Encyclopedic Entry

solar energy

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Solar energy is any type of energy generated by the sun.

Solar energy is created by nuclear fusion that takes place in the sun. Fusion occurs when protons of hydrogen atoms violently collide in the sun's core and fuse to create a helium atom.

This process, known as a PP (proton-proton) chain reaction, emits an enormous amount of energy. In its core, the sun fuses about 620 million metric tons of hydrogen every second. The PP chain reaction occurs in other stars that are about the size of our sun, and provides them with continuous energy and heat. The temperature for these stars is around 4 million degrees on the Kelvin scale (about 4 million degrees Celsius, 7 million degrees Fahrenheit).

In stars that are about 1.3 times bigger than the sun, the CNO cycle drives the creation of energy. The CNO cycle also converts hydrogen to helium, but relies on carbon, nitrogen, and oxygen (C, N, and O) to do so. Currently, less than 2% of the sun's energy is created by the CNO cycle.

Nuclear fusion by the PP chain reaction or CNO cycle releases tremendous amounts of energy in the form of waves and particles. Solar energy is constantly flowing away from the sun and throughout the solar system. Solar energy warms the Earth, causes wind and weather, and sustains plant and animal life.

The energy, heat, and light from the sun flow away in the form of electromagnetic radiation (EMR).

The electromagnetic spectrum exists as waves of different frequencies and wavelengths. The frequency of a wave represents how many times the wave repeats itself in a certain unit of time. Waves with very short wavelengths repeat themselves several times in a given unit of time, so they are high-frequency. In contrast, low-frequency waves have much longer wavelengths.

The vast majority of electromagnetic waves are invisible to us. The most high-frequency waves emitted by the sun are gamma rays, X-rays, and ultraviolet radiation (UV rays). The most harmful UV rays are almost completely absorbed by Earth's atmosphere. Less potent UV rays travel through the atmosphere, and can cause sunburn.

The sun also emits infrared radiation, whose waves are much lower-frequency. Most heat from the sun arrives as infrared energy.

Sandwiched between infrared and UV is the visible spectrum, which contains all the colors we see on Earth. The color red has the longest wavelengths (closest to infrared), and violet (closest to UV) the shortest.

Natural Solar Energy

Greenhouse Effect
The infrared, visible, and UV waves that reach the Earth take part in a process of warming the planet and making life possible—the so-called "greenhouse effect."

About 30% of the solar energy that reaches Earth is reflected back into space. The rest is absorbed into Earth's atmosphere. The radiation warms the Earth's surface, and the surface radiates some of the energy back out in the form of infrared waves. As they rise through the atmosphere, they are intercepted by greenhouse gases, such as water vapor and carbon dioxide.

Greenhouse gases trap the heat that reflects back up into the atmosphere. In this way, they act like the glass walls of a greenhouse. This greenhouse effect keeps the Earth warm enough to sustain life.

Photosynthesis
Almost all life on Earth relies on solar energy for food, either directly or indirectly.

Producers rely directly on solar energy. They absorb sunlight and convert it into nutrients through a process called photosynthesis. Producers, also called autotrophs, include plants, algae, bacteria, and fungi. Autotrophs are the foundation of the food web.

Consumers rely on producers for nutrients. Herbivores, carnivores, omnivores, and detritivores rely on solar energy indirectly. Herbivores eat plants and other producers. Carnivores and omnivores eat both producers and herbivores. Detritivores decompose plant and animal matter by consuming it.

Fossil Fuels
Photosynthesis is also responsible for all of the fossil fuels on Earth. Scientists estimate that about 3 billion years ago, the first autotrophs evolved in aquatic settings. Sunlight allowed plant life to thrive and evolve. After the autotrophs died, they decomposed and shifted deeper into the Earth, sometimes thousands of meters. This process continued for millions of years.

Under intense pressure and high temperatures, these remains became what we know as fossil fuels. Microorganisms became petroleum, natural gas, and coal.

People have developed processes for extracting these fossil fuels and using them for energy. However, fossil fuels are a nonrenewable resource. They take millions of years to form.

Harnessing Solar Energy

Solar energy is a renewable resource, and many technologies can harvest it directly for use in homes, businesses, schools, and hospitals. Some solar energy technologies include photovoltaic cells and panels, concentrated solar energy, and solar architecture.

There are different ways of capturing solar radiation and converting it into usable energy. The methods use either active solar energy or passive solar energy.

Active solar technologies use electrical or mechanical devices to actively convert solar energy into another form of energy, most often heat or electricity. Passive solar technologies do not use any external devices. Instead, they take advantage of the local climate to heat structures during the winter, and reflect heat during the summer.

Photovoltaics

Photovoltaics is a form of active solar technology that was discovered in 1839 by 19-year-old French physicist

Alexandre-Edmond Becquerel. Becquerel discovered that when he placed silver-chloride in an acidic solution and exposed it to sunlight, the platinum electrodes attached to it generated an electric current. This process of generating electricity directly from solar radiation is called the photovoltaic effect, or photovoltaics.

Today, photovoltaics is probably the most familiar way to harness solar energy. Photovoltaic arrays usually involve solar panels, a collection of dozens or even hundreds of solar cells.

Each solar cell contains a semiconductor, usually made of silicon. When the semiconductor absorbs sunlight, it knocks electrons loose. An electrical field directs these loose electrons into an electric current, flowing in one direction. Metal contacts at the top and bottom of a solar cell direct that current to an external object. The external object can be as small as a solar-powered calculator or as large as a power station.

Photovoltaics was first widely used on spacecraft. Many satellites, including the International Space Station, feature wide, reflective “wings” of solar panels. The ISS has two solar array wings (SAWs), each using about 33,000 solar cells. These photovoltaic cells supply all electricity to the ISS, allowing astronauts to operate the station, safely live in space for months at a time, and conduct scientific and engineering experiments.

Photovoltaic power stations have been built all over the world. The largest stations are in the United States, India, and China. These power stations emit hundreds of megawatts of electricity, used to supply homes, businesses, schools, and hospitals.

Photovoltaic technology can also be installed on a smaller scale. Solar panels and cells can be fixed to the roofs or exterior walls of buildings, supplying electricity for the structure. They can be placed along roads to light highways. Solar cells are small enough to power even smaller devices, such as calculators, parking meters, trash compactors, and water pumps.

Concentrated Solar Energy

Another type of active solar technology is concentrated solar energy or concentrated solar power (CSP). CSP technology uses lenses and mirrors to focus (concentrate) sunlight from a large area into a much smaller area. This intense area of radiation heats a fluid, which in turn generates electricity or fuels another process.

Solar furnaces are an example of concentrated solar power. There are many different types of solar furnaces, including solar power towers, parabolic troughs, and Fresnel reflectors. They use the same general method to capture and convert energy.

Solar power towers use heliostats, flat mirrors that turn to follow the sun’s arc through the sky. The mirrors are arranged around a central “collector tower,” and reflect sunlight into a concentrated ray of light that shines on a focal point on the tower.

In previous designs of solar power towers, the concentrated sunlight heated a container of water, which produced steam that powered a turbine. More recently, some solar power towers use liquid sodium, which has a higher heat capacity and retains heat for a longer period of time. This means that the fluid not only reaches temperatures of 773 to 1,273 K (500 to 1,000° C or 932 to 1,832° F), but it can continue to boil water and generate power even when the sun is not shining.

Parabolic troughs and Fresnel reflectors also use CSP, but their mirrors are shaped differently. Parabolic mirrors are curved, with a shape similar to a saddle. Fresnel reflectors use flat, thin strips of mirror to capture sunlight and direct it onto a tube of liquid. Fresnel reflectors have more surface area than parabolic troughs and can concentrate the sun’s energy to about 30 times its normal intensity.

Concentrated solar power plants were first developed in the 1980s. The largest facility in the world is a series of plants in California's Mojave Desert. This Solar Energy Generating System (SEGS) generates more than 650 gigawatt-hours of electricity every year. Other large and effective plants have been developed in Spain and India.

Concentrated solar power can also be used on a smaller scale. It can generate heat for solar cookers, for instance. People in villages all over the world use solar cookers to boil water for sanitation and to cook food.

Solar cookers provide many advantages over wood-burning stoves: They are not a fire hazard, do not produce smoke, do not require fuel, and reduce habitat loss in forests where trees would be harvested for fuel. Solar cookers also allow villagers to pursue time for education, business, health, or family during time that was previously used for gathering firewood. Solar cookers are used in areas as diverse as Chad, Israel, India, and Peru.

Solar Architecture

Throughout the course of a day, solar energy is part of the process of thermal convection, or the movement of heat from a warmer space to a cooler one. When the sun rises, it begins to warm objects and material on Earth. Throughout the day, these materials absorb heat from solar radiation. At night, when the sun sets and the atmosphere has cooled, the materials release their heat back into the atmosphere.

Passive solar energy techniques take advantage of this natural heating and cooling process.

Homes and other buildings use passive solar energy to distribute heat efficiently and inexpensively. Calculating a building's "thermal mass" is an example of this. A building's thermal mass is the bulk of material heated throughout the day. Examples of a building's thermal mass are wood, metal, concrete, clay, stone, or mud. At night, the thermal mass releases its heat back into the room. Effective ventilation systems—hallways, windows, and air ducts—distribute the warmed air and maintain a moderate, consistent indoor temperature.

Passive solar technology is often involved in the design of a building. For example, in the planning stage of construction, the engineer or architect may align the building with the sun's daily path to receive desirable amounts of sunlight. This method takes into account the latitude, altitude, and typical cloud cover of a specific area. In addition, buildings can be constructed or retrofitted to have thermal insulation, thermal mass, or extra shading.

Other examples of passive solar architecture are cool roofs, radiant barriers, and green roofs. Cool roofs are painted white, and reflect the sun's radiation instead of absorbing it. The white surface reduces the amount of heat that reaches the interior of the building, which in turn reduces the amount of energy that is needed to cool the building.

Radiant barriers work similarly to cool roofs. They provide insulation with highly reflective materials, such as aluminum foil. The foil reflects, instead of absorbs, heat, and can reduce cooling costs up to 10%. In addition to roofs and attics, radiant barriers may also be installed beneath floors.

Green roofs are roofs that are completely covered with vegetation. They require soil and irrigation to support the plants, and a waterproof layer beneath. Green roofs not only reduce the amount of heat that is absorbed or lost, but also provide vegetation. Through photosynthesis, the plants on green roofs absorb carbon dioxide and emit oxygen. They filter pollutants out of rainwater and air, and offset some of the effects of energy use in that space.

Green roofs have been a tradition in Scandinavia for centuries, and have recently become popular in Australia, Western Europe, Canada, and the United States. For example, the Ford Motor Company covered 42,000 square meters (450,000 square feet) of its assembly plant roofs in Dearborn, Michigan, with vegetation. In addition to reducing greenhouse gas emissions, the roofs reduce stormwater runoff by absorbing several centimeters of rainfall.

Green roofs and cool roofs can also counteract the "urban heat island" effect. In busy cities, the temperature can be consistently higher than the surrounding areas. Many factors contribute to this: Cities are constructed of materials such as asphalt and concrete that absorb heat; tall buildings block wind and its cooling effects; and high amounts of waste heat is generated by industry, traffic, and high populations. Using the available space on the roof to plant trees, or reflecting heat with white roofs, can partially alleviate local temperature increases in urban areas.

Solar Energy and People

Since sunlight only shines for about half of the day in most parts of the world, solar energy technologies have to include methods of storing the energy during dark hours.

Thermal mass systems use paraffin wax or various forms of salt to store the energy in the form of heat. Photovoltaic systems can send excess electricity to the local power grid, or store the energy in rechargeable batteries.

There are many pros and cons to using solar energy.

Advantages
A major advantage to using solar energy is that it is a renewable resource. We will have a steady, limitless supply of sunlight for another 5 billion years. In one hour, the Earth's atmosphere receives enough sunlight to power the electricity needs of every human being on Earth for a year.

Solar energy is clean. After the solar technology equipment is constructed and put in place, solar energy does not need fuel to work. It also does not emit greenhouse gases or toxic materials. Using solar energy can drastically reduce the impact we have on the environment.

There are locations where solar energy is practical. Homes and buildings in areas with high amounts of sunlight and low cloud cover have the opportunity to harness the sun's abundant energy.

Solar cookers provide an excellent alternative to cooking with wood-fired stoves—on which 2 billion people still rely. Solar cookers provide a cleaner and safer way to sanitize water and cook food.

Solar energy complements other renewable sources of energy, such as wind or hydroelectric energy.

Homes or businesses that install successful solar panels can actually produce excess electricity. These homeowners or businessowners can sell energy back to the electric provider, reducing or even eliminating power bills.

Disadvantages
The main deterrent to using solar energy is the required equipment. Solar technology equipment is expensive. Purchasing and installing the equipment can cost tens of thousands of dollars for individual homes. Although the government often offers reduced taxes to people and businesses using solar energy, and the technology can eliminate electricity bills, the initial cost is too steep for many to consider.

Solar energy equipment is also heavy. In order to retrofit or install solar panels on the roof of a building, the roof must be strong, large, and oriented toward the sun's path.

Both active and passive solar technology depend on factors that are out of our control, such as climate and cloud cover. Local areas must be studied to determine whether or not solar power would be effective in that area.

Sunlight must be abundant and consistent for solar energy to be an efficient choice. In most places on Earth, sunlight's variability makes it difficult to implement as the only source of energy.

VOCABULARY

Term	Part of Speech	Definition
active solar energy	*noun*	energy from the sun that is increased by the use of electricity or other mechanical equipment.
altitude	*noun*	the distance above sea level.
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.
autotroph	*noun*	organism that can produce its own food and nutrients from chemicals in the atmosphere, usually through photosynthesis or chemosynthesis.
climate	*noun*	all weather conditions for a given location over a period of time.
cloud cover	*noun*	amount of sky covered with clouds.
concentrated solar energy	*noun*	process of using mirrors to focus a large area of sunlight into a smaller area.
consumer	*noun*	organism on the food chain that depends on autotrophs (producers) or other consumers for food, nutrition, and energy.
convection	*noun*	transfer of heat by the movement of the heated parts of a liquid or gas.
current	*noun*	steady, predictable flow of fluid within a larger body of that fluid.
electrode	*noun*	conductor through which an electric current enters or leaves a substance (or a vacuum) whose electrical characteristics are being measured.
electromagnetic spectrum	*noun*	continous band of all kinds of radiation (heat and light).
food web	*noun*	all related food chains in an ecosystem. Also called a food cycle.
fossil fuel	*noun*	coal, oil, or natural gas. Fossil fuels formed from the remains of ancient plants and animals.
frequency	*noun*	number of waves made in a specific area over specific time period.
greenhouse effect	*noun*	phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.
greenhouse gas	*noun*	gas in the atmosphere, such as carbon dioxide, methane, water vapor, and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.
green roof	*noun*	top of a residential or industrial building that is wholly or partially covered in vegetation.
heliostat	*noun*	instrument consisting of a large mirror moving (usually by clockwork) with the arc of the sun and reflecting light in a specific direction.
hydroelectric energy	*noun*	energy generated by moving water converted to electricity. Also known as hydroelectricity.
infrared radiation	*noun*	part of the electromagnetic spectrum with wavelengths longer than visible light but shorter than microwaves.
International Space Station (ISS)	*noun*	satellite in low-Earth orbit that houses several astronauts for months at a time.

Kelvin scale	*noun*	scale for measuring temperature where zero Kelvin is absolute zero, the absence of all energy.
latitude	*noun*	distance north or south of the Equator, measured in degrees.
nonrenewable resource	*noun*	natural resource that exists in a limited supply.
nuclear fusion	*noun*	process where the nuclei of one element, usually hydrogen, fuse with each other to form the nuclei of another element, usually helium.
nutrient	*noun*	substance an organism needs for energy, growth, and life.
passive solar energy	*noun*	power from the sun that requires no other energy or mechanical system.
photosynthesis	*noun*	process by which plants turn water, sunlight, and carbon dioxide into water, oxygen, and simple sugars.
photovoltaic	*adjective*	able to convert solar radiation to electrical energy.
pollutant	*noun*	chemical or other substance that harms a natural resource.
potent	*adjective*	very powerful.
power grid	*noun*	network of cables or other devices through which electricity is delivered to consumers. Also called an electrical grid.
practical	*adjective*	useful or easy to use.
radiant barrier	*noun*	reflective area that prevents heat transfer.
renewable resource	*noun*	resource that can replenish itself at a similar rate to its use by people.
sanitation	*noun*	promotion of hygiene, health, and cleanliness.
satellite	*noun*	object that orbits around something else. Satellites can be natural, like moons, or made by people.
semiconductor	*noun*	material that conducts electricity, but more slowly than a true conductor.
solar architecture	*noun*	the planning and design of buildings to make the most use of the sun's heat and light.
solar cooker	*noun*	oven that uses sunlight to heat food.
solar energy	*noun*	radiation from the sun.
solar furnace	*noun*	structure that uses concentrated solar energy to produce very high temperatures.
solar panel	*noun*	group of cells that converts sunlight into electricity.
solar power tower	*noun*	solar furnace that uses a central tower to receive focused sunlight from surrounding mirrors.
solar system	*noun*	the sun and the planets, asteroids, comets, and other bodies that orbit around it.
star	*noun*	large ball of gas and plasma that radiates energy through nuclear fusion, such as the sun.
sun	*noun*	star at the center of our solar system.

tax	*noun*	money or goods citizens provide to government in return for public services such as military protection.
thermal mass	*noun*	the ability of a substance or structure to store heat.
toxic	*adjective*	poisonous.
turbine	*noun*	machine that captures the energy of a moving fluid, such as air or water.
ultraviolet radiation	*noun*	powerful light waves that are too short for humans to see, but can penetrate Earth's atmosphere. Ultraviolet is often shortened to UV.
urban heat island	*noun*	city area that is always warmer than the surrounding area.
vegetation	*noun*	all the plant life of a specific place.
ventilation	*noun*	movement or circulation of fresh air in a closed environment. Also called air circulation.
weather	*noun*	state of the atmosphere, including temperature, atmospheric pressure, wind, humidity, precipitation, and cloudiness.
wind	*noun*	movement of air (from a high pressure zone to a low pressure zone) caused by the uneven heating of the Earth by the sun.

For Further Exploration

Articles & Profiles

- The Green Guide: Solar Panels

Audio & Video

- National Geographic Video: Solar-Powered Water Heaters

Websites

- California Energy Commission: Energy Quest—Solar Energy
- U.S. Department of Energy: Solar
- National Geographic Environment: Solar Energy

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