Solar energy

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Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar heating, solar photovoltaics, solar thermal electricity and solar architecture, which can make considerable contributions to solving some of the most urgent problems the world now faces.[1]

Nellis Solar Power Plant in the United States, one of the largest photovoltaic power plants in North America.

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared".[1]

Renewable energy

Biofuel
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Hydroelectricity
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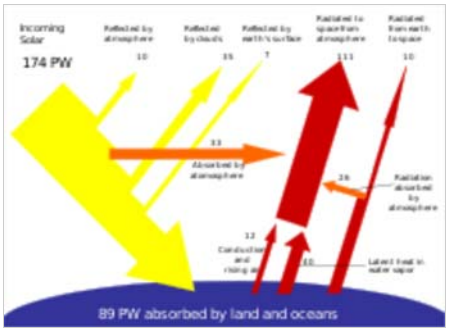
Energy from the Sun

Main articles: Insolation and Solar radiation



About half the incoming solar energy reaches the Earth's surface.

The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere.[2] Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet.[3]

Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones.[4] Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C.[5] By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.[6]

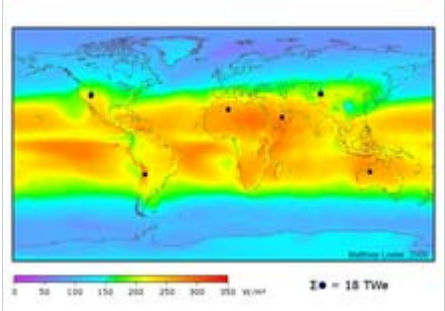
The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year.[7] In 2002, this was more energy in one hour than the world used in one year.[12][13] Photosynthesis captures approximately 3,000 EJ per year in biomass.[9] The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined.[14]

Yearly Solar fluxes & Human Energy Consumption	
Solar	3,850,000 EJ[7]
Wind	2,250 EJ[8]
Biomass	3,000 EJ[9]
Primary energy use (2005)	487 EJ[10]
Electricity (2005)	56.7 EJ[11]

Solar energy can be harnessed in different levels around the world. Depending on a geographical location the closer to the equator the more "potential" solar energy is available.[15]

Applications of solar technology

Solar energy refers primarily to the use of solar radiation for practical ends. However, all renewable energies, other than geothermal and tidal, derive their energy from the sun.



Average insolation showing land area (small black dots) required to replace the world primary energy supply with solar electricity. 18 TW is 568 Exajoule (EJ) per year. Insolation for most people is from 150 to 300 W/m^2 or 3.5 to 7.0 kWh/m^2/day.

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.[16]

Architecture and urban planning

Main articles: Passive solar building design and Urban heat island

Darmstadt University of Technology in Germany won the 2007 Solar Decathlon in Washington, D.C. with this passive house designed specifically for the humid and hot subtropical climate.[17]

Sunlight has influenced building design since the beginning of architectural history.[18] Advanced solar architecture and urban planning methods were first employed by the Greeks and Chinese, who oriented their buildings toward the south to provide light and warmth.[19]

The common features of passive solar architecture are orientation relative to the Sun, compact proportion (a low surface area to volume ratio), selective shading (overhangs) and thermal mass.[18] When these features are tailored to the local climate and environment they can produce well-lit spaces that stay in a comfortable temperature range. Socrates' Megaron House is a classic example of passive solar design.[18] The most recent approaches to solar design use computer modeling tying together solar lighting, heating and ventilation systems in an integrated solar design package.[20] Active solar equipment such as pumps, fans and switchable windows can complement passive design and improve system performance.

Urban heat islands (UHI) are metropolitan areas with higher temperatures than that of the surrounding environment. The higher temperatures are a result of increased absorption of the Solar light by urban materials such as asphalt and concrete, which have lower albedos and higher heat capacities than those in the natural environment. A straightforward method of counteracting the UHI effect is to paint buildings and roads white and plant trees. Using these methods, a hypothetical "cool communities" program in Los Angeles has projected that urban temperatures could be reduced by approximately 3 °C at an estimated cost of US$1 billion, giving estimated total annual benefits of US$530 million from reduced air-conditioning costs and healthcare savings.[21]

Agriculture and horticulture

Agriculture and horticulture seek to optimize the capture of solar energy in order to optimize the productivity of plants. Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows and

the mixing of plant varieties can improve crop yields.[22][23] While sunlight is generally considered a plentiful resource, the exceptions highlight the importance of solar energy to agriculture. During the short growing seasons of the Little Ice Age, French and English farmers employed fruit walls to maximize the collection of solar energy. These walls acted as thermal masses and accelerated ripening by keeping plants warm. Early fruit walls were built perpendicular to the ground and facing south, but over time, sloping walls were developed to make better use of sunlight. In 1699, Nicolas Fatio de Duillier even suggested using a tracking mechanism which could pivot to follow the Sun.[24] Applications of solar energy in agriculture aside from growing crops include pumping water, drying crops, brooding chicks and drying chicken manure.[25][26] More recently the technology has been embraced by vinters, who use the energy generated by solar panels to power grape presses.[27]

Greenhouses like these in the Westland municipality of the Netherlands grow vegetables, fruits and flowers.

Greenhouses convert solar light to heat, enabling year-round production and the growth (in enclosed environments) of specialty crops and other plants not naturally suited to the local climate. Primitive greenhouses were first used during Roman times to produce cucumbers year-round for the Roman emperor Tiberius.[28] The first modern greenhouses were built in Europe in the 16th century to keep exotic plants brought back from explorations abroad.[29] Greenhouses remain an important part of horticulture today, and plastic transparent materials have also been used to similar effect in polytunnels and row covers.

Solar lighting

The history of lighting is dominated by the use of natural light. The Romans recognized a right to light as early as the 6th century and English law echoed these judgments with the Prescription Act of 1832.[30][31] In the 20th century artificial lighting became the main source of interior illumination but daylighting techniques and hybrid solar lighting solutions are ways to reduce energy consumption.

Daylighting features such as this oculus at the top of the Pantheon, in Rome, Italy have been in use since antiquity.

Daylighting systems collect and distribute sunlight to provide interior illumination. This passive technology directly offsets energy use by replacing artificial lighting, and indirectly offsets non-solar energy use by reducing the need for air-conditioning.[32] Although difficult to quantify, the use of natural lighting also offers physiological and psychological benefits compared to artificial lighting.[32] Daylighting design implies careful selection of window types, sizes and orientation; exterior shading devices may be considered as well. Individual features include sawtooth roofs, clerestory windows, light shelves, skylights and light tubes. They may be incorporated into existing structures, but are most effective when integrated into a solar design package that accounts for factors such as glare, heat flux and time-of-use. When daylighting features are properly implemented they can reduce lighting-related energy requirements by 25%.[33]

Hybrid solar lighting is an active solar method of providing interior illumination. HSL systems collect sunlight using focusing mirrors that track the Sun and use optical fibers to transmit it inside the building to supplement conventional lighting. In single-story applications these systems are able to transmit 50% of the direct sunlight received.[34]

Solar lights that charge during the day and light up at dusk are a common sight along walkways.[35] Solar-charged lanterns have become popular in developing countries where they provide a safer and cheaper alternative to kerosene lamps.[36]

Although daylight saving time is promoted as a way to use sunlight to save energy, recent research has been limited and reports contradictory results: several studies report savings, but just as many suggest no effect or even a net loss, particularly when gasoline consumption is taken into account. Electricity use is greatly affected by geography, climate and economics, making it hard to generalize from single studies.[37]

Solar thermal

Main article: Solar thermal energy

Solar thermal technologies can be used for water heating, space heating, space cooling and process heat generation.[38]

Water heating

Main articles: Solar hot water and Solar combisystem

Solar hot water systems use sunlight to heat water. In low geographical latitudes (below 40 degrees) from 60 to 70% of the domestic hot water use with temperatures up to 60 °C can be provided by solar heating systems.[39] The most common types of solar water heaters are evacuated tube collectors (44%) and glazed flat plate collectors (34%) generally used for domestic hot water; and unglazed plastic collectors (21%) used mainly to heat swimming pools.[40]

Solar water heaters facing the Sun to maximize gain.

As of 2007, the total installed capacity of solar hot water systems is approximately 154 GW.[41] China is the world leader in their deployment with 70 GW installed as of 2006 and a long term goal of 210 GW by 2020.[42] Israel and Cyprus are the per capita leaders in the use of solar hot water systems with over 90% of homes using them.[43] In the United States, Canada and Australia heating swimming pools is the dominant application of solar hot water with an installed capacity of 18 GW as of 2005.[16]

Heating, cooling and ventilation

Main articles: Solar heating, Thermal mass, Solar chimney, and Solar air conditioning

In the United States, heating, ventilation and air conditioning (HVAC) systems account for 30% (4.65 EJ) of the energy used in commercial buildings and nearly 50% (10.1 EJ) of the energy used in residential buildings.[33][44] Solar heating, cooling and ventilation technologies can be used to offset a portion of this energy.

Thermal mass is any material that can be used to store heat—heat from the Sun in the case of solar energy. Common thermal mass materials include stone, cement and water. Historically they have been used in arid climates or warm temperate regions to keep buildings cool by absorbing solar energy during the day and

radiating stored heat to the cooler atmosphere at night. However they can be used in cold temperate areas to maintain warmth as well. The size and placement of thermal mass depend on several factors such as climate, daylighting and shading conditions. When properly incorporated, thermal mass maintains space temperatures in a comfortable range and reduces the need for auxiliary heating and cooling equipment.[45]

Solar House #1 of Massachusetts Institute of Technology in the United States, built in 1939, used seasonal thermal storage for year-round heating.

A solar chimney (or thermal chimney, in this context) is a passive solar ventilation system composed of a vertical shaft connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. Performance can be improved by using glazing and thermal mass materials[46] in a way that mimics greenhouses.

Deciduous trees and plants have been promoted as a means of controlling solar heating and cooling. When planted on the southern side of a building, their leaves provide shade during the summer, while the bare limbs allow light to pass during the winter.[47] Since bare, leafless trees shade 1/3 to 1/2 of incident solar radiation, there is a balance between the benefits of summer shading and the corresponding loss of winter heating.[48] In climates with significant heating loads, deciduous trees should not be planted on the southern side of a building because they will interfere with winter solar availability. They can, however, be used on the east and west sides to provide a degree of summer shading without appreciably affecting winter solar gain.[49]

Water treatment

Main articles: Solar still, Solar water disinfection, Solar desalination, and Solar Powered Desalination Unit

Solar distillation can be used to make saline or brackish water potable. The first recorded instance of this was by 16th century Arab alchemists.[50] A large-scale solar distillation project was first constructed in 1872 in the Chilean mining town of Las Salinas.[51] The plant, which had solar collection area of 4,700 m^2, could produce up to 22,700 L per day and operated for 40 years.[51] Individual still designs include single-slope, double-slope (or greenhouse type), vertical, conical, inverted absorber, multi-wick, and multiple effect.[50] These stills can operate in passive, active, or hybrid modes. Double-slope stills are the most economical for decentralized domestic purposes, while active multiple effect units are more suitable for large-scale applications.[50]

Solar water disinfection in Indonesia

Solar water disinfection (SODIS) involves exposing water-filled plastic polyethylene terephthalate (PET) bottles to sunlight for several hours.[52] Exposure times vary depending on weather and climate from a minimum of six hours to two days during fully overcast conditions.[53] It is recommended by the World Health Organization as a viable method for household water treatment and safe storage.[54] Over two million people in developing countries use this method for their daily drinking water.[53]

Small scale solar powered sewerage

Solar energy may be used in a water stabilisation pond to treat waste water without chemicals or electricity. A further environmental advantage is that algae grow in such ponds and consume carbon dioxide in photosynthesis, although algae may produce toxic chemicals that make the water unusable.[55][56]

treatment plant.

Cooking

Main article: Solar cooker

Solar cookers use sunlight for cooking, drying and pasteurization. They can be grouped into three broad categories: box cookers, panel cookers and reflector cookers.[57] The simplest solar cooker is the box cooker first built by Horace de Saussure in 1767.[58] A basic box cooker consists of an insulated container with a transparent lid. It can be used effectively with partially overcast skies and will typically reach temperatures of 90–150 °C.[59] Panel cookers use a reflective panel to direct sunlight onto an insulated container and reach temperatures comparable to box cookers. Reflector cookers use various concentrating geometries (dish, trough, Fresnel mirrors) to focus light on a cooking container. These cookers reach temperatures of 315 °C and above but require direct light to function properly and must be repositioned to track the Sun.[60]

The Solar Bowl in Auroville, India, concentrates sunlight on a movable receiver to produce steam for cooking.

The solar bowl is a concentrating technology employed by the Solar Kitchen in Auroville, Pondicherry, India, where a stationary spherical reflector focuses light along a line perpendicular to the sphere's interior surface, and a computer control system moves the receiver to intersect this line. Steam is produced in the receiver at temperatures reaching 150 °C and then used for process heat in the kitchen.[61]

A reflector developed by Wolfgang Scheffler in 1986 is used in many solar kitchens. Scheffler reflectors are flexible parabolic dishes that combine aspects of trough and power tower concentrators. Polar tracking is used to follow the Sun's daily course and the curvature of the reflector is adjusted for seasonal variations in the incident angle of sunlight. These reflectors can reach temperatures of 450–650 °C and have a fixed focal point, which simplifies cooking.[62] The world's largest Scheffler reflector system in Abu Road, Rajasthan, India is capable of cooking up to 35,000 meals a day.[63] As of 2008, over 2,000 large Scheffler cookers had been built worldwide.[64]

Process heat

Main articles: Solar pond, Salt evaporation pond, and Solar furnace

Solar concentrating technologies such as parabolic dish, trough and Scheffler reflectors can provide process heat for commercial and industrial applications. The first commercial system was the Solar Total Energy Project (STEP) in Shenandoah, Georgia, USA where a field of 114 parabolic dishes provided 50% of the process heating, air conditioning and electrical requirements for a clothing factory. This grid-connected cogeneration system provided 400 kW of electricity plus thermal energy in the form of 401 kW steam and 468 kW chilled water, and had a one hour peak load thermal storage.[65]

Evaporation ponds are shallow pools that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from sea water is one of the oldest applications of solar energy. Modern uses

include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams.[66]

Clothes lines, clotheshorses, and clothes racks dry clothes through evaporation by wind and sunlight without consuming electricity or gas. In some states of the United States legislation protects the "right to dry" clothes.[67]

Unglazed transpired collectors (UTC) are perforated sun-facing walls used for preheating ventilation air. UTCs can raise the incoming air temperature up to 22 °C and deliver outlet temperatures of 45–60 °C.[68] The short payback period of transpired collectors (3 to 12 years) makes them a more cost-effective alternative than glazed collection systems.[68] As of 2003, over 80 systems with a combined collector area of 35,000 m^2 had been installed worldwide, including an 860 m^2 collector in Costa Rica used for drying coffee beans and a 1,300 m^2 collector in Coimbatore, India used for drying marigolds.[26]

Solar power

Main article: Solar power

Solar power is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect.

The PS10 concentrates sunlight from a field of heliostats on a central tower.

Commercial CSP plants were first developed in the 1980s, and the 354 MW SEGS CSP installation is the largest solar power plant in the world and is located in the Mojave Desert of California. Other large CSP plants include the Solnova Solar Power Station (150 MW) and the Andasol solar power station (100 MW), both in Spain. The 97 MW Sarnia Photovoltaic Power Plant in Canada, is the world's largest photovoltaic plant.

Concentrated solar power

See also: Concentrated solar power

Concentrating Solar Power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists; the most developed are the parabolic trough, the concentrating linear fresnel reflector, the Stirling dish and the solar power tower. Various techniques are used to track the Sun and focus light. In all of these systems a working fluid is heated by the concentrated sunlight, and is then used for power generation or energy storage.[69]

Photovoltaics

Main article: Photovoltaics

A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photoelectric effect. The first solar cell was constructed by Charles Fritts in the 1880s.[70] In 1931 a German engineer, Dr Bruno Lange, developed a photo cell using silver selenide in place of copper oxide.[71] Although the prototype selenium cells converted less than 1% of incident light into electricity, both Ernst Werner von Siemens and

James Clerk Maxwell recognized the importance of this discovery.[72] Following the work of Russell Ohl in the 1940s, researchers Gerald Pearson, Calvin Fuller and Daryl Chapin created the silicon solar cell in 1954.[73] These early solar cells cost 286 USD/watt and reached efficiencies of 4.5–6%.[74]

80 MW Ohotnikovo Solar Park in Ukraine.

Solar chemical

Main article: Solar chemical

Solar chemical processes use solar energy to drive chemical reactions. These processes offset energy that would otherwise come from a fossil fuel source and can also convert solar energy into storable and transportable fuels. Solar induced chemical reactions can be divided into thermochemical or photochemical.[75] A variety of fuels can be produced by artificial photosynthesis.[76] The multielectron catalytic chemistry involved in making carbon-based fuels (such as methanol) from reduction of carbon dioxide is challenging; a feasible alternative is hydrogen production from protons, though use of water as the source of electrons (as plants do) requires mastering the multielectron oxidation of two water molecules to molecular oxygen.[77] Some have envisaged working solar fuel plants in coastal metropolitan areas by 2050- the splitting of sea water providing hydrogen to be run through adjacent fuel-cell electric power plants and the pure water by-product going directly into the municipal water system.[78]

Hydrogen production technologies been a significant area of solar chemical research since the 1970s. Aside from electrolysis driven by photovoltaic or photochemical cells, several thermochemical processes have also been explored. One such route uses concentrators to split water into oxygen and hydrogen at high temperatures (2300-2600 °C).[79] Another approach uses the heat from solar concentrators to drive the steam reformation of natural gas thereby increasing the overall hydrogen yield compared to conventional reforming methods.[80] Thermochemical cycles characterized by the decomposition and regeneration of reactants present another avenue for hydrogen production. The Solzinc process under development at the Weizmann Institute uses a 1 MW solar furnace to decompose zinc oxide (ZnO) at temperatures above 1200 °C. This initial reaction produces pure zinc, which can subsequently be reacted with water to produce hydrogen.[81]

Sandia's Sunshine to Petrol (S2P) technology uses the high temperatures generated by concentrating sunlight along with a zirconia/ferrite catalyst to break down atmospheric carbon dioxide into oxygen and carbon monoxide (CO). The carbon monoxide can then be used to synthesize conventional fuels such as methanol, gasoline and jet fuel.[82]

A photogalvanic device is a type of battery in which the cell solution (or equivalent) forms energy-rich chemical intermediates when illuminated. These energy-rich intermediates can potentially be stored and subsequently reacted at the electrodes to produce an electric potential. The ferric-thionine chemical cell is an example of this technology.[83]

Photoelectrochemical cells or PECs consist of a semiconductor, typically titanium dioxide or related titanates, immersed in an electrolyte. When the semiconductor is illuminated an electrical potential develops. There are two types of photoelectrochemical cells: photoelectric cells that convert light into electricity and photochemical cells that use light to drive chemical reactions such as electrolysis.[84]

A combination thermal/photochemical cell has also been proposed. The Stanford PETE process uses solar

thermal energy to raise the temperature of a thermionic metal to about 800C to increase the rate of production of electricity to electrolyse atmospheric CO2 down to carbon or carbon monoxide which can then be used for fuel production, and the waste heat can be used as well.[85]

Solar vehicles

Main articles: Solar vehicle, Solar-charged vehicle, Electric boat, and Solar balloon

Development of a solar powered car has been an engineering goal since the 1980s. The World Solar Challenge is a biannual solar-powered car race, where teams from universities and enterprises compete over 3,021 kilometres (1,877 mi) across central Australia from Darwin to Adelaide. In 1987, when it was founded, the winner's average speed was 67 kilometres per hour (42 mph) and by 2007 the winner's average speed had improved to 90.87 kilometres per hour (56.46 mph).[86] The North American Solar Challenge and the planned South African Solar Challenge are comparable competitions that reflect an international interest in the engineering and development of solar powered vehicles.[87][88]

Australia hosts the World Solar Challenge where solar cars like the Nuna3 race through a 3,021 km (1,877 mi) course from Darwin to Adelaide.

Some vehicles use solar panels for auxiliary power, such as for air conditioning, to keep the interior cool, thus reducing fuel consumption.[89][90]

In 1975, the first practical solar boat was constructed in England.[91] By 1995, passenger boats incorporating PV panels began appearing and are now used extensively.[92] In 1996, Kenichi Horie made the first solar powered crossing of the Pacific Ocean, and the *sun21* catamaran made the first solar powered crossing of the Atlantic Ocean in the winter of 2006–2007.[93] There are plans to circumnavigate the globe in 2010.[94]

In 1974, the unmanned AstroFlight Sunrise plane made the first solar flight. On 29 April 1979, the *Solar Riser* made the first flight in a solar powered, fully controlled, man carrying flying machine, reaching an altitude of 40 feet (12 m). In 1980, the *Gossamer Penguin* made the first piloted flights powered solely by photovoltaics. This was quickly followed by the *Solar Challenger* which crossed the English Channel in July 1981. In 1990 Eric Scott Raymond in 21 hops flew from California to North Carolina using solar power.[95] Developments then turned back to unmanned aerial vehicles (UAV) with the *Pathfinder* (1997) and subsequent designs, culminating in the *Helios* which set the altitude record for a non-rocket-propelled aircraft at 29,524 metres (96,864 ft) in 2001.[96] The *Zephyr*, developed by BAE Systems, is the latest in a line of record-breaking solar aircraft, making a 54-hour flight in 2007, and month-long flights are envisioned by 2010.[97]

Helios UAV in solar powered flight.

A solar balloon is a black balloon that is filled with ordinary air. As sunlight shines on the balloon, the air inside is heated and expands causing an upward buoyancy force, much like an artificially heated hot air balloon. Some solar balloons are large enough for human flight, but usage is generally limited to the toy market as the surface-area to payload-weight ratio is relatively high.[98]

Solar sails are a proposed form of spacecraft propulsion using large membrane mirrors to exploit radiation

pressure from the Sun. Unlike rockets, solar sails require no fuel. Although the thrust is small compared to rockets, it continues as long as the Sun shines onto the deployed sail and in the vacuum of space significant speeds can eventually be achieved.[99]

The High-altitude airship (HAA) is an unmanned, long-duration, lighter-than-air vehicle using helium gas for lift, and thin film solar cells for power. The United States Department of Defense Missile Defense Agency has contracted Lockheed Martin to construct it to enhance the Ballistic Missile Defense System (BMDS).[100] Airships have some advantages for solar-powered flight: they do not require power to remain aloft, and an airship's envelope presents a large area to the Sun.

Energy storage methods

Main articles: Thermal mass, Thermal energy storage, Phase change material, Grid energy storage, and V2G

Solar energy is not available at night, and energy storage is an important issue because modern energy systems usually assume continuous availability of energy.[101]

Solar Two's thermal storage system generated electricity during cloudy weather and at night.

Thermal mass systems can store solar energy in the form of heat at domestically useful temperatures for daily or seasonal durations. Thermal storage systems generally use readily available materials with high specific heat capacities such as water, earth and stone. Well-designed systems can lower peak demand, shift time-of-use to off-peak hours and reduce overall heating and cooling requirements.[102][103]

Phase change materials such as paraffin wax and Glauber's salt are another thermal storage media. These materials are inexpensive, readily available, and can deliver domestically useful temperatures (approximately 64 °C). The "Dover House" (in Dover, Massachusetts) was the first to use a Glauber's salt heating system, in 1948.[104]

Solar energy can be stored at high temperatures using molten salts. Salts are an effective storage medium because they are low-cost, have a high specific heat capacity and can deliver heat at temperatures compatible with conventional power systems. The Solar Two used this method of energy storage, allowing it to store 1.44 TJ in its 68 m^3 storage tank with an annual storage efficiency of about 99%.[105]

Off-grid PV systems have traditionally used rechargeable batteries to store excess electricity. With grid-tied systems, excess electricity can be sent to the transmission grid, while standard grid electricity can be used to meet shortfalls. Net metering programs give household systems a credit for any electricity they deliver to the grid. This is often legally handled by 'rolling back' the meter whenever the home produces more electricity than it consumes. If the net electricity use is below zero, the utility is required to pay for the extra at the same rate as they charge consumers.[106] Other legal approaches involve the use of two meters, to measure electricity consumed vs. electricity produced. This is less common due to the increased installation cost of the second meter.

Pumped-storage hydroelectricity stores energy in the form of water pumped when energy is available from a lower elevation reservoir to a higher elevation one. The energy is recovered when demand is high by releasing the water to run through a hydroelectric power generator.[107]

Development, deployment and economics

Main article: Deployment of solar power to energy grids

See also: Cost of electricity by source

Beginning with the surge in coal use which accompanied the Industrial Revolution, energy consumption has steadily transitioned from wood and biomass to fossil fuels. The early development of solar technologies starting in the 1860s was driven by an expectation that coal would soon become scarce. However development of solar technologies stagnated in the early 20th century in the face of the increasing availability, economy, and utility of coal and petroleum.[108]

The 1973 oil embargo and 1979 energy crisis caused a reorganization of energy policies around the world and brought renewed attention to developing solar technologies.[109][110] Deployment strategies focused on incentive programs such as the Federal Photovoltaic Utilization Program in the US and the Sunshine Program in Japan. Other efforts included the formation of research facilities in the US (SERI, now NREL), Japan (NEDO), and Germany (Fraunhofer Institute for Solar Energy Systems ISE).[111]

Commercial solar water heaters began appearing in the United States in the 1890s.[112] These systems saw increasing use until the 1920s but were gradually replaced by cheaper and more reliable heating fuels.[113] As with photovoltaics, solar water heating attracted renewed attention as a result of the oil crises in the 1970s but interest subsided in the 1980s due to falling petroleum prices. Development in the solar water heating sector progressed steadily throughout the 1990s and growth rates have averaged 20% per year since 1999.[41] Although generally underestimated, solar water heating and cooling is by far the most widely deployed solar technology with an estimated capacity of 154 GW as of 2007.[41]

The International Energy Agency has said that solar energy can make considerable contributions to solving some of the most urgent problems the world now faces:[1]

> The development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared.[1]

In 2011, the International Energy Agency said that solar energy technologies such as photovoltaic panels, solar water heaters and power stations built with mirrors could provide a third of the world's energy by 2060 if politicians commit to limiting climate change. The energy from the sun could play a key role in de-carbonizing the global economy alongside improvements in energy efficiency and imposing costs on greenhouse gas emitters. "The strength of solar is the incredible variety and flexibility of applications, from small scale to big scale".[114]

ISO Standards

The International Organization for Standardization has established a number of standards relating to solar energy equipment. For example, ISO 9050 relates to glass in building while ISO 10217 relates to the materials used in solar water heaters.

See also

- Airmass
- Community solar farm
- Desertec
- Energy storage
- Global dimming
- Greasestock
- Green electricity
- Heliostat
- List of conservation topics
- List of renewable energy organizations
- List of solar energy topics
- List of solar thermal power stations
- Photovoltaic cell
- Photovoltaic module
- Renewable heat
- Solar Decathlon
- Solar easement
- Solar flower tower
- Solar lamp
- Solar power satellite
- Solar pond
- Solar tracker
- Soil solarization
- Sun
- Timeline of solar cells
- Trombe wall
- SolarEdge
- Solar inverter
- Photovoltaic system

Notes

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External links

- "How do Photovoltaics Work?" (http://science.nasa.gov/headlines/y2002/solarcells.htm) . NASA. http://science.nasa.gov/headlines/y2002/solarcells.htm.
- Solar Energy Back in the Day (http://www.life.com/image/first/in-gallery/43861/solar-energy-back-in-the-day) - slideshow by *Life magazine*
- Compendium of Solar Cooker Designs (http://solarcooking.wikia.com /wiki/Compendium_of_solar_cooker_designs)
- U.S. Solar Farm Map (1 MW or Higher) (http://www.solarpowerworldonline.com/u-s-solar-farm-map/)

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