Types of Renewable Energy

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DEFINITION

Renewable energy is energy produced from sources like the sun and wind that are naturally replenished and do not run out, it can be used for electricity generation, space and water heating and cooling, and transportation. Non-renewable energy, in contrast, comes from finite sources that could get used up, such as fossil fuels like coal and oil.

BENEFITS OF RENEWABLE ENERGY

The advantages of renewable energy are numerous and affect the economy, environment, national security, and human health. Here are some of the benefits of using renewable energy in the United States:

- Enhanced reliability, security, and resilience of the nation's power grid,
- Job creation throughout renewable energy industries,
- Reduced carbon emissions and air pollution from energy production,
- Increased U.S. energy independence,
- Increased affordability, as many types of renewable energy are cost-competitive with traditional energy sources,
- Expanded clean energy access for non-grid-connected or remote, coastal, or islanded communities.

RENEWABLE ENERGY IN THE UNITED STATES

Renewable energy generates about 20% of all U.S. electricity, and that percentage continues to grow. The following graphic breaks down the shares of total electricity production in 2021 among the types of renewable power:

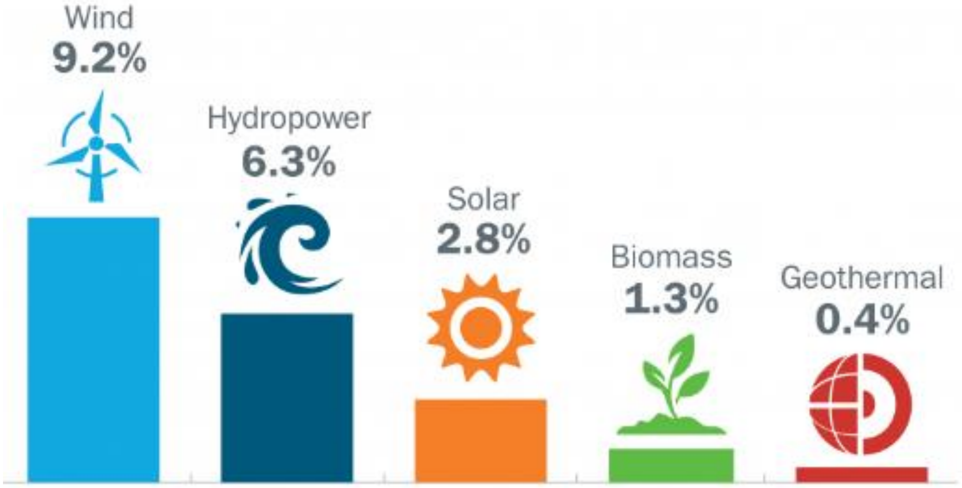

Figure 1: Shares of total electricity production in 2021 among the types of renewable power

In 2022, solar and wind energy are expected to add more than 60% of the utility-scale generating capacity to the U.S. power grid (46% from solar, 17% from wind). The United States is a resource-rich country with abundant renewable energy resources. The amount available is 100 times that of the nation's annual electricity need. Read more about renewable energy potential in the United States. The U.S. Department of Energy's 17 national laboratories conduct research and help bring renewable energy technologies to market.

TYPES OF RENEWABLE ENERGY

Renewable energy sources, such as biomass, geothermal resources, sunlight, water, and wind, are natural resources that can be converted into these types of clean, usable energy:

- Bioenergy
- Geothermal energy
- Hydropower
- Marine energy
- Solar energy
- Wind energy

BIOENERGY

What Is Bioenergy

Bioenergy is one of many diverse resources available to help meet our demand for energy. It is a form of renewable energy that is derived from recently living organic materials known as biomass, which can be used to produce transportation fuels, heat, electricity, and products.

Benefits Of A Robust Bioenergy Industry

Abundant and renewable bioenergy can contribute to a more secure, sustainable, and economically sound future by:

- Supplying domestic clean energy sources,
- Reducing U.S. dependence on foreign oil,
- Generating U.S. jobs,
- Revitalizing rural economies.

Biomass: A Renewable Energy Resource

Biomass is a versatile renewable energy source. It can be converted into liquid transportation fuels that are equivalent to fossil-based fuels, such as gasoline, jet, and diesel fuel. Biomass resources that are available on a renewable basis and are used either directly as a fuel or converted to another form or energy product are commonly referred to as "feedstocks."

It is a renewable energy resource derived from plant- based and algae-based materials that include:

- Crop wastes
- Forest residues
- Purpose-grown grasses
- Woody energy crops
- Microalgae
- Urban wood waste
- Food waste

Figure 2: Switchgrass fields and facilities in East Tennessee

Bioenergy technologies enable the reuse of carbon from biomass and waste streams into reduced-emissions fuels for cars trucks, jets and ships; bioproducts; and renewable power.

Biomass Feedstocks:

Biomass feedstocks include dedicated energy crops, agricultural crop residues, forestry residues, algae, wood processing residues, municipal waste, and wet waste (crop wastes, forest residues, purpose-grown grasses, woody energy crops, algae, industrial wastes, sorted municipal solid waste [MSW], urban wood waste, and food waste).

Dedicated Energy Crops:

Dedicated energy crops are non-food crops that can be grown on marginal land (land not suitable for traditional crops like corn and soybeans) specifically to provide biomass. These break down into two general categories: herbaceous and woody.

Herbaceous energy crops are perennial (plants that live for more than 2 years) grasses that are harvested annually after taking 2 to 3 years to reach full productivity. These include switchgrass, miscanthus, bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and others.

Short-rotation woody crops are fast-growing hardwood trees that are harvested within 5 to 8 years of planting. These include hybrid poplar, hybrid willow, silver maple, eastern cottonwood, green ash, black walnut, sweetgum, and sycamore. Many of these species can help improve water and soil quality, improve wildlife habitat relative to annual crops, diversify sources of income, and improve overall farm productivity.

Agricultural crop residue:

There are many opportunities to leverage agricultural resources on existing lands without interfering with the production of food, feed, fiber, or forest products. Agricultural crop residues, which include the stalks and leaves, are abundant, diverse, and widely distributed across the United States. Examples include corn stover (stalks, leaves, husks, and cobs), wheat straw, oat straw, barley straw, sorghum stubble, and rice straw. The sale of these residues to a local biorefinery also represents an opportunity for farmers to generate additional income.

Forestry Residues:

Forest biomass feedstocks fall into one of two categories: forest residues left after logging timber (including limbs, tops, and culled trees and tree components that would be otherwise unmerchantable) or whole-tree biomass harvested explicitly for biomass. Dead, diseased, poorly formed, and other unmerchantable trees are often left in the woods following timber harvest. This woody debris can be collected for use in bioenergy, while leaving enough behind to provide habitat and maintain proper nutrient and hydrologic features.

There are also opportunities to make use of excess biomass on millions of acres of forests. Harvesting excessive woody biomass can reduce the risk of fire and pests, as well as aid in forest restoration, productivity, vitality, and resilience. This biomass could be harvested for bioenergy without negatively impacting the health and stability of forest ecological structure and function.

Algae:

Algae as feedstocks for bioenergy refers to a diverse group of highly productive organisms that include microalgae, macroalgae (seaweed), and cyanobacteria (formerly called "blue-green algae"). Many use sunlight and nutrients to create biomass, which contains key components—including lipids, proteins, and carbohydrates— that can be converted and upgraded to a variety of biofuels and products. Depending on the strain, algae can grow by using fresh, saline, or brackish water from surface water sources, groundwater, or seawater. Additionally, they can grow in water from second-use sources, such as treated industrial wastewater; municipal, agricultural, or aquaculture wastewater; or produced water generated from oil and gas drilling operations.

Wood Processing Residues:

Wood processing yields byproducts and waste streams that are collectively called wood processing residues and have significant energy potential. For example, the processing of wood for products or pulp produces unused sawdust, bark, branches, and leaves/needles. These residues can then be converted into biofuels or bioproducts. Because these residues are already collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

Sorted Municipal Waste:

MSW resources include mixed commercial and residential garbage, such as yard trimmings, paper and paperboard, plastics, rubber, leather, textiles, and food wastes. MSW for bioenergy also represents an opportunity to reduce residential and commercial waste by diverting significant volumes from landfills to the refinery.

Wet Waste

Wet waste feedstocks include commercial, institutional, and residential food wastes (particularly those currently disposed of in landfills); organic-rich biosolids; manure slurries from concentrated livestock operations; organic wastes from industrial operations; and biogas derived from any of the above feedstock streams. Transforming these “waste streams” into energy can help create additional revenue for rural economies and solve waste-disposal problems.

Biofuels: Energy For Transportation

Biomass is one type of renewable resource that can be converted into liquid fuels—known as biofuels—for transportation. Biofuels include cellulosic ethanol, biodiesel, and renewable hydrocarbon "drop-in" fuels. The two most common types of biofuels in use today are ethanol and biodiesel.

Ethanol (CH3CH2OH) is a renewable fuel that can be made from various plant materials, collectively known as “biomass.” Ethanol is an alcohol used as a blending agent with gasoline to increase octane and cut down carbon monoxide and other smog-causing emissions. The most common blend of ethanol is E10 and is approved for use in most conventional gasoline-powered vehicles up to E15. Most ethanol is made from plant starches and sugars—particularly corn starch in the United States—but scientists are continuing to develop technologies that would allow for the use of cellulose and hemicellulose, the non-edible fibrous material that constitutes the bulk of plant matter. The common method for converting biomass into ethanol is called fermentation. During fermentation, microorganisms metabolize plant sugars and produce ethanol. Biodiesel is a liquid fuel produced from renewable sources, such as new and used vegetable oils and animal fats and is a cleaner-burning replacement for petroleum-based diesel fuel. Biodiesel is nontoxic and biodegradable and is produced by combining alcohol with vegetable oil, animal fat, or recycled cooking grease.

Like petroleum-derived diesel, biodiesel is used to fuel compression-ignition (diesel) engines. Biodiesel can be blended with petroleum diesel in any percentage, including B100 (pure biodiesel) and, the most common blend, B20. Biofuels can be used in airplanes and most vehicles that are on the road. Renewable transportation fuels that are functionally equivalent to petroleum fuels lower the carbon intensity of our vehicles and airplanes.

Renewable hydrocarbon "drop-in" fuels:

Petroleum fuels, such as gasoline, diesel, and jet fuel, contain a complex mixture of hydrocarbons (molecules of hydrogen and carbon), which are burned to produce energy. Hydrocarbons can also be produced from biomass sources through a variety of biological and thermochemical processes. Biomass-based renewable hydrocarbon fuels are nearly identical to the petroleum-based fuels they are designed to replace—so they're compatible with today's engines, pumps, and other infrastructure.

Biofuel Conversion Processes

Deconstruction:

Producing advanced biofuels (e.g., cellulosic ethanol and renewable hydrocarbon fuels) typically involves a multistep process. First, the tough rigid structure of the plant cell wall—which includes the biological molecules cellulose, hemicellulose, and lignin bound tightly together—must be broken down. This can be accomplished in one of two ways: high temperature deconstruction or low temperature deconstruction. High-temperature deconstruction makes use of extreme heat and pressure to break down solid biomass into liquid or gaseous intermediates. There are three primary routes used in Hight temperature deconstruction: Pyrolysis, Gasification, and Hydrothermal liquefaction.

During pyrolysis, biomass is heated rapidly at high temperatures (500°C–700°C) in an oxygen-free environment. The heat breaks down biomass into pyrolysis vapor, gas, and char. Once the char is removed, the vapors are cooled and condensed into a liquid “bio-crude” oil.

Gasification follows a slightly similar process; however, biomass is exposed to a higher temperature range (>700°C) with some oxygen present to produce synthesis gas (or syngas)—a mixture that consists mostly of carbon monoxide and hydrogen.

When working with wet feedstocks like algae, hydrothermal liquefaction is the preferred thermal process. This process uses water under moderate temperatures (200°C–350°C) and elevated pressures to convert biomass into liquid bio-crude oil.

Low-temperature deconstruction typically makes use of biological catalysts called enzymes or chemicals to breakdown feedstocks into intermediates. First, biomass undergoes a pretreatment step that opens up the physical structure of plant and algae cell walls, making sugar polymers like cellulose and hemicellulose more accessible. These polymers are then broken down enzymatically or chemically into simple sugar building blocks during a process known as hydrolysis.

Upgrading:

Following deconstruction, intermediates such as crude bio-oils, syngas, sugars, and other chemical building blocks must be upgraded to produce a finished product. This step can involve either biological or chemical processing. Microorganisms, such as bacteria, yeast, and cyanobacteria, can ferment sugar or gaseous intermediates into fuel blend-stocks and chemicals. Alternatively, sugars and other intermediate streams, such as bio-oil and syngas, may be processed using a catalyst to remove any unwanted or reactive compounds in order to improve storage and handling properties.

The finished products from upgrading may be fuels or bioproducts ready to sell into the commercial market or stabilized intermediates suitable for finishing in a petroleum refinery or chemical manufacturing plant.

Biopower: Energy For Heat And Electricity

Biopower technologies convert renewable biomass fuels into heat and electricity using processes like those used with fossil fuels.

There are three ways to harvest the energy stored in biomass to produce biopower: burning, bacterial decay, and conversion to a gas or liquid fuel.

Burning:

Most electricity generated from biomass is produced by direct combustion. Biomass is burned in a boiler to produce high-pressure steam. This steam flows over a series of turbine blades, causing them to rotate. The rotation of the turbine drives a generator, producing electricity. Biomass can also serve as substitute for a portion of coal in an existing power plant furnace in a process called co-firing (combusting two different types of materials at the same time).

Bacterial decomposition (anaerobic digestion):

Organic waste material, such as animal dung or human sewage, is collected in oxygen-free tanks called digesters. Here, the material is decomposed by anaerobic bacteria that produce methane and other byproducts to form a renewable natural gas, which can then be purified and used to generate electricity.

Conversion to a gas or liquid fuel:

Biomass can be converted to a gaseous or liquid fuel through gasification and pyrolysis.

Gasification is a process that exposes solid biomass material to high temperatures with very little oxygen present, to produce synthesis gas. The gas can then be burned in a conventional boiler to produce electricity. It can also be used to replace natural gas in a combined-cycle gas turbine.

Pyrolysis uses a similar process to gasification but under different operating conditions. In this scenario, biomass is heated at a lower temperature range but in the complete absence of oxygen to produce a crude bio-oil. This bio-oil is then substituted for fuel oil or diesel in furnaces, turbines, and engines for electricity production.

Biopower can offset the need for carbon fuels burned in power plants, thus lowering the carbon intensity of electricity generation. Unlike some forms of intermittent renewable energy, biopower can increase the flexibility of electricity generation and enhance the reliability of the electric grid.

Bioproducts: Everyday Commodities Made From Biomass

Biomass is a versatile energy resource, much like petroleum. Beyond converting biomass to biofuels for vehicle use, it can also serve as a renewable alternative to fossil fuels in the manufacturing of bioproducts such as plastics, lubricants, industrial chemicals, and many other products currently derived from petroleum or natural gas.

Mimicking the existing petroleum refinery model, integrated biorefineries can produce bioproducts alongside biofuels. This co-production strategy offers a more efficient, cost-effective, and integrated approach to the use of U.S. biomass resources. Revenue generated from bioproducts also offers added value, improving the economics of biorefinery operations and creating more cost-competitive biofuels. Manufacturing bioproducts from biomass involves a variety of industrial techniques. Many of these processes are similar to those used in the production of biofuels.

Biomass is first broken down into relatively stable chemical building blocks, which are then converted into a wide range of marketable products using a combination of biological, thermal, and chemical processes.

Integrated biorefineries:

A key component of developing a diverse, robust, and resilient bioeconomy is the establishment of integrated biorefineries, where biomass is converted into fuels, power, and chemicals. Chemicals and materials produced alongside biofuels can improve the overall economics of the refinery process. For example, in the petroleum industry, almost 75% of a barrel of crude oil goes towards making fuels, corresponding to approximately $935 billion in revenue. In contrast, only 16% of a barrel of oil goes towards making petrochemicals, generating nearly as much revenue ($812 billion) as fuels, despite the much smaller volume. Applying this same strategy to the bioenergy sector could enhance the long-term economic viability of the industry.

GEOTHERMAL ENERGY

What is Geothermal Energy

Geothermal energy is heat energy from the earth — Geo (earth) + thermal (heat). Geothermal resources are reservoirs of hot water that exist or are human made at varying temperatures and depths below the earth's surface. Wells, ranging from a few feet to several miles deep, can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications, including electricity generation, direct use, and heating and cooling. In the United States, most geothermal reservoirs are in the western states.

Benefits of Geothermal Energy

Renewable: The heat flowing from Earth’s interior is continually replenished by the decay of naturally occurring radioactive elements and will remain available for billions of years.

Baseload: Geothermal power plants produce electricity consistently and can run essentially 24 hours per day/7 days per week, regardless of weather conditions.

Domestic: U.S. geothermal resources can be harnessed for power production and heating and cooling without importing fuel.

Small footprint: Geothermal power plants and geothermal heat pumps are compact. Geothermal power plants use less land per gigawatt-hour (404 m2) than comparable-capacity coal (3,642 m2), wind (1,335 m2), and solar photovoltaic (PV) power stations (3,237 m2). GHPs can be retrofitted or integrated in new buildings.

Clean: Modern geothermal power plants emit no greenhouse gasses and have life cycle emissions four times lower than solar PV, and six to 20 times lower than natural gas. Geothermal power plants consume less water on average over the lifetime energy output than most conventional electricity-generation technologies.

U.S. Geothermal Growth Potential

The 2019 Geo-Vision analysis indicates potential for up to 60 gigawatts of electricity-generating capacity, more than 17,000 district heating systems, and up to 28 million geothermal heat pumps by 2050. If we realize those maximum projections across sectors, it would be the emissions reduction equivalent of taking 26 million cars off U.S. roads every year. In 2022, the Enhanced Geothermal Shot™ analysis confirmed the potential for even more geothermal electricity-generating capacity—90 gigawatts by 2050—if we can achieve aggressive cost reductions in enhanced geothermal systems.

Geothermal Electricity Generation

The presence of hot rocks, fluid, and permeability underground creates natural geothermal systems. Small underground pathways, such as fractures, conduct fluids through the hot rocks.

In geothermal electricity generation, this fluid can be drawn as energy in the form of heat through wells to the earth's surface. At the surface, that energy is converted to steam, which drives turbines that produce electricity. Conventional hydrothermal resources naturally contain all three elements. Sometimes, though, these conditions do not exist naturally—for instance, the rocks are hot, but they lack permeability or sufficient fluid flow. Enhanced geothermal systems (EGS) use human-made reservoirs to create the proper conditions by injecting fluid into the hot rocks. This reopens fractures and enhances the size and connectivity of fluid pathways.

Figure 3: Geothermal Plant

Once created, an EGS functions just as a natural geothermal system does: The now-available fluids carry energy to the surface through wells, driving turbines and generating electricity. By overcoming natural limitations in the subsurface, EGS can expand geothermal energy nationwide. Geothermal power plants draw fluids from underground reservoirs to the surface to produce steam. This steam then drives turbines that generate electricity. There are three main types of geothermal power plant technologies: dry steam, flash steam, and binary cycle. The type of conversion is part of the power plant design and generally depends on the state of the subsurface fluid (steam or water) and its temperature.

Dry Steam Power Plant: Dry steam plants use hydrothermal fluids that are already mostly steam, which is a relatively rare natural occurrence. The steam is drawn directly to a turbine, which drives a generator that produces electricity. After the steam condenses, it is frequently reinjected into the reservoir. Dry steam power plant systems are the oldest type of geothermal power plants, first used in Lardarello, Italy, in 1904. Steam technology is still relevant today and is currently in use in northern California at The Geysers, the world's largest single source of geothermal power.

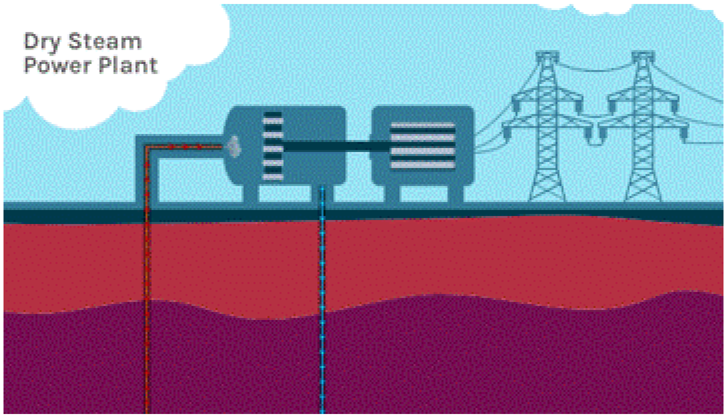

Figure 4: Dry steam power plant

Flash Steam Power Plant: Flash steam plants are the most common type of geothermal power plants in operation today. Fluids at temperatures greater than 182°C/360°F, pumped from deep underground, travel under high pressures to a low-pressure tank at the earth's surface.

The change in pressure causes some of the fluid to rapidly transform, or "flash," into vapor. The vapor then drives a turbine, which drives a generator. If any liquid remains in the low-pressure tank, it can be "flashed" again in a second tank to extract even more energy.

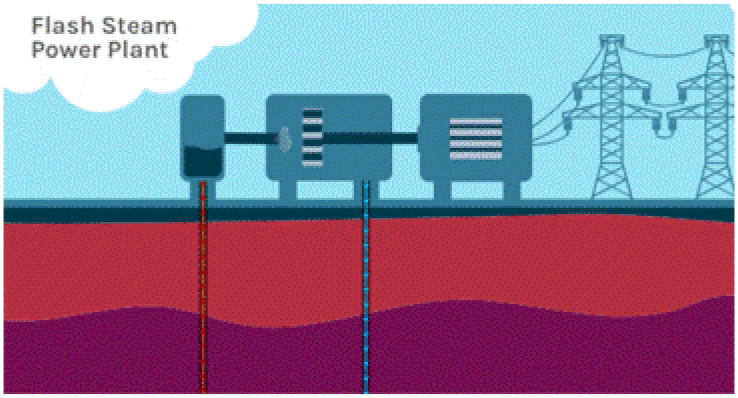

Figure 5: Flash steam power plant

Binary-Cycle Power Plant: Binary-cycle geothermal power plants can use lower temperature geothermal resources, making them an important technology for deploying geothermal electricity production in more locations.

Binary-cycle geothermal power plants differ from dry steam and flash steam systems in that the geothermal reservoir fluids never come into contact with the power plant's turbine units. Low-temperature geothermal fluids pass through a heat exchanger with a secondary fluid. This binary fluid has a much lower boiling point than water, and the modest heat from the geothermal fluid causes it to flash to vapor, which then drives the turbines, spins the generators, and creates electricity.

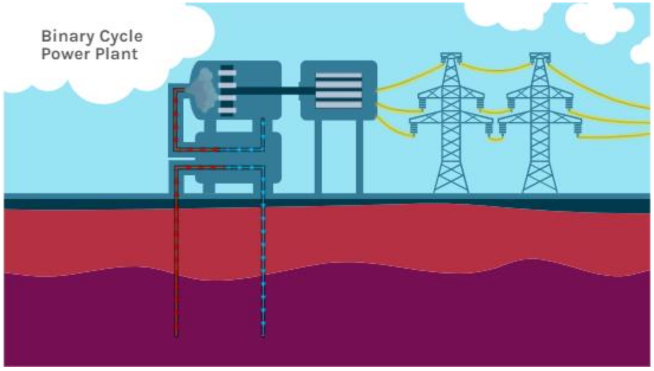

Figure 6: Binary cycle power plant

Geothermal Heat Pump

Heat pumps move heat from one place to another using electricity. Air conditioners and refrigerators are two common examples of heat pumps. Heat pumps can also be used to heat and cool buildings. Temperatures at about 30 feet below the surface remain relatively constant year-round—between about 50°F (10°C) and 59°F (15°C). For most areas in the United States, this means soil temperatures are usually warmer than the air in winter and cooler than the air in summer. Geothermal heat pumps (GHPs) take advantage of these constant underground temperatures to efficiently exchange temperatures, heating homes in the winter and cooling homes in the summer.

Figure 7: Geothermal heat pump

What is in a Geothermal Heat Pump System

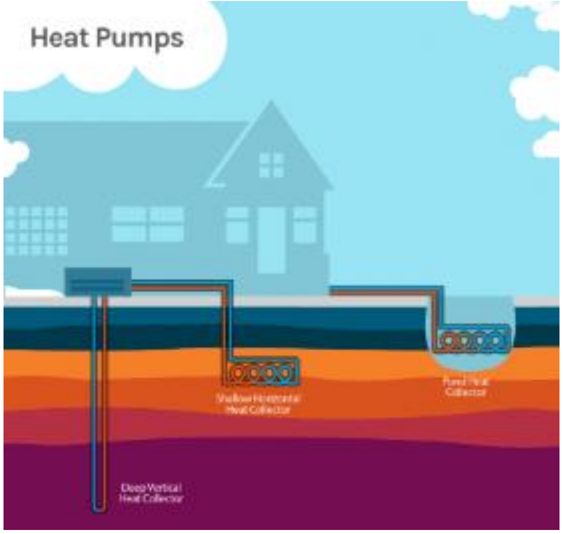

Figure 8: GHP system

A GHP system includes:

1. An underground heat collector—A geothermal heat pump uses the earth as a heat source and sink (thermal storage), using a series of connected pipes buried in the ground near a building. The loop can be buried either vertically or horizontally. It circulates a fluid that absorbs or deposits heat to the surrounding soil, depending on whether the ambient (outside) air is colder or warmer than the soil.

2. A heat pump—When ambient temperatures are colder than the ground, a geothermal heat pump removes heat from the collector’s fluids, concentrates it, and transfers it to the building. When ambient temperatures are warmer than the ground, the heat pump removes heat from the building and deposits it underground.

3. A heat distribution subsystem—Conventional ductwork is generally used to distribute heated or cooled air from the geothermal heat pump throughout the building.

GHPs can be:

- Used to heat and cool a single house, single business, or an entire community (college campus, neighborhood, etc.)
- Implemented as part of new construction or retroactively added for existing buildings
- Installed in urban or rural environments.

Geothermal heat pumps (GHPs) are different from air-source heat pumps. GHP systems exchange heat from the earth, while air-source heat pumps exchange heat from the air. Compared to air-source systems, geothermal systems have been shown to be quieter, last longer, and require less maintenance, and they do not depend on the temperature of the outside air. Geothermal systems are typically more expensive than air-source systems, but the additional costs are often returned with energy savings.

Geothermal Heating & Cooling

Geothermal heating and cooling technologies, including geothermal heat pumps and district heating, offer green, efficient temperature control solutions for buildings, campuses, and even entire communities. Widespread adoption of these technologies helps to decarbonize the building and electricity sectors, reduce energy costs for families, stabilize the grid, and boost community resilience.

How Does Geothermal District Heating Work

District and community-scale geothermal heating and cooling systems use one or more underground loops to create a heating and cooling network that can use a series of heat pumps.

Figure 9: Geothermal District Heating

New and different configurations of these systems are emerging in universities and communities all over the United States. The U.S. Department of Energy (DOE) Community Geothermal Heating and Cooling Design and Deployment initiative is supporting 11 community coalitions in 10 states to design and deploy geothermal district heating and cooling systems, create related workforce training, and identify and address environmental justice concerns. In December 2023, DOE announced results of an analysis highlighting that, deployed at mass scale and coupled with building efficiency improvements, geothermal heat pumps could decarbonize heating and cooling and save energy in U.S. buildings, avoiding as much as 24,500 miles of new grid transmission lines by 2050—enough to cross the continental United States eight times.

What Are Hydrothermal Resources

Hydrothermal resources are considered conventional geothermal resources because they can be developed using existing technologies and do not require creation of human-made reservoirs as needed with enhanced geothermal systems. The natural formation of a hydrothermal resource requires three principal elements: heat, water, and permeability. When water is heated in the earth, hot water or steam is trapped in porous and fractured rocks beneath a layer of relatively impermeable caprock, resulting in the formation of a hydrothermal reservoir. If the conditions underground are right, humans can harness that geothermal hot water or steam by drilling and then bring it to the surface to generate electricity.

These types of geothermal systems typically occur close to tectonic plate boundaries, like in the western portions of the United States. Sometimes the resource is easy to find because of indicators on the surface like hot springs. Other times, conventional geothermal resources are “hidden,” with no signs of the underground reservoir on the surface.

Hydrothermal Resources Program

Looking for and accessing hydrothermal resources—even those with surface expressions—can be challenging and expensive. The Geothermal Technologies Office (GTO) funds research, development, and demonstration of tools and methodologies to reduce the costs and risks of exploring and drilling for hydrothermal resources. GTO’s Hydrothermal Resources program focuses on improving geothermal exploration, subsurface characterization, and drilling to reduce overall geothermal deployment costs. Hydrothermal resources are well positioned to contribute to the goal of realizing a carbon-free electric grid by 2035.

Examples of projects the Hydrothermal Resources program supports include:

- Machine Learning,
- Hidden Systems,
- GeoFlight,
- FedGeo Partnerships,
- Geothermal Drilling Research, Development, and Demonstration,
- Play Fairway Analysis.

What Are Low-Temperature Geothermal Resources

Low-temperature geothermal resources are generally considered those below 300°F (150°C). Low-temperature geothermal uses include geothermal heat pumps (GHPs) for individual homes and businesses, district heating and cooling, and direct-use applications, where water from the geothermal resource is piped through heat exchangers or directly into commercial or residential buildings to meet heating and hot water demands. These resources can meet many energy needs, from heating and cooling to industrial processes like paper drying, greenhouses, and even beer brewing.

Low-Temperature and Coproduced Resources Program

The Geothermal Technologies Office's (GTO) Low-Temperature and Coproduced Resources program conducts research, development, and demonstration (RD&D) activities focus on improving the efficiency of low-temperature geothermal systems and expanding their utility through additional revenue streams. The program also researches the direct use of thermal resources for energy storage as well as process and space-heating applications, which have the potential to provide cost-effective, renewable thermal energy in large portions of the United States.

In addition to contributing toward the Administration's goal to reduce the carbon footprint of the U.S. building stock by 80% by 2035, low-temperature geothermal energy resources can be used by a wide array of community customers, including urban centers, rural areas, and remote communities.

Hybrid Technologies

Under certain conditions, geothermal energy can be harnessed in combination with other clean energy technologies. Many types of hybrid systems exist and are commercially deployed already. GTO supports work to expand the efficiency and use of these systems, including through hybrid demonstrations, research on solar hybrids at geothermal fields, and research into reservoir thermal energy storage (RTES).

HYDROPOWER

What is Hydropower

Hydropower, or hydroelectric power, is one of the oldest and largest sources of renewable energy, which uses the natural flow of moving water to generate electricity. Hydropower currently accounts for 28.7% of total U.S. renewable electricity generation and about 6.2% of total U.S. electricity generation.

While most people might associate the energy source with the Hoover Dam, a huge facility harnessing the power of an entire river behind its wall, hydropower facilities come in all sizes. Some may be very large, but they can be tiny, too, taking advantage of water flows in municipal water facilities or irrigation ditches. They can even be "dam-less," with diversions or run-of-river facilities that channel part of a stream through a powerhouse before the water rejoins the main river.

Whatever the method, hydropower is much easier to obtain and more widely used than most people realize. In fact, all but two states (Delaware and Mississippi) use hydropower for electricity, some more than others. For example, in 2020 about 66% of the state of Washington's electricity came from hydropower.

How Does Hydropower Work

Hydropower technologies generate power by using the elevation difference, created by a dam or diversion structure, of water flowing in on one side and out, far below, on the other.

Figure 10: Hydro-dam

The energy available from the moving water depends on both the volume of the water flow and the change in elevation—also known as the head—from one point to another. The greater the flow and the higher the head, the more the electricity that can be generated.

At the plant level, water flows through a pipe—also known as a penstock—and then spins the blades in a turbine, which, in turn, spins a generator that ultimately produces electricity. Most conventional hydroelectric facilities operate this way, including run-of-the-river systems and pumped storage systems.

Types of Hydropower Turbines

There are two main types of hydropower turbines:

- Reaction
- Impulse

Reaction Turbine:

A reaction turbine generates power from the combined forces of pressure and moving water. A runner is placed directly in the water stream, allowing water to flow over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows and are the most common type currently used in the United States. The two most common types of reaction turbines are Propeller (including Kaplan) and Francis. Kinetic turbines are also a type of reaction turbine.

Impulse Turbine:

An impulse turbine generally uses the velocity of the water to move the runner and discharges at atmospheric pressure. A water stream hits each bucket on the runner. With no suction on the down side of the turbine, the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high-head, low-flow applications. The two main types of impulse turbine are Pelton and cross-flow turbines.

MARINE ENERGY

What is Marine Energy

Marine energy, also known as marine and hydrokinetic energy or marine renewable energy, is a renewable power source that is harnessed from the natural movement of water, including waves, tides, and river and ocean currents. Marine energy can also be harnessed from temperature differences in water through a process known as ocean thermal energy conversion. The opportunities to harness marine energy are abundant. The total available marine energy resource in the United States is equivalent to approximately 57% of all U.S. power generation in 2019.

Even if only a small portion of this technical resource potential is captured, marine energy technologies would make significant contributions to the nation’s energy needs. Researchers are testing and deploying new technologies with the goal of harnessing energy from these plentiful water resources.

How Does Marine Energy Work

Marine energy technologies use the kinetic energy of waves, currents, tides, and thermal energy of deep cold water to surface water conversion to generate clean energy. For example, some wave energy converters use buoys to capture energy from the ocean’s vertical and horizontal movement, while turbines can harness energy from tides and currents.

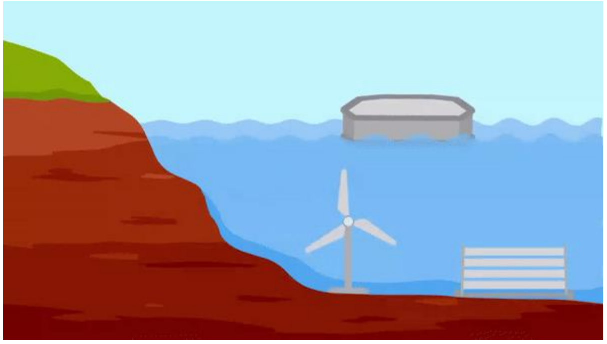

Figure 11: Harnessing of marine energy

What are the Benefits of Marine Energy

Marine energy is a renewable, clean source of energy, only requiring water's natural movement to generate power. Marine energy resources are abundant throughout the United States, the country is home to miles of ocean coastline and river resources, posing incredible potential for capitalizing on this resource. Marine energy is also highly predictable due to the cyclical nature of waves, tides, and currents. The predictability of marine energy and its daily and seasonal cycles allow it to complement other energy sources like solar and wind, whose electricity generation usually dips when waves and tides are most powerful.

It is also a resilient source of energy, usually positioned close to where power is needed, marine energy technologies would require short transmission lines, supporting the power grid's reliability and resilience. Marine energy can provide power to remote, coastal, and island communities. By using the water that surrounds these communities, marine energy can power microgrids that support these communities' homes and businesses.

Marine energy technologies open the door for other innovations in the maritime sector, such as turning seawater into clean drinking water and powering sea and ocean exploration. Marine energy has the ability to create jobs and provide renewable energy to remote or rural communities. As marine energy technologies are deployed, likely in remote coastal or island communities, the jobs will stay there. Because regardless of where the systems are built, there must be people locally to operate and maintain them.

SOLAR ENERGY

How Does Solar Work

The amount of sunlight that strikes the earth's surface in an hour and a half is enough to handle the entire world's energy consumption for a full year. Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. This energy can be used to generate electricity or be stored in batteries or thermal storage.

Solar radiation is light – also known as electromagnetic radiation – that is emitted by the sun. While every location on Earth receives some sunlight over a year, the amount of solar radiation that reaches any one spot on the Earth's surface varies. Solar technologies capture this radiation and turn it into useful forms of energy.

There are two main types of solar energy technologies—photovoltaics (PV) and concentrating solar-thermal power (CSP).

Photovoltaics Basics

You're likely most familiar with PV, which is utilized in solar panels. When the sun shines onto a solar panel, energy from the sunlight is absorbed by the PV cells in the panel. PV materials and devices convert sunlight into electrical energy. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. These cells are made of different semiconductor materials and are often less than the thickness of four human hairs. In order to withstand the outdoors for many years, cells are sandwiched between protective materials in a combination of glass and/or plastics.

To boost the power output of PV cells, they are connected together in chains to form larger units known as modules or panels. Modules can be used individually, or several can be connected to form arrays. One or more arrays is then connected to the electrical grid as part of a complete PV system. Because of this modular structure, PV systems can be built to meet almost any electric power need, small or large.

PV modules and arrays are just one part of a PV system. Systems also include mounting structures that point panels toward the sun, along with the components that take the direct-current (DC) electricity produced by modules and convert it to the alternating-current (AC) electricity used to power all of the appliances in your home.

The largest PV systems in the country are located in California and produce power for utilities to distribute to their customers. The Solar Star PV power station produces 579 megawatts of electricity, while the Topaz Solar Farm and Desert Sunlight Solar Farm each produce 550 megawatts.

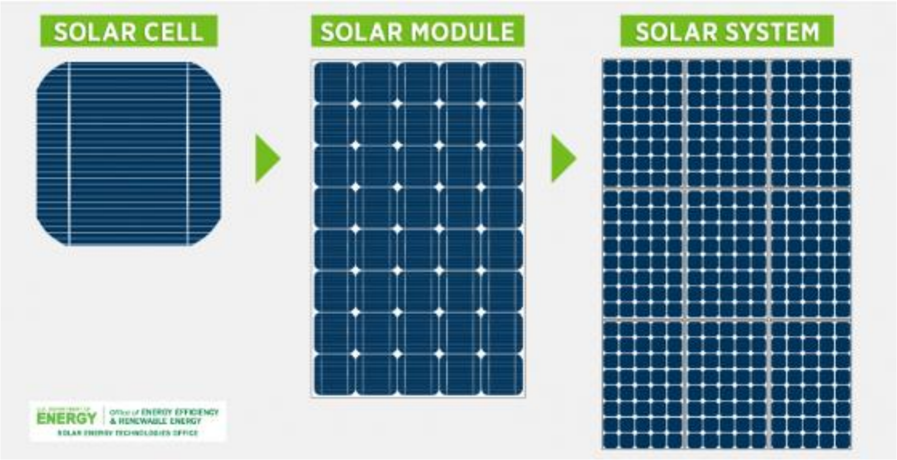

Figure 12: PV panels

Design of PV

Solar photovoltaic modules are where the electricity gets generated but are only one of the many parts in a complete photovoltaic (PV) system. In order for the generated electricity to be useful in a home or business, a number of other technologies must be in place. PV arrays must be mounted on a stable, durable structure that can support the array and withstand wind, rain, hail, and corrosion over decades. These structures tilt the PV array at a fixed angle determined by the local latitude, orientation of the structure, and electrical load requirements. To obtain the highest annual energy output, modules in the northern hemisphere are pointed due south and inclined at an angle equal to the local latitude.

Rack mounting is currently the most common method because it is robust, versatile, and easy to construct and install. More sophisticated and less expensive methods continue to be developed. For PV arrays mounted on the ground, tracking mechanisms automatically move panels to follow the sun across the sky, which provides more energy and higher returns on investment. One-axis trackers are typically designed to track the sun from east to west. Two-axis trackers allow for modules to remain pointed directly at the sun throughout the day. Naturally, tracking involves more up-front costs and sophisticated systems are more expensive and require more maintenance. As systems have improved, the cost-benefit analysis increasingly favors tracking for ground-mounted systems.

While most solar modules are placed in dedicated mounting structures, they can also be integrated directly into building materials like roofing, windows, or façades. These systems are known as building-integrated PV (BIPV). Integrating solar into buildings could improve material and supply chain efficiencies by combining redundant parts, and reduce system cost by using existing building systems and support structures. BIPV systems could provide power for direct current (DC) applications in buildings, like LED lighting, computers, sensors, and motors, and support grid-integrated efficient building applications, like electric vehicle charging. BIPV systems still face technical and commercial barriers to widespread use, but their unique value makes them a promising alternative to traditional mounting structures and building materials.

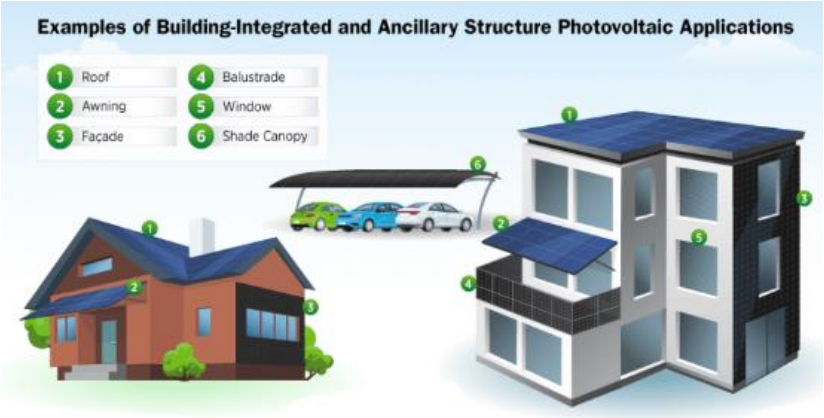

Figure 13: BIPV system

Inverters are used to convert the direct current (DC) electricity generated by solar photovoltaic modules into alternating current (AC) electricity, which is used for local transmission of electricity, as well as most appliances in our homes. PV systems either have one inverter that converts the electricity generated by all of the modules, or microinverters that are attached to each individual module. A single inverter is generally less expensive and can be more easily cooled and serviced when needed. The microinverter allows for independent operation of each panel, which is useful if some modules might be shaded, for example. It is expected that inverters will need to be replaced at least once in the 25-year lifetime of a PV array.

Advanced inverters, or "smart inverters," allow for two-way communication between the inverter and the electrical utility. This can help balance supply and demand either automatically or via remote communication with utility operators. Allowing utilities to have this insight into (and possible control of) supply and demand allows them to reduce costs, ensure grid stability, and reduce the likelihood of power outages.

Batteries allow for the storage of solar photovoltaic energy, so we can use it to power our homes at night or when weather elements keep sunlight from reaching PV panels. Not only can they be used in homes, but batteries are playing an increasingly important role for utilities. As customers feed solar energy back into the grid, batteries can store it so it can be returned to customers at a later time. The increased use of batteries will help modernize and stabilize our country's electric grid.

How a Solar Cell Works

Solar cells contain a material that conducts electricity only when energy is provided—by sunlight, in this case. This material is called a semiconductor; the “semi” means its electrical conductivity is less than that of a metal but more than an insulator’s. When the semiconductor is exposed to sunlight, it absorbs the light, transferring the energy to negatively charged particles called electrons. The electrons flow through the semiconductor as electrical current, because other layers of the PV cell are designed to extract the current from the semiconductor. Then the current flows through metal contacts—the grid-like lines on a solar cell—before it travels to an inverter. The inverter converts the current to AC, which flows into the electric grid and, eventually, connects to the circuit that is your home’s electrical system. As long as sunlight continues to reach the module and the circuit is connected, electricity will continue to be generated.

A module’s ability to convert sunlight into electricity depends on the semiconductor. In the lab, this ability is called photovoltaic conversion efficiency. Outside, environmental conditions like heat, dirt, and shade can reduce conversion efficiency, along with other factors. But researchers are coming up with solutions, such as back sheets that are placed on the panels to reduce their operating temperature, and new cell designs that capture more light. Capturing more light during the day increases energy yield, or the electricity output of a PV system over time.

To boost energy yield, researchers and manufacturers are looking at bifacial solar cells, which are double-sided to capture light on both sides of a silicon solar module—they capture light reflected off the ground or roof where the panels are installed.

The jury is still out on how bifacials will affect a system's energy yield, but some SETO-funded projects are working to reduce this uncertainty by establishing baseline metrics to quantify and model bifacial efficiency gains.

The main semiconductor used in solar cells, not to mention most electronics, is silicon, an abundant element. In fact, it's found in sand, so it's inexpensive, but it needs to be refined in a chemical process before it can be turned into crystalline silicon and conduct electricity. To make a silicon solar cell, blocks of crystalline silicon are cut into very thin wafers. The wafer is processed on both sides to separate the electrical charges and form a diode, a device that allows current to flow in only one direction. The diode is sandwiched between metal contacts to let the electrical current easily flow out of the cell.

About 95% of solar panels on the market today use either monocrystalline silicon or polycrystalline silicon as the semiconductor. Monocrystalline silicon wafers are made up of one crystal structure, and polycrystalline silicon is made up of lots of different crystals. Monocrystalline panels are more efficient because the electrons move more freely to generate electricity, but polycrystalline cells are less expensive to manufacture. The maximum theoretical efficiency level for a silicon solar cell is about 32% because of the portion of sunlight the silicon semiconductor is able to absorb above the bandgap. The best panels for commercial use have efficiencies around 18% to 22%, but researchers are studying how to improve efficiency and energy yield while keeping production costs low.

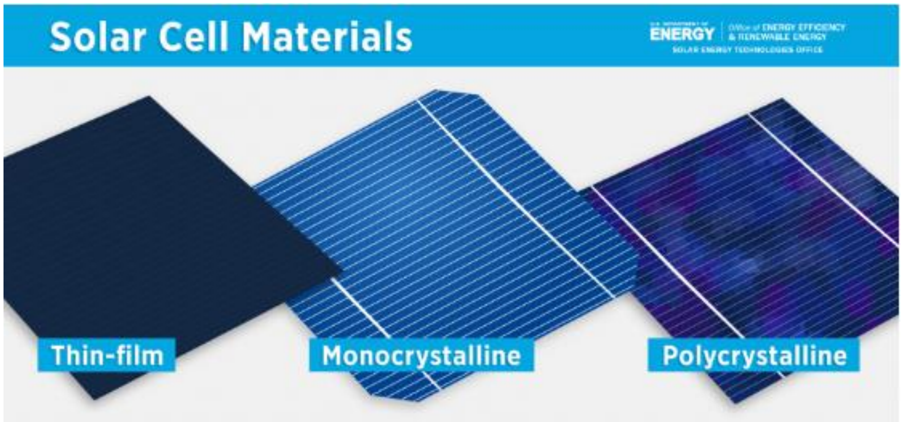

Figure 14: PV cell materials

Solar Performance and Efficiency

The conversion efficiency of a photovoltaic (PV) cell, or solar cell, is the percentage of the solar energy shining on a PV device that is converted into usable electricity. Improving this conversion efficiency is a key goal of research and helps make PV technologies cost-competitive with conventional sources of energy.

Not all of the sunlight that reaches a PV cell is converted into electricity. In fact, most of it is lost. Multiple factors in solar cell design play roles in limiting a cell's ability to convert the sunlight it receives. Designing with these factors in mind is how higher efficiencies can be achieved, these factors are:

Wavelength:

Light is composed of photons—or packets of energy—that have a wide range of wavelengths and energies. The sunlight that reaches the earth's surface has wavelengths from ultraviolet, through the visible range, to infrared. When light strikes the surface of a solar cell, some photons are reflected, while others pass right through. Some of the absorbed photons have their energy turned into heat. The remainder have the right amount of energy to separate electrons from their atomic bonds to produce charge carriers and electric current.

Recombination:

One way for electric current to flow in a semiconductor is for a "charge carrier," such as a negatively charged electron, to flow across the material. Another such charge carrier is known as a "hole," which represents the absence of an electron within the material and acts like a positive charge carrier. When an electron encounters a hole, they may recombine and therefore cancel out their contributions to the electrical current.

Direct recombination, in which light-generated electrons and holes encounter each other, recombine, and emit a photon, reverses the process from which electricity is generated in a solar cell. It is one of the fundamental factors that limits efficiency. Indirect recombination is a process in which the electrons or holes encounter an impurity, a defect in the crystal structure, or interface that makes it easier for them to recombine and release their energy as heat.

Temperature:

Solar cells generally work best at low temperatures. Higher temperatures cause the semiconductor properties to shift, resulting in a slight increase in current, but a much larger decrease in voltage. Extreme increases in temperature can also damage the cell and other module materials, leading to shorter operating lifetimes. Since much of the sunlight shining on cells becomes heat, proper thermal management improves both efficiency and lifetime.

Reflection:

A cell's efficiency can be increased by minimizing the amount of light reflected away from the cell's surface. For example, untreated silicon reflects more than 30% of incident light. Anti-reflection coatings and textured surfaces help decrease reflection. A high-efficiency cell will appear dark blue or black.

Determining Conversion Efficiency:

Researchers measure the performance of a PV device to predict the power the cell will produce. Electrical power is the product of current and voltage. Current-voltage relationships measure the electrical characteristics of PV devices. If a certain "load" resistance is connected to the two terminals of a cell or module, the current and voltage being produced will adjust according to Ohm's law (the current through a conductor between two points is directly proportional to the potential difference across the two points). Efficiencies are obtained by exposing the cell to a constant, standard level of light while maintaining a constant cell temperature and measuring the current and voltage that are produced for different load resistances.

Concentrating Solar-Thermal Power Basics

Concentrating solar-thermal power (CSP) systems use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. This heat - also known as thermal energy - can be used to spin a turbine or power an engine to generate electricity. It can also be used in a variety of industrial applications, like water desalination, enhanced oil recovery, food processing, chemical production, and mineral processing.

Concentrating solar-thermal power systems are generally used for utility-scale projects. These utility-scale CSP plants can be configured in different ways. Power tower systems arrange mirrors around a central tower that acts as the receiver, while linear systems have rows of mirrors that concentrate the sunlight onto parallel tube receivers positioned above them. Smaller CSP systems can be located directly where power is needed. For example, single dish/engine systems can produce 5 to 25 kilowatts of power per dish and be used in distributed applications.

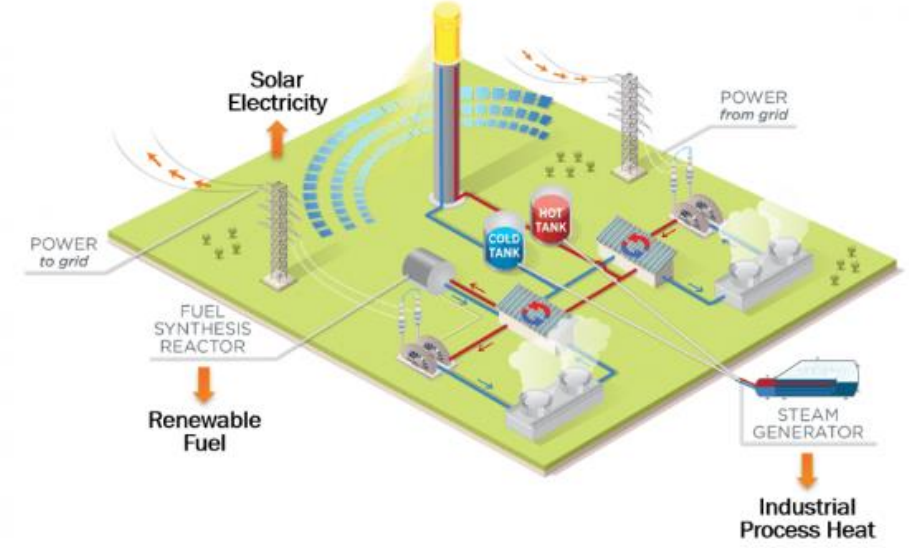

Figure 15: CSP system illustration

Thermal Storage System Concentrating Solar-Thermal Power Basics

One challenge facing the widespread use of solar energy is reduced or curtailed energy production when the sun sets or is blocked by clouds. Thermal energy storage provides a workable solution to this challenge.

In a concentrating solar power (CSP) system, the sun's rays are reflected onto a receiver, which creates heat that is used to generate electricity that can be used immediately or stored for later use. This enables CSP systems to be flexible, or dispatchable, options for providing clean, renewable energy. Several sensible thermal energy storage technologies have been tested and implemented since 1985. These include the two-tank direct system, two-tank indirect system, and single-tank thermocline system.

Two-tank direct system:

Solar thermal energy in this system is stored in the same fluid used to collect it. The fluid is stored in two tanks—one at high temperature and the other at low temperature. Fluid from the low-temperature tank flows through the solar collector or receiver, where solar energy heats it to a high temperature, and it then flows to the high-temperature tank for storage. Fluid from the high-temperature tank flows through a heat exchanger, where it generates steam for electricity production. The fluid exits the heat exchanger at a low temperature and returns to the low-temperature tank.

Two-tank direct storage was used in early parabolic trough power plants (such as Solar Electric Generating Station I) and at the Solar Two power tower in California. The trough plants used mineral oil as the heat-transfer and storage fluid; Solar Two used molten salt.

Figure 16: Thermal Storage System

Two-tank indirect system:

Two-tank indirect systems function in the same way as two-tank direct systems, except different fluids are used as the heat-transfer and storage fluids. This system is used in plants in which the heat-transfer fluid is too expensive or not suited for use as the storage fluid.

The storage fluid from the low-temperature tank flows through an extra heat exchanger, where it is heated by the high-temperature heat-transfer fluid. The high-temperature storage fluid then flows back to the high-temperature storage tank. The fluid exits this heat exchanger at a low temperature and returns to the solar collector or receiver, where it is heated back to a high temperature. Storage fluid from the high-temperature tank is used to generate steam in the same manner as the two-tank direct system. The indirect system requires an extra heat exchanger, which adds cost to the system.

This system will be used in many of the parabolic power plants in Spain and has also been proposed for several U.S. parabolic plants. The plants will use organic oil as the heat-transfer fluid and molten salt as the storage fluid.

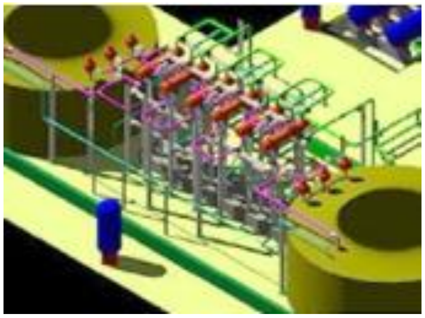

Figure 17: CSP system

Single-Tank Thermocline System:

Single-tank thermocline systems store thermal energy in a solid medium—most commonly, silica sand—located in a single tank. At any time during operation, a portion of the medium is at high temperature, and a portion is at low temperature. The hot- and cold-temperature regions are separated by a temperature gradient or thermocline. High-temperature heat-transfer fluid flows into the top of the thermocline and exits the bottom at low temperature. This process moves the thermocline downward and adds thermal energy to the system for storage. Reversing the flow moves the thermocline upward and removes thermal energy from the system to generate steam and electricity. Buoyancy effects create thermal stratification of the fluid within the tank, which helps to stabilize and maintain the thermocline. Using a solid storage medium and only needing one tank reduces the cost of this system relative to two-tank systems. This system was demonstrated at the Solar One power tower, where steam was used as the heat-transfer fluid and mineral oil was used as the storage fluid.

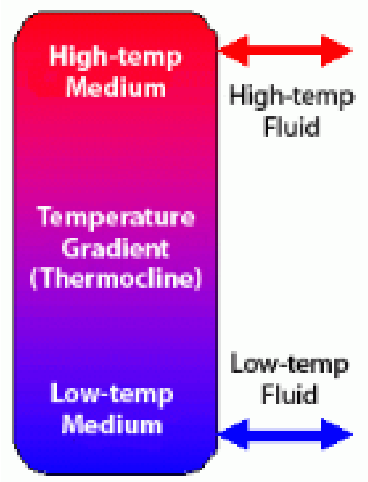

Figure 18: Single-tank thermocline system illustration

Power Tower System

In power tower concentrating solar power systems, a large number of flat, sun-tracking mirrors, known as heliostats, focus sunlight onto a receiver at the top of a tall tower. A heat-transfer fluid heated in the receiver is used to heat a working fluid, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with high temperature molten salts or sand-like particles to maximize the power cycle temperature.

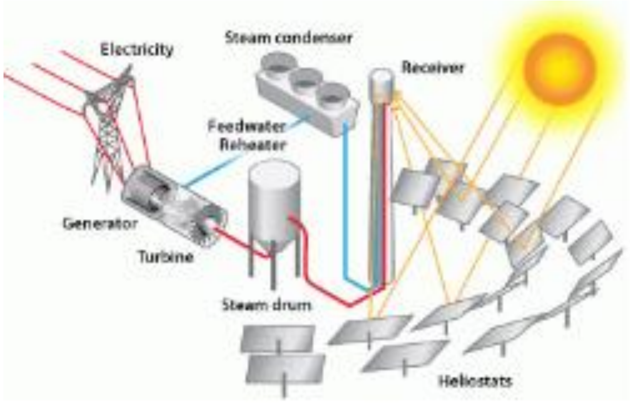

Figure 19: Power Tower System

The Ivanpah Solar Electric Generating System is the largest concentrated solar thermal plant in the U.S. Located in California's Mojave Desert, the plant is capable of producing 392 megawatts of electricity using 173,500 heliostats, each with two mirrors that focus sunlight onto three solar power towers. Aside from the U.S., Spain has several power tower systems. Planta Solar 10 and Planta Solar 20 are water/steam systems with capacities of 11 and 20 megawatts, respectively. Gemasolar, previously known as Solar Tres, produces nearly 20 megawatts of electricity and utilizes molten-salt thermal storage.

Linear Concentrator System

Linear concentrating solar power (CSP) collectors capture the sun's energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube. The receiver contains a fluid that is heated by the sunlight and then used to heat a traditional power cycle that spins a turbine that drives a generator to produce electricity. Alternatively, steam can be generated directly in the solar field, which eliminates the need for costly heat exchangers. Linear concentrating collector fields consist of a large number of collectors in parallel rows that are typically aligned in a north-south orientation to maximize annual and summer energy collection. With a single-axis sun-tracking system, this configuration enables the mirrors to track the sun from east to west during the day, which ensures that the sun reflects continuously onto the receiver tubes.

Linear systems may incorporate thermal storage. In these systems, the collector field is oversized to heat a storage system during the day so the additional steam it generates can be used to produce electricity in the evening or during cloudy weather. These plants can also be designed as hybrids, meaning that they use fossil fuel to supplement the solar output during periods of low solar radiation. In such a design, a natural gas-fired heater or gas-steam boiler/reheater is used.

In the future, linear systems may be integrated with existing or new combined-cycle natural-gas- and coal-fired plants.

Parabolic Trough Systems:

The most common CSP system in the United States is a linear concentrator that uses parabolic trough collectors. In such a system, the receiver tube is positioned along the focal line of each parabola-shaped reflector. The tube is fixed to the mirror structure and the heat transfer fluid flows through and out of the field of solar mirrors to where it is used to create steam (or, in the case of a water/steam receiver, it is sent directly to the turbine).

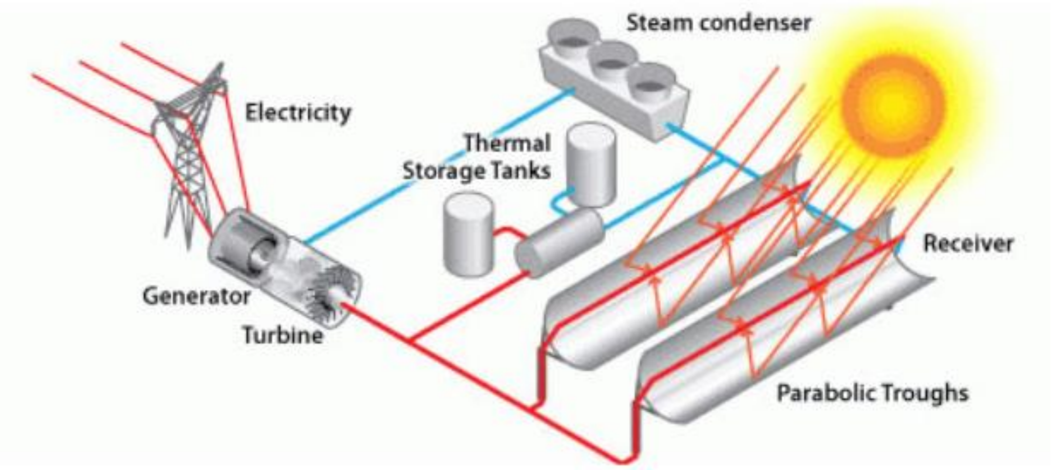

Figure 20: Parabolic through system

Linear Fresnel Reflector Systems:

A second linear concentrator technology is the linear Fresnel reflector system. Flat or slightly curved mirrors mounted on trackers on the ground are configured to reflect sunlight onto a receiver tube fixed in space above the mirrors. A small parabolic mirror is sometimes added atop the receiver to further focus the sunlight.

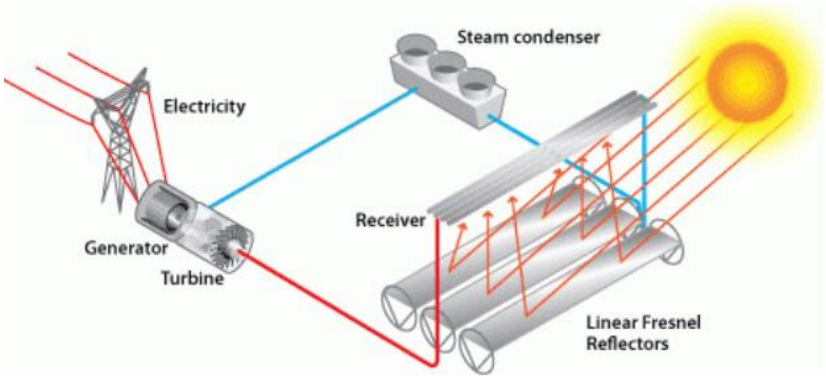

Figure 21: Linear Fresnel Reflector Systems

Solar Integration

Simply put, we need a reliable and secure energy grid. Two ways to ensure continuous electricity regardless of the weather or an unforeseen event are by using distributed energy resources (DER) and microgrids.

DER produce and supply electricity on a small scale and are spread out over a wide area. Rooftop solar panels, backup batteries, and emergency diesel generators are examples of DER. While traditional generators are connected to the high-voltage transmission grid, DER are connected to the lower-voltage distribution grid, like residences and businesses are.

Microgrids are localized electric grids that can disconnect from the main grid to operate autonomously. Because they can operate while the main grid is down, microgrids can strengthen grid resilience, help mitigate grid disturbances, and function as a grid resource for faster system response and recovery.

Distributed Energy Resources:

Solar DER can be built at different scales—even one small solar panel can provide energy. In fact, about one-third of solar energy in the United States is produced by small-scale solar, such as rooftop installations. Household solar installations are called behind-the-meter solar, the meter measures how much electricity a consumer buys from a utility. Since distributed solar is “behind” the meter, customers do not pay the utility for the solar power generated. The cost of owning DER varies from state to state and among utility companies.

One way the electric bill is determined is through net metering, where utilities calculate the total power generated by the customer’s solar system and subtract it from the total power the customer consumes. Customers are credited for the amount of power they supply to the grid.

DER could fundamentally change the way the electric grid works. With DER, power is generated right where it is used and can be connected with other DER to optimize its use. Households and other electricity consumers are also part-time producers, selling excess generation to the grid and to each other. Energy storage, such as batteries, can also be distributed, helping to ensure power when solar or other DER don't generate power. Electric cars can even store excess energy in the batteries of idle cars.

DER can also include controllable loads, like water heaters or air-conditioning units that the utility can use to shift power consumption away from peak hours. While the grid was designed to generate power at large facilities and move it through the transmission grid to the distribution grid for consumption, DER enable local generation and consumption of electricity.

Islands And Microgrids:

Distribution grids are vulnerable to outages that can affect large regions and millions of people and businesses, particularly as a consequence of extreme, destructive weather events. When parts of the grid are equipped with DER, they can continue serving other loads on the same distribution network, meeting local needs with local generation, this is called islanding. Electrical systems that can disconnect from the larger grid, engaging in intentional islanding, are often called microgrids.

Microgrids vary in size from a single-customer microgrid to a full-substation microgrid, which may include hundreds of individual generators and consumers of power. Small, off-the-grid electrical systems are not a recent invention. Ships, military bases, remote outposts, and communities around the world have long relied on local generation and electricity management to meet their energy needs. DER make microgrids a more widespread option, because the means of energy production are now more easily obtained and sited in neighborhoods. Community-scale microgrids may provide resiliency and backup during and after disasters like hurricanes.

Technology is advancing to manage the risks caused by islanding with better control software and to provide grid services. Without the larger grid to help stabilize the power supply, an islanded grid could damage connected equipment or injure workers who think it is disconnected from power. For this reason, many solar energy systems are programmed to detect islanding and disconnect from the grid if it occurs. Beyond microgrids, some researchers are studying nano-grids—smart electricity systems on the scale of a single building.

BLACK START:

Another way DER and microgrids can contribute to grid stability is by aiding "black start" processes, which turn power on after it has gone down. During a widespread electrical failure, electrical generators can be put offline. To come back online, many electrical generators require an external battery to start, just like a car engine does. To achieve this, utilities create black start plans, in which small generators start larger ones to steadily bring generation online. Throughout this process, service restoration must be well-timed, to ensure that generation and load are matched continuously.

DER could become a valuable black start resource by allowing communities with microgrids to begin start-up processes on their own and provide the capacity required to start up larger generators.

WIND ENERGY

What is Wind Energy

The technology used to harness the power of wind has advanced significantly over the past ten years, with the United States increasing its wind power capacity 30% year over year. Wind turbines collect and convert the kinetic energy that wind produces into electricity to help power the grid. Since wind is in plentiful supply, it's a sustainable resource for as long as the sun's rays heat the planet. Currently, there are utility-scale wind plants in 41 states that have created more than 100,000 jobs for Americans.

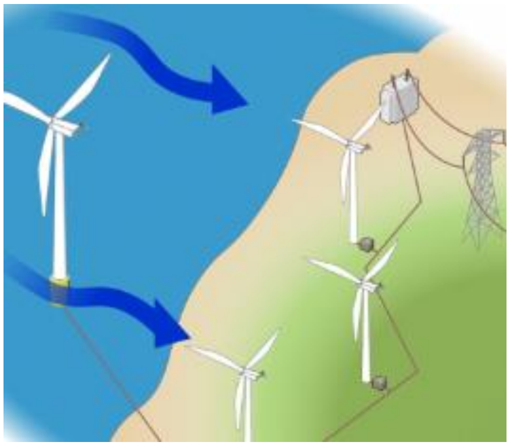

Figure 22: Wind farm illustration

How Do Wind Turbines Work

Wind turbines work on a simple principle: instead of using electricity to make wind—like a fan—wind turbines use wind to make electricity. Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity. Wind is a form of solar energy caused by a combination of three concurrent events:

- The sun unevenly heating the atmosphere
- Irregularities of the earth's surface
- The rotation of the earth.

Wind flow patterns and speeds vary greatly across the United States and are modified by bodies of water, vegetation, and differences in terrain. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity.

The terms "wind energy" and "wind power" both describe the process by which the wind is used to generate mechanical power or electricity. This mechanical power can be used for specific tasks (such as grinding grain or pumping water), or a generator can convert this mechanical power into electricity. A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade.

When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

Types of Wind Turbines

The majority of wind turbines fall into two basic types:

Horizontal-Axis Turbines:

Most commonly, they have three blades and operate "upwind," with the turbine pivoting at the top of the tower so the blades face into the wind.

Figure 23: Horizontal-Axis Turbine

Vertical-Axis Turbines:

These turbines are omnidirectional, meaning they don’t need to be adjusted to point into the wind to operate. They come in several varieties, including the eggbeater-style Darrieus model, named after its French inventor. Wind turbines can be built on land or offshore in large bodies of water like oceans and lakes. The U.S. Department of Energy is currently funding projects to facilitate offshore wind deployment in U.S. waters.

Figure 24: Vertical-Axis Turbine

Applications of Wind Turbines

Modern wind turbines can be categorized by where they are installed and how they are connected to the grid:

Land-based wind turbines: range in size from 100 kilowatts to as large as several megawatts. Larger wind turbines are more cost effective and are grouped together into wind plants, which provide bulk power to the electrical grid.

Figure 25: Land-based wind turbine

Offshore wind turbines: tend to be massive, and taller than the Statue of Liberty. They do not have the same transportation challenges of land-based wind installations, as the large components can be transported on ships instead of on roads. These turbines are able to capture powerful ocean winds and generate vast amounts of energy.

Figure 26: Offshore wind turbine

Distributed Wind:

When wind turbines of any size are installed on the "customer" side of the electric meter or are installed at or near the place where the energy they produce will be used, they're called "distributed wind.

Distributed Wind

Distributed wind systems use wind energy to produce clean, emissions-free power for homes, farms, schools, and businesses.

Figure 27: Distributed Wind system

Many turbines used in distributed applications are small wind turbines. Single small wind turbines—below 100 kilowatts—are typically used for residential, agricultural, and small commercial and industrial applications. Small turbines can be used in hybrid energy systems with other distributed energy resources, such as microgrids powered by diesel generators, batteries, and photovoltaics. These systems are called hybrid wind systems and are typically used in remote, off-grid locations (where a connection to the utility grid is not available) and are becoming more common in grid-connected applications for resiliency.\

Figure 28: Small turbine

Advantages of Wind Power

Wind energy offers many advantages, which explains why it's one of the fastest-growing energy sources in the world. To further expand wind energy's capabilities and community benefits, researchers are working to address technical and socio-economic challenges in support of a decarbonized electricity future. Most notably:

Wind power creates good-paying job:

There are over 125,000 people working in the U.S. wind industry across all 50 states, and that number continues to grow.

Wind power is a domestic resource that enables U.S. economic growth:

In 2022, wind turbines operating in all 50 states generated more than 10% of the net total of the country's energy. That same year, investments in new wind projects added $20 billion to the U.S. economy.

Wind power benefits local communities:

Wind projects deliver an estimated $2 billion in state and local tax payments and land-lease payments each year. Communities that develop wind energy can use the extra revenue to put towards school budgets, reduce the tax burden on homeowners, and address local infrastructure projects.

Wind power is a clean and renewable energy source:

Wind turbines harness energy from the wind using mechanical power to spin a generator and create electricity. Not only is wind an abundant and inexhaustible resource, but it also provides electricity without burning any fuel or polluting the air. Wind energy in the United States helps avoid 336 million metric tons of carbon dioxide emissions annually—equivalent to the emissions from 73 million cars.

Wind power is cost-effective:

Land-based, utility-scale wind turbines provide one of the lowest-priced energy sources available today. Furthermore, wind energy's cost competitiveness continues to improve with advances in the science and technology of wind energy.

Wind turbines work in different settings:

Wind energy generation fits well in agricultural and multi-use working landscapes. Wind energy is easily integrated in rural or remote areas, such as farms and ranches or coastal and island communities, where high-quality wind resources are often found.

Challenges of Wind Power

Wind power must compete with other low-cost energy sources: When comparing the cost of energy associated with new power plants, wind and solar projects are now more economically competitive than gas, geothermal, coal, or nuclear facilities. However, wind projects may not be cost-competitive in some locations that are not windy enough.

Ideal wind sites are often in remote locations: Installation challenges must be overcome to bring electricity from wind farms to urban areas, where it is needed to meet demand. Upgrading the nation's transmission network to connect areas with abundant wind resources to population centers could significantly reduce the costs of expanding land-based wind energy.

Turbines produce noise and alter visual aesthetics: Wind farms have different impacts on the environment compared to conventional power plants, but similar concerns exist over both the noise produced by the turbine blades and the visual impacts on the landscape.

Wind plants can impact local wildlife: Although wind projects rank lower than other energy developments in terms of wildlife impacts, research is still needed to minimize wind-wildlife interactions.