up the rotation to a high speed suitable for running the turbine generator at its optimum generation speed. The high speed output shaft from the gearbox then directly drives the rotation of the generator.

b. Aerodynamic Braking

All modern wind turbines use two different kinds of braking systems – aerodynamic braking and mechanical (friction) braking.

Aerodynamic braking, or "rotor feathering" as it is sometimes called, is achieved by twisting the rotor blades so they present a thinner cross section to the oncoming wind; This means they 'catch' less of the wind, and so rotate slower.

c. Mechanical Braking

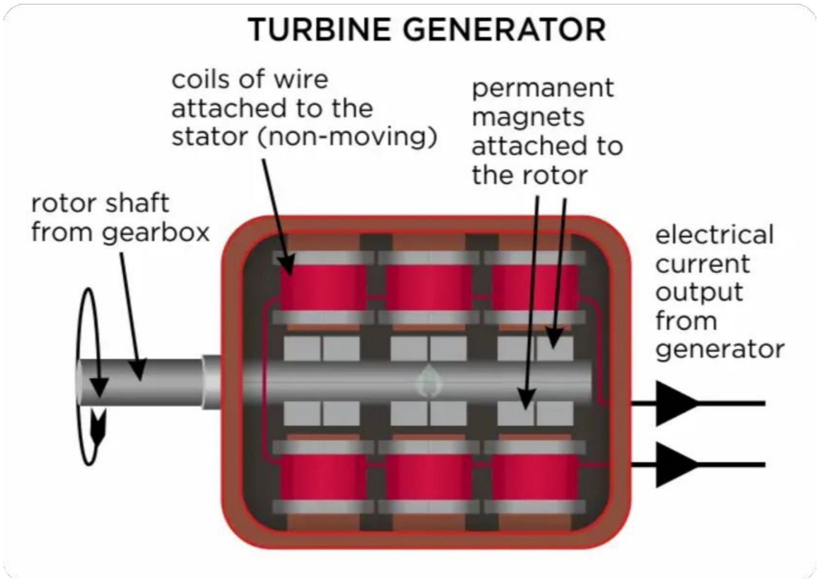
The mechanical braking system is incorporated into the gearbox assembly. Mechanical braking is just another term for friction braking – identical to what you would find in a motor vehicle's brakes. A rotating disc is mounted onto the input shaft of the gearbox, and using a hydraulic actuator, brake pads are clamped onto the disc, thus gradually slowing the blade assembly to a complete stop.

Under the vast majority of wind speeds, the mechanical braking systems do not need to be used under normal operation – the rotation speed of the blades is controlled using aerodynamic braking alone. Mechanical brakes are only used if the turbine needs to be stopped completely; for example, to allow workers to carry out maintenance or to stop the turbine generating if there is too much power on the electrical grid.

d. Turbine Generator

The turbine generator is the component that turns the rotational energy in the high-speed output shaft from the gearbox into an electrical current. The electrical principle of electromagnetic induction shows that while a magnet is moving past a coil of wire, an electric current is created (or "induced") in the wire.

Inside the generator, there are two main components – the rotor and the stator. The rotor is all the bits that rotate, and the stator is all the bits that don't. Some systems use rotating magnets against static coils of wire, and some systems use rotating coils of wire against static magnets, but the end result is the same – an electric current is generated at the output of the coils.



The cross-section illustration above shows a generator that has the magnets attached to the rotor, and the coils attached to the stator. As the rotor shaft turns round, the magnets spin past the coils that are mounted all around the rotor, and an electric current is induced in the coils. The coils are all wired together to increase the power, and the wires carrying the current are routed through the shell of the generator to be sent to the next system.

e. Electrical Power Transmission Systems

The electrical current from the generator is not yet ready for sending to the national electricity grid, and so it is first fed into a series of electrical circuits that transform the voltage to the appropriate level such that it can be connected with optimum efficiency to the grid. This electrical power is then fed through cables back down inside the support tower where it is taken to connect to the grid. From there, that electricity is supplied for use by homes and businesses.

3. *Rotor Blades*

The rotor blades are the three (usually three) long thin blades that attach tothe hub of the nacelle. These blades are designed to capture the kinetic energy in the wind as it passes, and convert it into rotational energy.

The largest wind turbines being manufactured in the world (as of 2021) are 15MW turbines. These turbines have rotor blades just over 115m long. When rotating at normal operational speeds, the blade tips of a 15MW wind turbine sweep through the air at approximately 230 mph!

To withstand the very high stresses they experience, wind turbine blades are made from modern composite materials like carbon fiber or glass fiber to give the most amount of strength and rigidity for the least amount of weight. Under normal operating conditions, a wind turbine blade is expected to give 20 - 25 years of service before it needs to be recycled and replaced.

References:

- ✓ https://www.windpowerengineering.com/
- ✓ https://www.williamsform.com/
- ✓ https://www.wind-watch.org/
- ✓ http://xn--drmstrre-64ad.dk/
- ✓ https://www.compositesworld.com/
- ✓ https://wind.nrel.gov/
- ✓ https://www.renewablesfirst.co.uk/

Featured Image Credit ©zvonce1959/123RF.COM

Solar Components: What's in a Solar Power System?

What are the components of a solar power system?

The main solar components that come with every solar power system or solar panel kit are:

- Solar panels
- Inverters
- Racking (mounting system)
- Batteries

But how do these solar system components convert the sun's energy into usable electricity for your home or business? On this page, we'll break down all the solar system components and explain how they work.

Solar Panels

Solar panels convert sunlight into electricity through a process called the photovoltaic effect. During this process, solar panels collect electrons from the sun's light in the form of direct current (DC) electricity, which then pass through the inverter to convert into usable AC electricity (more on that below).

Individual panels are made of up several solar cells, which are silicon wafers that are wired together and held in place by the backsheet, frame, and a pane of glass.

A panel string is a group of — typically 4-10 — panels wired together in series, which then plugs into an input on a string inverter.

Your solar array refers to all the panels that make up your system. An array may contain one or more panel strings wired into a string inverter or any number of panels individually paired with microinverters.

When you're browsing solar panels, you'll come across two types: monocrystalline or polycrystalline, and two different sizes.

Monocrystalline vs. Polycrystalline

Monocrystalline (mono) solar panels contain solar cells which are cut from a single source of silicon.

Polycrystalline (poly) solar panels are created by melting smaller silicon fragments and blending them to create solar cells. The blended nature of poly cells makes them slightly less efficient than mono cells, which means mono panels allow you to fit more solar in a smaller space.

While mono panels used to carry a higher price tag due to their increased efficiency, that is no longer the case. As companies have geared their production lines to focus on mono panels, more efficient manufacturing processes have brought the cost of mono and poly panels right in line with each other. Mono cells now represent about 75% of the panels on the market.

In terms of aesthetics, poly cells give solar panels their signature blue hue, while mono panels have a more sleek and modern all-black look to them.

60/120-Cell vs 72/144-Cell

Full-sized solar panels come in two standardized sizes:

60-cell and *120-cell* panels are about 40” by 66”, give or take an inch depending on the manufacturer. *60*-cell panels contain 10 rows of 6 cells each. *120-cell* panels are the same size and configuration, but the cells are cut in half, which boosts panel efficiency slightly.

72-cell and *144-cell* panels are about 40” by 78”, again with small variations depending on the manufacturer. *72-cell* panels contain 12 rows of 6 cells each. *144-cell* panels are the same form factor, but with half-cut cells.

Larger solar panels are about a foot taller and 8 pounds heavier, which can make them a bit harder to carry during installation, especially if you are installing a system on your roof. Regardless, it should be easily doable with 2+ people assisting the installation.

Larger panels can be slightly more cost-effective, however, your choice often comes down to whichever one will fit best on your rooftop. If you have a tall roof, you may be able to fit two rows of 60-cell panels, whereas a smaller roof may need 72-cell panels to fit as much solar as possible into a limited space.

These are the most common sizes in the industry, but there are other less common sizes and form factors. Smaller panels are more portable, making them a viable option for mobile applications like a boat or RV system.

What to look for in solar panels?

Here are a few considerations to keep in mind while you're shopping for solar panels or solar panel kits:

- **Cost per watt:** Panels come in all sizes. Divide the panel price by its wattage rating to compare the cost of solar panels on a level playing field.
- **Efficiency rating:** High-efficiency panels are great if you have limited space to work with.
- **Warranty period and terms**: Higher-quality panels will retain more of their production capacity over time. Look for the "degradation rate" in the performance warranty.

Inverters

Inverters are the brains of a solar power system. They are responsible for converting DC power (from your panels) into AC power (the format that is usable by your household appliances). They also route the flow of electricity between system components, and most provide a monitoring solution to track your system's performance.

There are a few types of inverters to choose from:

- String inverters
- String inverters with PV optimizers
- Microinverters
- Storage-ready inverters

String Inverters

A string inverter is a central unit with inputs for strings (groups) of solar panels. In string inverter systems, solar panels are chained together in series, with the final panel in the chain plugging into an input on the inverter.

For example, this sample 8 kw kit is designed with two strings of 10 panels apiece, for a total of 20 panels, at a cost of over $12,700.

String inverters are the most cost-effective option when your system is built-in full sunlight. However, shading presents problems for string inverters. When one panel in a string is shaded, its output drops, and the rest of the string drops to match the reduced output of the shaded panel.

If your build site is blocked by trees, chimneys, or other obstructions, a string inverter alone won't be enough to get the most out of your solar array. In those scenarios, you'll want to add PV optimizers to mitigate the impact of shading.

String Inverters + PV Optimizers

A PV optimizer is a small device that attaches to the back of each panel. The optimizer isolates the output of each panel, allowing it to produce power (and report back to your monitoring system) independently from the rest of the panels in your array.

That means that if a panel is covered in shade, only that panel will be affected. The rest of the array will continue to perform at its full capabilities.

PV optimizers also allow for individual panel-level monitoring. You'll be able to see how each panel is performing in your monitoring portal. If a panel is underperforming, that may be a sign that it needs to be cleaned or replaced. (In pure string inverter systems, monitoring only reports the performance of the system as a whole, and you'd have to test them one by one to identify the issue.)

Microinverters

Like PV optimizers, microinverters attach to the back of each panel to optimize the system's output and allow for individual panel-level monitoring.

Unlike optimizers, microinverters do not need a centralized string inverter unit to tie the system together. Instead, the inverting capabilities are handled by the microinverter unit itself.

That means that each microinverter + panel pairing is like a mini self-contained solar power system. You no longer have to worry about sizing panel strings to match a string inverter's power limitations.

The result is that microinverter system design is much more flexible, modular, and expandable than string inverter systems:

- Start small and expand your system later; no retrofitting or re-installation needed
- For oddly-shaped roofs, place panels on different roof facings without needing to string panels together
- Repair or replace individual panels or microinverter units without taking the whole system out of commission

While microinverters are more costly up front, they have a longer warranty period that makes them a better value over the life of the system. String inverters are typically warrantied for 5-15 years and often require replacement in the middle of your system's lifespan. In contrast, Enphase's IQ7 series microinverters are warrantied for 25 years to match the length of most solar panel warranties.

Storage-ready inverters

By default, grid-tie inverters like the SMA Sunny Boy are not equipped with battery charging capabilities. If you decide to add energy storage to your system, be sure to look for an inverter that facilitates battery charging. These are often referred to as "storage-ready" or "hybrid" inverters.

If you want to add storage to a microinverter system, the Enphase Ensemble package is a good choice. It combines Enphase's microinverters, batteries, and monitoring into a streamlined system. With all-native Enphase components, it was designed with compatibility and ease of installation in mind.

Another option is the Sol-Ark all-in-one hybrid inverter, which combines functions like inverting, charging, and monitoring into a single unit. This reduces the number of components to make installation even easier, but the tradeoff is that it is less flexible and expandable than Enphase's modular system.

Racking

Racking is the foundational structure that secures your solar panels in place. Racking systems come with mounting rails and flashings to secure the rails to your rooftop or ground mount.

The majority of home solar systems fall into one of two categories:

- Roof mount racking
- Ground mount racking

We'll also cover a few unique racking solutions with more niche applications, like pole mounts and ballasted mounts.

Roof Mount Racking

Roof mounts make use of your home's rafters to support the weight of the solar array.

For roof-mounted systems, you'll need a way to locate and mark your roof rafters, so that you can drill holes into the rafters and bolt the flashings in place. If your rafters aren't visible under the edge of your roof, you can use a stud finder to locate them or measure their position from the inside of your attic.

Roof mount systems are the standard choice for most home solar installations, as they are the most convenient and cost-effective option available. Putting panels on your roof saves valuable space, which is crucial if you have limited yard space and can't fit a ground mount on your property.

If you have a viable South, West, or East facing roof with enough space to build your array, a roof mount is usually the most cost-effective option.

Ground Mount Racking

A ground mount is a standalone support structure built out of metal pipes that are securely set into concrete footings in the ground. Ground mounts take more time and money to install, given that you will be building a new structure to support the solar array.

Ground mounts offer greater flexibility with the orientation of your array. You can point the panels directly toward the Equator and tilt them at the perfect angle to maximize the system's output. With roof mounts, you're locked into the tilt angle and facing of your rooftop.

Ground mounts are also easier to access for routine cleaning and maintenance. With a ground mount, you won't need to climb on your roof to clean the dust off the face of your panels.

Commercial and rural properties are especially suited to ground mount systems, as they often have plenty of space to build an array that takes advantage of the full capacity of their solar panels.

Pole Mounts

A pole mount is a type of ground mount that elevates solar panels high off the ground on a tall pole. They are useful in a few scenarios, such as snowy climates.

Pole mounts can tilt panels at a steeper angle, using the force of gravity to shed snow off the face of the panels. They can also be adjusted to lift the array higher in the air, providing clearance over snowbanks that accumulate in the winter months.

Steep hillsides prevent challenges for standard ground mount systems, which use several distributed concrete footings to anchor the mount in place. It can be tough to dig deep enough trenches to pour the concrete and level off the mount on a steep slope. Pole mounts only require one anchor point, which makes it much simpler to install them on a steep hillside.

A ballasted racking solution is a container with a frame that allows you to mount your solar panels. The container is filled with ballast, a heavy material such as dirt or gravel, which provides enough weight to hold the system in place.

Because ballasted mounting systems rely on counterweights to hold the system in place, there is no need to dig holes and pour concrete to anchor the mount into the ground. As a result, ballasted systems are cheaper, easier and quicker to install.

Solar Power Batteries

In off-grid and battery backup systems, a local battery bank is necessary to store usable energy on-site. This is helpful in the event of grid failure, extreme weather, or other interruptions.

There are three types of batteries that you can use with your solar power system:

- Flooded lead-acid batteries
- Sealed lead-acid batteries
- Lithium batteries

Flooded Lead-Acid Batteries

Flooded lead-acid (FLA) batteries are sometimes referred to as "wet cell" batteries because the electrolyte is in liquid form and can be accessed by removing the battery caps.

Charging flooded batteries causes water in the electrolyte solution to evaporate, so they regularly need to be refilled with distilled water to keep them topped off. This need for routine maintenance means flooded batteries are only suitable for those who have the time (and the desire) to perform maintenance checks on their battery bank on a monthly basis. FLA batteries are especially prone to failure if not properly maintained, and we find that most people can't (or won't) commit to the monthly maintenance schedule needed to properly care for FLA batteries.

Their strict maintenance requirements means they are not suitable for vacation homes, nor would we recommend them for full-time off-grid residences, unless you really love the idea of getting hands-on with your system. However, committed homesteaders and DIYers may find FLA batteries to be a cost-effective option, so long as they take excellent care of the battery bank.

Sealed Lead-Acid Batteries

Sealed lead-acid (SLA) batteries get their name because the compartment containing the electrolyte is sealed, which prevents leaks and noxious fumes coming from the battery.

Unlike flooded lead-acid (FLA) batteries, sealed batteries have minimal maintenance requirements and do not need to be installed in a ventilated battery enclosure. SLA batteries can also be mounted in any orientation because the contents of the battery are sealed shut.

There are two sealed lead acid battery types: absorbent glass mat (AGM) and gel batteries.

AGM batteries are less expensive and perform better than gel batteries in cold temperatures. They are also capable of higher charge and discharge rates. They are the more cost-effective sealed battery option, recommended in most off-grid solar applications.

Gel batteries are an older technology that cost more than AGM batteries. They take longer to charge and are not as widely available as AGM. Gel batteries do perform better in high ambient temperatures, so they may make sense in hot climates, but AGM is usually the more cost-effective option.

Lithium Batteries

Lithium batteries tend to be about 3x the cost of SLA batteries, but they also last about 3x longer, so the higher initial cost balances out over the life of the system.

If you want a high-performance battery that you don't have to replace for a decade, lithium batteries are the most convenient option. They have faster discharge and recharge rates, weigh less, and are maintenance-free. In addition, lithium batteries are modular, meaning you can start small and expand your battery bank as needed.

While lithium batteries cost more upfront, the cost falls in line with lead-acid batteries over the life of ownership.