SEMINAR REPORT ON

SOLAR POWER SYSTEM

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Submitted by

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INRODUCTION

Solar Power:- How to use its energy?

Solar Power is energy obtained by the sun in the form of light.

(When you are at the beach, you feel the sun as heat energy, but heat energy can't travel through space. It is just light energy that gives the hot feeling)

The sun is 150 million km from the earth and is 5 billion years old (so don´t worry about sun death).

The temperature of the sun ranges from 6000 degrees Celsius at its surface to 10 million degrees Celsius at its Centre.

It takes about 8 minutes for the light energy to touch the earth. The sun is a star made up of hydrogen and helium gas and it radiates an enormous amount of energy every second and it is clean.

If we could "catch" the amount of solar energy that arrive every single day to earth and convert it into electrical energy, it would be enough to supply our energy needs for up to one a year.

DEFINITON OF SOLAR ENEGY

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 radiation, along with secondary solar-powered resources such as wind and wave power, hydroelectricity and biomass, account for most of the available renewable energy on earth. Only a minuscule fraction of the available solar energy is used.

Solar powered electrical generation relies on heat engines and photovoltaics. Solar energy's uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, daylighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes.To harvest the solar energy, the most common way is to use solar panels.

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.

Solar power is the generation of electricity from sunlight. This can be direct as with photovoltaics (PV), or indirect as with concentrating solar power (CSP), where the sun's energy is focused to boil water which is then used to provide power. Solar power has the potential to provide over 1,000 times total world energy consumption in 2008, though it provided only 0.02% of the total that year. If it continues to double in use every two to three years, or less, it would become the dominant energy source this century. The largest solar power plants, like the 354 MW SEGS, are concentrating solar thermal plants, but recently multi-megawatt photovoltaic plants have been built. Completed in 2008, the 46 MW Moura photovoltaic power station in Portugal and the 40 MW Waldpolenz Solar Park in Germany are characteristic of the trend toward larger photovoltaic power stations. Much larger ones are proposed, such as the 100 MW Fort Peck Solar Farm, the 550 MW Topaz Solar Farm, and the 600 MW Rancho Cielo Solar Farm.

Terrestrial solar power is a predictably intermittent energy source, meaning that whilst solar power is not available at all times, we can predict with a very good degree of accuracy when it will and will not be available. Some technologies, such as solar thermal concentrators have an element of thermal storage, such as molten salts. These store spare solar energy in the form of heat which can be made made available overnight or during periods that solar power is not available to produce electricity. Orbital solar power collection (as in solar power satellites) avoids this intermittent issue, but requires satellite launching and beaming of the collected power to receiving antennas on Earth. The increased intensity of sunlight above the atmosphere also increases generation efficiency

CONCENTATING SOLAR POWER SYSTEM

A legend claims that Archimedes used polished shields to concentrate sunlight on the invading Roman fleet and repel them from Syracuse. Auguste Mouchout used a parabolic trough to produce steam for the first solar steam engine in 1866.[9]

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.

A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line. The receiver is a tube positioned right above the middle of the parabolic mirror and is filled with a working fluid. The reflector is made to follow the Sun during the daylight hours by tracking along a single axis. Parabolic trough systems provide the best land-use factor of any solar technology. The SEGS plants in California and Acciona's Nevada Solar One near Boulder City, Nevada are representatives of this technology. The Suntrof-Mulk parabolic trough, developed by Melvin Prueitt, uses a technique inspired by Archimedes' principle to rotate the mirrors.

Concentrating Linear Fresnel Reflectors are CSP-plants which use many thin mirror strips instead of parabolic mirrors to concentrate sunlight onto two tubes with working fluid. This has the advantages that flat mirrors can be used which are much cheaper than parabolic mirrors, and that more reflectors can be placed in the same amount of space, allowing more of the available sunlight to be used. Concentrating linear Fresnel reflectors can be used in either large or more compact plants.

A Stirling solar dish, or dish engine system, consists of a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point. The reflector tracks the Sun along two axes. Parabolic dish systems give the highest efficiency among CSP technologies. The 50 kW Big Dish in Canberra, Australia is an example of this technology. The Stirling solar dish combines a parabolic concentrating dish with a Stirling heat engine which normally drives an electric generator. The advantages of Stirling solar over photovoltaic cells are higher efficiency of converting sunlight into electricity and longer lifetime. A solar power tower uses an array of tracking reflectors (heliostats) to concentrate light on a central receiver atop a tower. Power towers are more cost effective, offer higher efficiency and better energy storage capability among CSP technologies. The Solar Two in Barstow, California and the Planta Solar 10 in Sanlucar la Mayor, Spain are representatives of this technology.

A solar bowl is a spherical dish mirror that is fixed in place. The receiver follows the line focus created by the dish (as opposed to a point focus with tracking parabolic mirrors).

PHOTOVOLTAICS

Photovoltaics (PVs) are arrays of cells containing a solar photovoltaic material that converts solar radiation into direct current electricity. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, cadmium telluride, and copper indium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacture of solar cells and photovoltaic arrays has advanced dramatically in recent years.

Photovoltaic production has been doubling every 2 years, increasing by an average of 48 percent each year since 2002, making it the world's fastest-growing energy technology. At the end of 2008, the cumulative global PV installations reached 15,200 megawatts. Roughly 90% of this generating capacity consists of grid-tied electrical systems. Such installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building, known as Building Integrated Photovoltaics or BIPV for short. Solar PV power stations today have capacities ranging from 10-60 MW although proposed solar PV power stations will have a capacity of 150 MW or more.

Driven by advances in technology and increases in manufacturing scale and sophistication, the cost of photovoltaics has declined steadily since the first solar cells were manufactured. Net metering and financial incentives, such as preferential feed-in tariffs for solar-generated electricity; have supported solar PV installations in many countries.

A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photoelectric effect. This is based on the discovery by Alexandre-Edmond Becquerel who noticed that some materials release electrons when hit with rays of photons from light, which produces an electrical current. The first solar cell was constructed by Charles Fritts in the 1880s.[21] 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.[22] Following the work of Russell Ohl in the 1940s, researchers Gerald Pearson, Calvin Fuller and Daryl Chapin created the silicon solar cell in 1954. These early solar cells cost 286 USD/watt and reached efficiencies of 4.5–6%. As of late 2009, the highest efficiency PV cells were produced commercially by Boeing/SpectroLab at about 41%. Other, similar, multi-layer cells are close. These are breathtakingly expensive however, and are used only for the most exacting applications. Thin film PV cells have been developed which are made in bulk and are far less expensive and much less fragile, but are at most around 20% efficient.

The most recent development (from Caltech, March 2010) is the experimental demonstration of a new design which is 85% efficient in plain sunlight and 95% efficient at certain wavelengths. It has only been produced in experimental laboratory examples, but may have some possibility for low cost bulk production in future.

There are many competing technologies, including at least fourteen types of photovoltaic cells, such as thin film, monocrystalline silicon, polycrystalline silicon, and amorphous cells, as well as multiple types of concentrating solar power. It is too early to know which technology will become dominant.

The earliest significant application of solar cells was as a back-up power source to the Vanguard I satellite in 1958, which allowed it to continue transmitting for over a year after its chemical battery was exhausted. The successful operation of solar cells on this mission was duplicated in many other Soviet and American satellites, and by the late 1960s, PV had become the established source of power for them. After the successful application of solar panels on the Vanguard satellite it still was not until the energy crisis, in the 1970s, that photovoltaic solar panels gained use outside of backup power suppliers on spacecraft. Photovoltaics went on to play an essential part in the success of early commercial satellites such as Telstar, and they remain vital to the telecommunications infrastructure today.

Building-integrated photovoltaics cover the roofs of an increasing number of homes.

The high cost of solar cells limited terrestrial uses throughout the 1960s. This changed in the early 1970s when prices reached levels that made PV generation competitive in remote areas without grid access. Early terrestrial uses included powering telecommunication stations, offshore oil rigs, navigational buoys and railroad crossings. These off-grid applications accounted for over half of worldwide installed capacity until 2004.

The 1973 oil crisis stimulated a rapid rise in the production of PV during the 1970s and early 1980s. Economies of scale which resulted from increasing production along with improvements in system performance brought the price of PV down from 100 USD/watt in 1971 to 7 USD/watt in 1985. Steadily falling oil prices during the early 1980s led to a reduction in funding for photovoltaic R&D and a discontinuation of the tax credits associated with the Energy Tax Act of 1978. These factors moderated growth to approximately 15% per year from 1984 through 1996.

Since the mid-1990s, leadership in the PV sector has shifted from the US to Japan and Europe. Between 1992 and 1994 Japan increased R&D funding, established net metering guidelines, and introduced a subsidy program to encourage the installation of residential PV systems. As a result, PV installations in the country climbed from 31.2 MW in 1994 to 318 MW in 1999, and worldwide production growth increased to 30% in the late 1990s.

Concentrating photovoltaics

Germany became the leading PV market worldwide since revising its feed-in tariffs as part of the Renewable Energy Sources Act. Installed PV capacity in Germany has risen from 100 MW in 2000 to approximately 4,150 MW at the end of 2007. After 2007, Spain became the largest PV market after adopting a similar feed-in tariff structure in 2004, installing almost half of the photovoltaics (45%) in the world, in 2008, while France, Italy, South Korea and the U.S. have seen rapid growth recently due to various incentive programs and local market conditions. The power output of domestic photovoltaic devices is usually described in kilowatt-peak (kWp) units, as most are from 1 to 10 kW.

Concentrating photovoltaics (CVP) are another new method of electricity generation from the sun. CPV systems employ sunlight concentrated onto photovoltaic surfaces for the purpose of electrical power production. Solar concentrators of all varieties may be used, which are often mounted on a solar tracker in order to keep the focal point upon the cell as the sun moves across the sky. Tracking can increase flat panel photovoltaic output by 20% in winter, and by 50% in summer.

Photovoltaic cells produce electricity directly from sunlight

Photovoltaics are best known as a method for generating electric power by using solar cells to convert energy from the sun into electricity. The photovoltaic effect refers to photons of light knocking electrons into a higher state of energy to create electricity. The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode.

Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. The first practical application of photovoltaics was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for grid connected power generation. In this case an inverter is required to convert the DC to AC. There is a smaller market for off-grid power for remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, remote sensing, and cathodic protection of pipelines.

Average solar irradiance, watts per square meter. Note that this is for a horizontal surface, whereas solar panels are normally mounted at an angle and receive more energy per unit area. The small black dots show the area of solar panels needed to generate all of the world's energy using 8% efficient photovoltaics.

Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When more power is required than a single cell can deliver, cells are electrically connected together to form photovoltaic modules, or solar panels. A single module is enough to power an emergency telephone, but for a house or a power plant the modules must be arranged in multiples as arrays.

The 89 petawatts of sunlight reaching the Earth's surface is plentiful - almost 6,000 times more than the 15 terawatts of average electrical power consumed by humans. Additionally, solar electric generation has the highest power density (global mean of 170 W/m²) among renewable energies.

Solar power is pollution-free during use. Production end-wastes and emissions are manageable using existing pollution controls. End-of-use recycling technologies are under development.

PV installations can operate for many years with little maintenance or intervention after their initial set-up, so after the initial capital cost of building any solar power plant, operating costs are extremely low compared to existing power technologies.

Solar electric generation is economically superior where grid connection or fuel transport is difficult, costly or impossible. Long-standing examples include satellites, island communities, remote locations and ocean vessels.

When grid-connected, solar electric generation replaces some or all of the highest-cost electricity used during times of peak demand (in most climatic regions). This can reduce grid loading, and can eliminate the need for local battery power to provide for use in times of darkness. These features are enabled by net metering. Time-of-use net metering can be highly favorable, but requires newer electronic metering, which may still be impractical for some users.

Grid-connected solar electricity can be used locally thus reducing transmission/distribution losses (transmission losses in the US were approximately 7.2% in 1995).

Compared to fossil and nuclear energy sources, very little research money has been invested in the development of solar cells, so there is considerable room for improvement. Nevertheless, experimental high efficiency solar cells already have efficiencies of over 40% in case of concentrating photovoltaic cells and efficiencies are rapidly rising while mass-production costs are rapidly falling.

Photovoltaics are costly to install. While the modules are often warranted for upwards of 20 years, much of the investment in a home-mounted system may be lost if the home-owner moves and the buyer puts less value on the system than the seller. The city of Berkeley has come up with an innovative financing method to remove this limitation, by adding a tax assessment that is transferred with the home to pay for the solar panels. Nine U.S. states have duplicated this solution.

Solar electricity is seen to be expensive. Once a PV system is installed it will produce electricity for no further cost until the inverter needs replacing. Current utility rates have increased every year for the past 20 years and with the increasing pressure on carbon reduction the rate will increase more aggressively. This increase will (in the long run) easily offset the increased cost at installation but the timetable for payback is too long for most.

Solar electricity is not available at night and is less available in cloudy weather conditions from conventional photovoltaic technologies. Therefore, a storage or complementary power system is required. This is why many buildings with photovoltaic arrays are tied into the power grid; the grid absorbs excess electricity generated throughout the day, and provides electricity in the evening.

Apart from their own efficiency figures, PV systems work within the limited power density of their location's insolation. Average daily insolation (output of a flat plate collector at latitude tilt) in the contiguous US is 3-7 kilowatt·h/m^2 and on average lower in Europe.

Solar cells produce DC which must be converted to AC (using a grid tie inverter) when used in current existing distribution grids. This incurs an energy loss of 4-12%.

Photovoltaics companies:-

Biosol TPF Photovoltaic Membrane (Integrated Polymer Systems Ltd- UK)

Spectrolab Inc.: A *Boeing Company* and Leading Merchant Supplier of High-Efficiency Multijunction Solar Cells for CPV and Spacecraft Power Systems

World’s largest PV plants are:-

- Sarnia Solar Project, Enbridge(Canada) -Peak power 80 MW
- Olmedilla Photovoltaic Park(Spain) -Peak power60W
- Strasskirchen Solar Park(Germany) - Peak power54W
- Lieberose Photovoltaic Park (Germany) - Peak power53W
- Puertollano Photovoltaic Park(Spain) - Peak power50W
- Moura photovoltaic power station(Portugal) - Peak power46W

- Kothen Solar Park(Germany) - Peak power45W
- Finsterwalde Solar Park(Germany) - Peak power41W
- Waldpolenz Solar Park (Germany) - Peak power40W

EXPERIMENTAL SOLAR POWER

A solar updraft tower (also known as a solar chimney or solar tower) consists of a large greenhouse that funnels into a central tower. As sunlight shines on the greenhouse, the air inside is heated, and expands. The expanding air flows toward the central tower, where a turbine converts the air flow into electricity. A 50 kW prototype was constructed in Ciudad Real, Spain and operated for eight years before decommissioning in 1989.

Thermoelectric, or "thermovoltaic" devices convert a temperature difference between dissimilar materials into an electric current. First proposed as a method to store solar energy by solar pioneer Mouchout in the 1800s, thermoelectrics reemerged in the Soviet Union during the 1930s. Under the direction of Soviet scientist Abram Ioffe a concentrating system was used to thermoelectrically generate power for a 1 hp engine. Thermogenerators were later used in the US space program as an energy conversion technology for powering deep space missions such as Cassini, Galileo and Viking. Research in this area is focused on raising the efficiency of these devices from 7–8% to 15–20%.

APPLICATION

Solar power is the conversion of sunlight to electricity. Sunlight can be converted directly into electricity using photovoltaics (PV), or indirectly with concentrating solar power (CSP), which normally focuses the sun's energy to boil water which is then used to provide power, and technologies such as the Stirling engine dishes which use a Stirling cycle engine to power a generator. Photovoltaics were initially used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array.

Solar power plants can face high installation costs, although this has been decreasing due to the learning curve. Developing countries have started to build solar power plants, replacing other sources of energy generation.

Solar power has great potential, but in 2008 supplied only 0.02% of the world's total energy supply. However, use has been doubling every two, or less, years, and at that rate solar power, which has the potential to supply over 1,000 times the total consumption of energy, would become the dominant energy source within a few decades.

Since solar radiation is intermittent, solar power generation is combined either with storage or other energy sources to provide continuous power, although for small distributed producer/consumers, net metering makes this transparent to the consumer. On a larger scale, in Germany, a combined power plant has been demonstrated, using a mix of wind, biomass, hydro-, and solar power generation, resulting in 100% renewable energy.

In Buildings

Building-integrated photovoltaics (BIPV) are increasingly incorporated into new domestic and industrial buildings as a principal or ancillary source of electrical power, and are one of the fastest growing segments of the photovoltaic industry. Typically, an array is incorporated into the roof or walls of a building and roof tiles with integrated PV cells can now be purchased. Arrays can also be retrofitted into existing buildings; in this case they are usually fitted on top of the existing roof structure. Alternatively, an array can be located separately from the building but connected by cable to supply power for the building.

Where a building is at a considerable distance from the public electricity supply (or grid) - in remote or mountainous areas – PV may be the preferred possibility for generating electricity, or PV may be used together with wind, diesel generators and/or hydroelectric power. In such off-grid circumstances batteries are usually used to store the electric power.

In locations near the grid, however, feeding the grid using PV panels is more practical, and leads to optimum use of the investment in the photovoltaic system. This requires both regulatory and commercial preparation, such as net-metering or feed-in-tariff (FiT) agreements. To provide for possible power failure, some grid tied systems are set up to allow local use disconnected from the grid. Most photovoltaics are grid connected. In the event the grid fails, the local system must not feed the grid to prevent the possible creation of dangerous islanding.

The power output of photovoltaic systems for installation in buildings is usually described in kilowatt-peak units (kWp).

In Transport

PV has traditionally been used for auxiliary power in space. PV is rarely used to provide motive power in transport applications, but is being used increasingly to provide auxiliary power in boats and cars. Recent advances in solar race cars, however, have produced cars that with little changes could be used for transportation.

Standalone devices

Until a decade or so ago, PV was used frequently to power calculators and novelty devices. Improvements in integrated circuits and low power LCD displays make it possible to power such devices for several years between battery changes, making PV use less common. In contrast, solar powered remote fixed devices have seen increasing use recently in locations where significant connection cost makes grid power prohibitively expensive. Such applications include parking meters, emergency telephones, temporary traffic signs, and remote guard posts & signals.

Rural electrification

Developing countries where many villages are often more than five kilometers away from grid power have begun using photovoltaics. In remote locations in India a rural lighting program has been providing solar powered LED lighting to replace kerosene lamps. The solar powered lamps were sold at about the cost of a few months' supply of kerosene Cuba is working to provide solar power for areas that are off grid.[] These are areas where the social costs and benefits offer an excellent case for going solar though the lack of profitability could relegate such endeavors to humanitarian goals.

Solar roadways

A 45 mi (72 km) section of roadway in Idaho is being used to test the possibility of installing solar panels into the road surface, as roads are generally unobstructed to the sun and represent about the percentage of land area needed to replace other energy sources with solar power.

Solar Power satellites

Design studies of large solar power collection satellites have been conducted for decades. The idea was first proposed by Peter Glaser, then of Arthur D. Little Inc.; NASA conducted a long series of engineering and economic feasibility studies in the 1970s, and interest has revived in first years of the 21st century.

From a practical economic viewpoint, the key issue for such satellites appears to be the launch cost. Additional considerations will include developing space based assembly techniques, but they seem to be less a hurdle than the capital cost. These will be reduced as photovoltaic cell costs are reduced or alternatively efficiency increased.

Agriculture and horticulture

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

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. 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. Applications of solar energy in agriculture aside from growing crops include pumping water, drying crops, brooding chicks and drying chicken manure. More recently the technology has been embraced by vinters, who use the energy generated by solar panels to power grape presses.[29]

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. The first modern greenhouses were built in Europe in the 16th century to keep exotic plants brought back from explorations abroad.[31] 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

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

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. 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 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. Although difficult to quantify, the use of natural lighting also offers physiological and psychological benefits compared to artificial lighting. 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%.

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.

Solar lights that charge during the day and light up at dusk are a common sight along walkways.

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.

Solar thermal

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

Heating, cooling and ventilation

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

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. 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.

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 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.[46] 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. 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.

Water treatment

Solar water disinfection in Indonesia

Small scale solar powered sewerage treatment plant.

Solar distillation can be used to make saline or brackish water potable. The first recorded instance of this was by 16th century Arab alchemists. A large-scale solar distillation project was first constructed in 1872 in the Chilean mining town of Las Salinas. The plant, which had solar collection area of 4,700 m², could produce up to 22,700 L per day and operated for 40 years. Individual still designs include single-slope, double-slope (or greenhouse type), vertical, conical, inverted absorber, multi-wick, and multiple effect. 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.

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

Solar energy may be used in a water stabilization 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.

Cooking

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

Solar cookers use sunlight for cooking, drying and pasteurization. They can be grouped into three broad categories: box cookers, panel cookers and reflector cookers. The simplest solar cooker is the box cooker first built by Horace de Saussure in 1767. 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. 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.

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.

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. The world's largest Scheffler reflector system in Abu Road, Rajasthan, India is capable of cooking up to 35,000 meals a day. As of 2008, over 2,000 large Scheffler cookers had been built worldwide.

Process heat

STEP parabolic dishes used for steam production and electrical generation.

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.

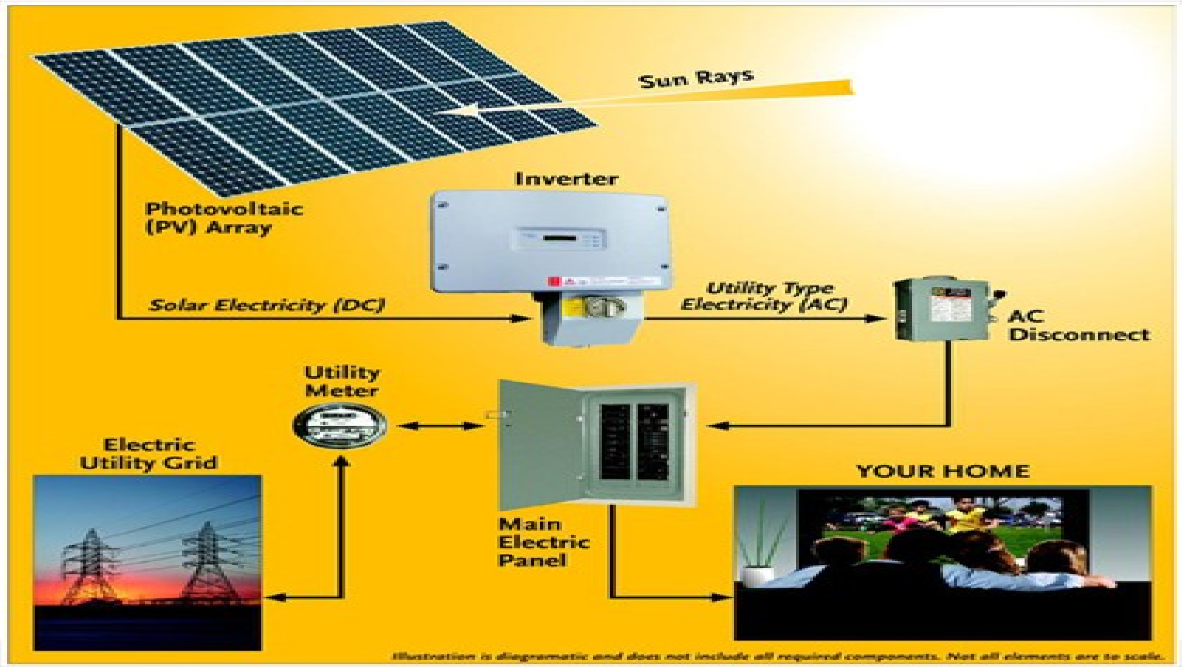
Evaporation ponds are shallow pools that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from sea water is one of the oldest applications of solar energy. Modern uses include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams.

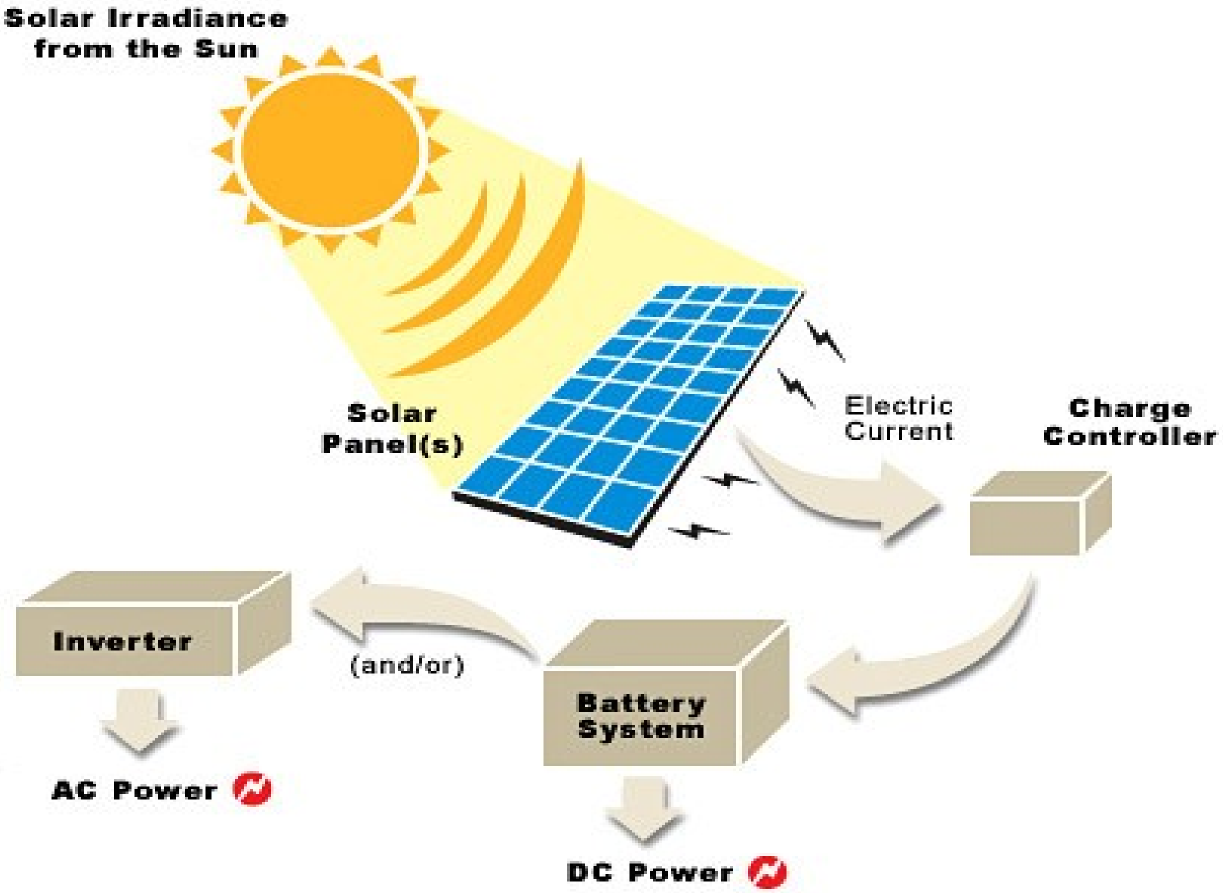
Clothes lines, clotheshorses, and clothes racks dry clothes through evaporation by wind and sunlight without consuming electricity or gas. In some states of the United States legislation protects the "right to dry" clothes.

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. The short payback period of transpired collectors (3 to 12 years) makes them a more cost-effective alternative than glazed collection systems. 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.

Electrical generation

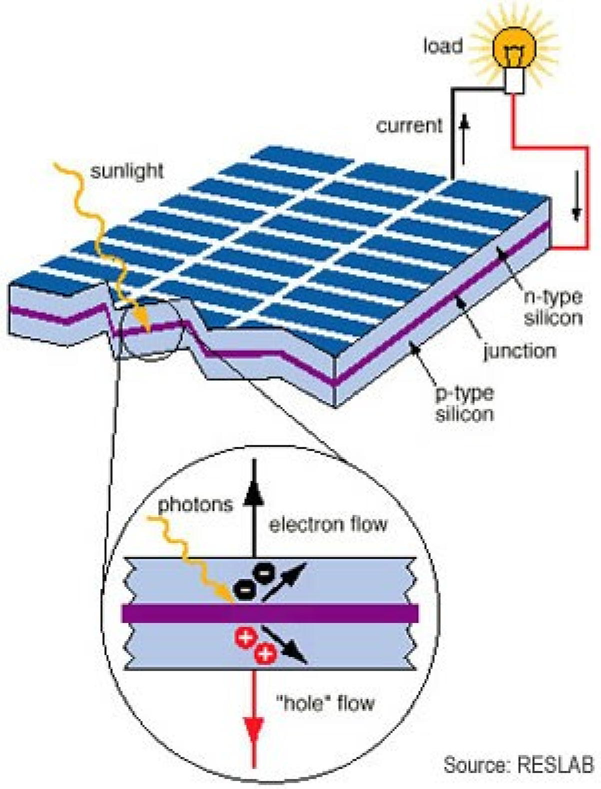
Sunlight can be converted into electricity using photovoltaics (PV), concentrating solar power (CSP), and various experimental technologies. PV has mainly been used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array. For large-scale generation, CSP plants like SEGS have been the norm but recently multi-megawatt PV plants are becoming common. Completed in 2007, the 14 MW power station in Clark County, Nevada, United States and the 20 MW site in Beneixama, Spain are characteristic of the trend toward larger photovoltaic power stations in the United States and Europe. As an intermittent power source, solar power requires a backup supply, which can partially be complemented with wind power. Local backup usually is done with batteries, while utilities normally use pumped-hydro storage. The Institute for Solar Energy Supply Technology of the University of Kassel in Germany pilot-tested a combined power plant linking solar, wind, biogas and hydrostorage to provide load-following power around the clock, entirely from renewable sources.




Solar Irradiance from the Sun
Solar Panel(s)
Electric Current
Charge Controller
Inverter
(and/or)
Battery System
AC Power
DC Power

Solar Cells

Originally developed in order to provide electrical energy for space satellites, photovoltaic energy uses photoelectric cells that convert light into electricity.



Source: RESLAB

Solar photovoltaic power or PV takes advantage of the photovoltaic effect in which a solar cell converts sunlight into electricity.

In 1839, nineteen-year-old Edmund Becquerel, while experimenting with an electrolytic cell made up of two metal electrodes; found that certain materials would produce small amounts of electric current when exposed to light.

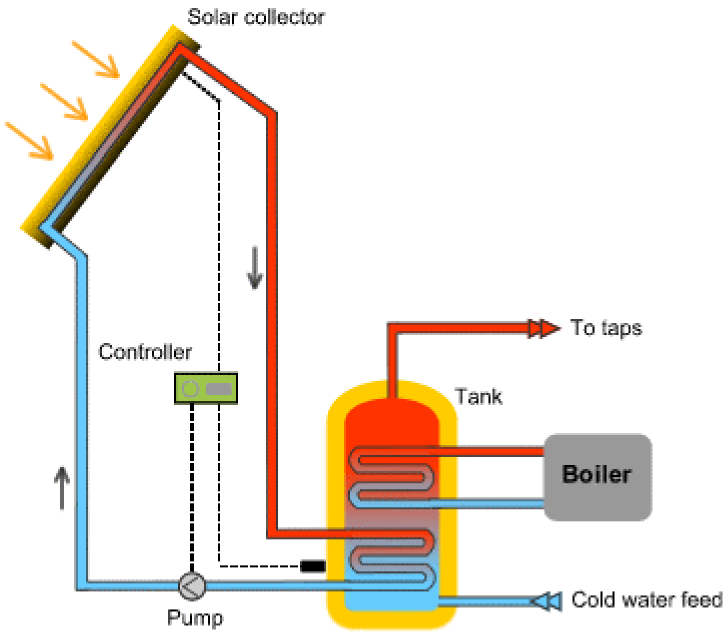
In Sunlight there is a particle called a photons. When photons strike a pv (solar cell), they may be absorbed by a atom, so that the energy of the photon is transferred to the electron of the atom that receives that energy.

In a modem cell, the materials used for the solar cell are semiconductors.

There are two types of semiconductor: the N-type (in which there are a lot of nearly free electrons) and the P-type (in which there are a lot of "Holes"). It is called a hole when an electron has left its place, so in P-type semiconductor, there is a positive charge.

If a photon strikes an N-type semiconductor, the electron can escape from its normal position. If the electron is free to move, and as it has a negative charge, it will try to catch a positive charge. The positive charges are located in the P-type semiconductor (below in the solar cell- see drawing) and although they are attracted by them, it is impossible for electrons to pass the junction (violet material) as it is an insulator component. What can they do then? The only way to find a Hole is by going out from the solar cell, passing through the load (a bulb in this case) and taking the wire toward the P-Type semiconductor. Now, we have electricity, clean, safe, non-polluting and getting cheaper every day.

SOLAR WATER HEATING.



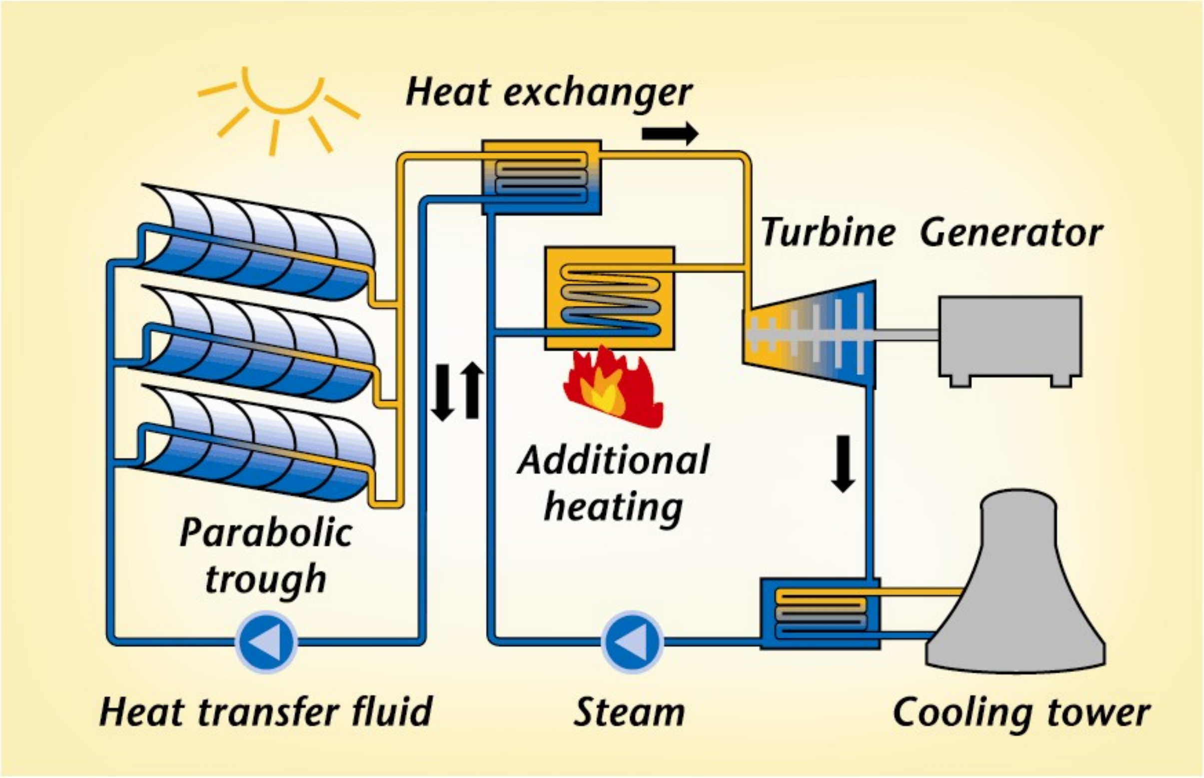
The diagram shown on the right illustrates a simple water heating circuit.

The solar collector contains two independent circuits. An oil circuit in a closed system comprises a solar collector, the tubes and a small pump (needed to move hot oil through the circuit) and a U-tube heat exchanger in the water tank.

The cold oil is moved by the pump, collects heat energy in the solar collector, goes to the u-tube heat exchanger and transfers some of its heat to the water in the tank.

The second circuit, starts in a cold water feed which fills up the thank and pick up energy from the U-tube heat exchanger. Once the water is warm it can be used in a tap water circuit.

If we want to produce electricity from the sun, the best way is by a thermal solar plant



In an industrial solar plant, an array of mirrors acts as a parabolic reflector concentrating solar energy onto a focal point (where the tube with a thermal liquid is installed. The temperature of the heat transfer fluid, at the focal point, may reach 3,000 ºC. This heat is used to give energy to the water circuit inside a Heat exchanger.

Water changes into stream and moves a turbine whose axle moves the generator, producing electricity.

Steam water is change into liquid and pushed again to the heat exchanger

San Lucar la Mayor Solar plant is the pride of Abengoa (a Spanish technology company). This plant generates 24.3 GWh per year of clean energy which is enough to supply 6000 households.

ADVANTAGES AND DISADVANTAGES

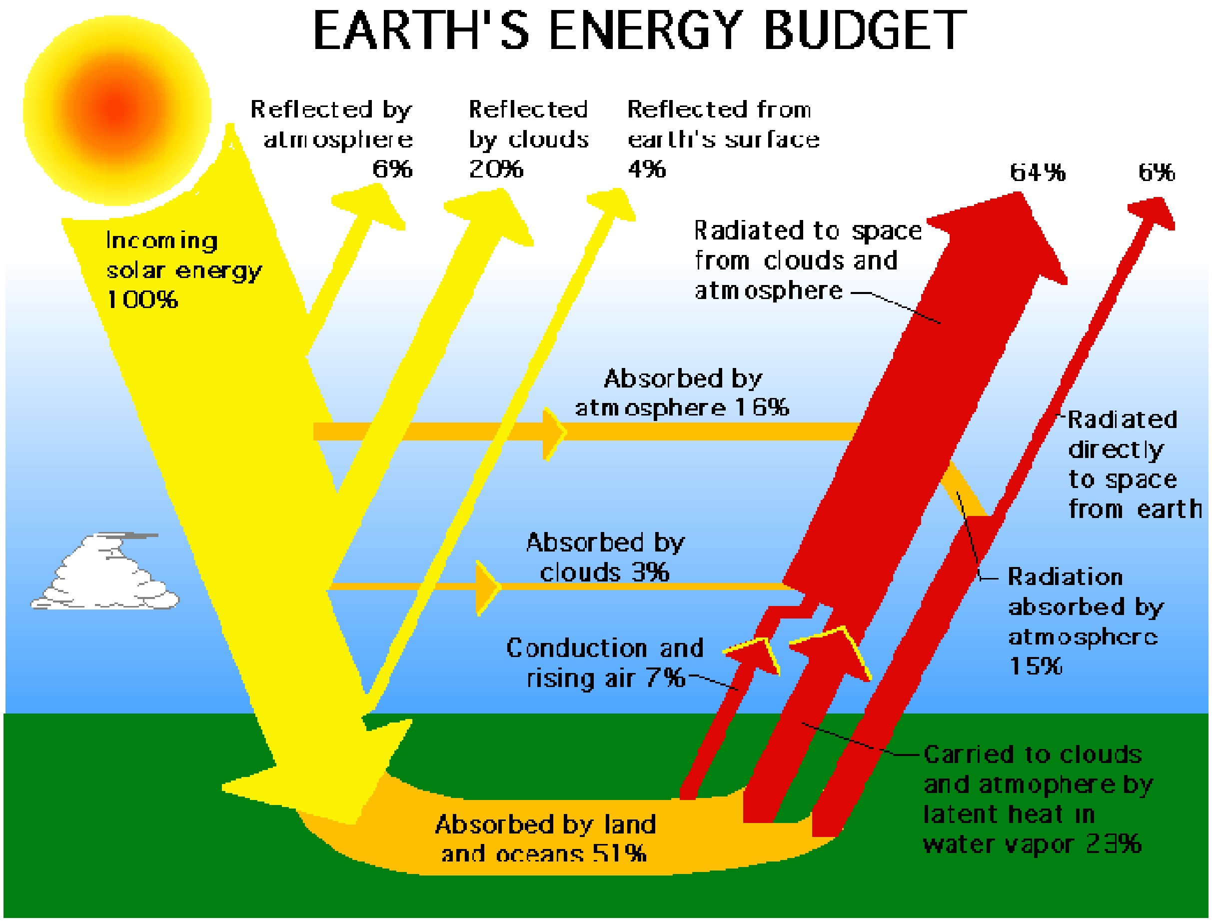
ADVANTAGES

- Once solar panels are installed, they produce energy without generating pollution.
- They operate with little maintenance.
- Competitive where grid connection or fuel transport is difficult. For example: island communities, remote locations, etc.
- A solar panel saves approximately 1kg of carbon dioxide per kWh. The below illustration below tell you a bit more

DISADVANTAGES

- Solar energy systems, of course, do not work at night.
- Nowadays solar cells are costly.
- For larger applications, a lot of land is needed

ENERGY FROM SUN



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. 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.

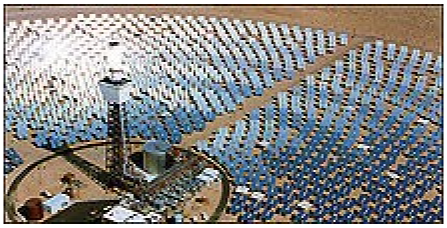
Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into 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. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass. 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.

From the table of resources it would appear that solar, wind or biomass would be sufficient to supply all of our energy needs, however, the increased use of biomass has had a negative effect on global warming and dramatically increased food prices by diverting forests and crops into biofuel production. As intermittent resources, solar and wind raise other issues.

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.

ENERGY STORAGE METHOD



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

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

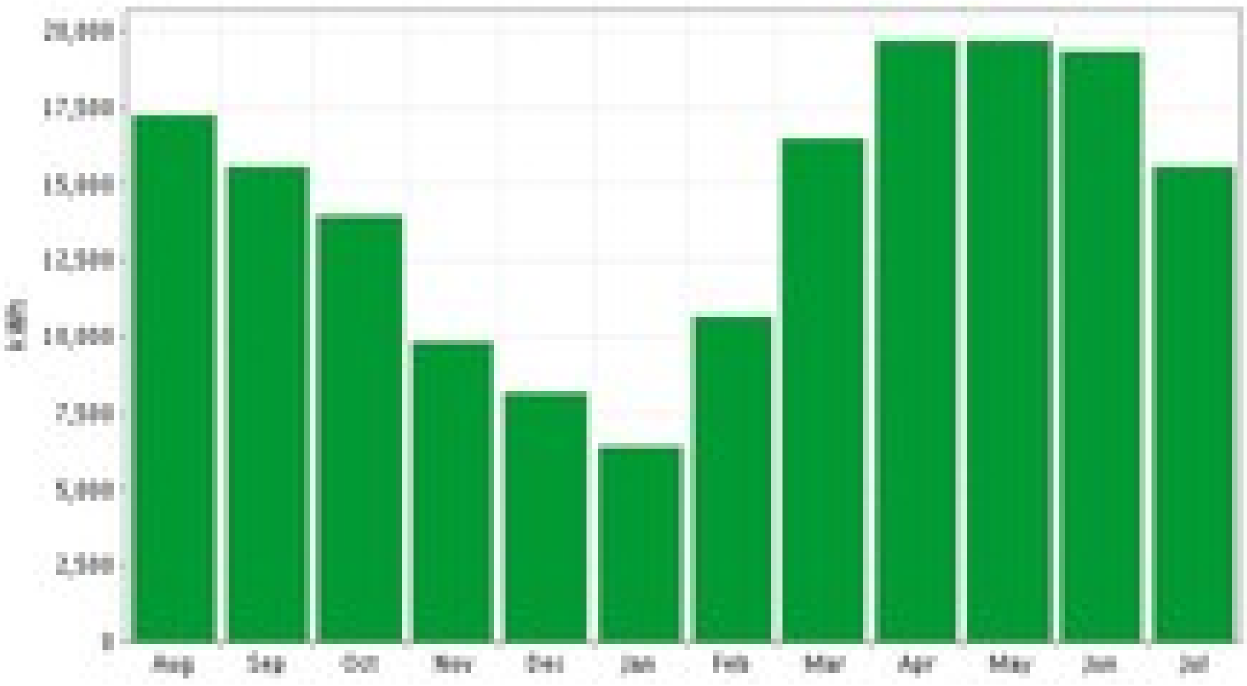
Thermal mass systems can store solar energy in the form of heat at domestically useful temperatures for daily or seasonal durations. Thermal storage systems generally use readily available materials with high specific heat capacities such as water, earth and stone. Well-designed systems can lower peak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

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.

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%.

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. Net metering programs give these systems a credit for the electricity they deliver to the grid. This credit offsets electricity provided from the grid when the system cannot meet demand, effectively using the grid as a storage mechanism.

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.

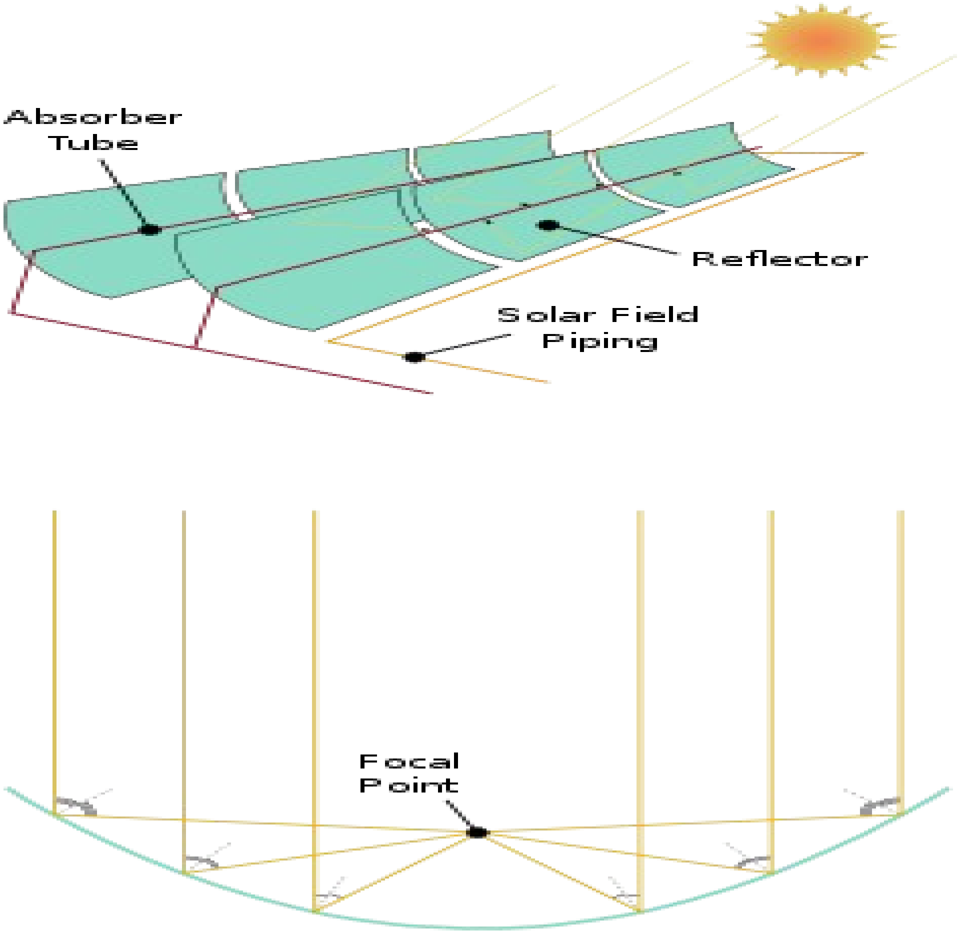


Seasonal variation of the output of the solar panels

TYPE OF SOLAR COLLECTOR FOR ELECTRICITY GENERATION

Parabolic troughs, dishes and towers described in this section are used almost exclusively in solar power generating stations or for research purposes. The conversion efficiency of a solar collector is expressed as eta0 or η0.

Parabolic trough



Parabolic trough

This type of collector is generally used in solar power plants. A trough-shaped parabolic reflector is used to concentrate sunlight on an insulated tube (Dewar tube) or heat pipe, placed at the focal point, containing coolant which transfers heat from the collectors to the boilers in the power station.

Parabolic dish

Solar Parabolic dish

It is the most powerful type of collector which concentrates sunlight at a single, focal point, via one or more parabolic dishes—arranged in a similar fashion to a reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This geometry may be used in solar furnaces and solar power plants.

There are two key phenomena to understand in order to comprehend the design of a parabolic dish. One is that the shape of a parabola is defined such that incoming rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. The second key is that the light rays from the sun arriving at the Earth's surface are almost completely parallel. So if dish can be aligned with its axis pointing at the sun, almost all of the incoming radiation will be reflected towards the focal point of the dish—most losses are due to imperfections in the parabolic shape and imperfect reflection.

Losses due to atmosphere between the dish and its focal point are minimal, as the dish is generally designed specifically to be small enough that this factor is insignificant on a clear, sunny day. Compare this though with some other designs, and you will see that this could be an important factor, and if the local weather is hazy, or foggy, it may reduce the efficiency of a parabolic dish significantly.

In some power plant designs, a Stirling engine coupled to a dynamo is placed at the focus of the dish, which absorbs the heat of the incident solar radiation, and converts it into electricity.

Power tower

Power Tower

A power tower is a large tower surrounded by small rotating (tracking) mirrors called heliostats. These mirrors align themselves and focus sunlight on the receiver at the top of tower, collected heat is transferred to a power station below.

Solar pyramids

Another design is a pyramid shaped structure, which works by drawing in air, heating it with solar energy and moving it through turbines to generate electricity. Solar pyramids have been built in places like Australia. Currently India is building such pyramids.

Advantages

- Very high temperatures reached. High temperatures are suitable for electricity generation using conventional methods like steam turbine or some direct high temperature chemical reaction.

- Good efficiency. By concentrating sunlight current systems can get better efficiency than simple solar cells.
- A larger area can be covered by using relatively inexpensive mirrors rather than using expensive solar cells.
- Concentrated light can be redirected to a suitable location via optical fiber cable. For example illuminating buildings.
- Heat storage for power production during cloudy and overnight conditions can be accomplished, often by underground tank storage of heated fluids. Molten salts have been used to good effect.
-

Disadvantages

- Concentrating systems require sun tracking to maintain Sunlight focus at the collector.
- Inability to provide power in diffused light conditions. Solar Cells are able to provide some output even if the sky becomes a little bit cloudy, but power output from concentrating systems drop drastically in cloudy conditions as diffused light cannot be concentrated passively.

Types of solar collectors for heat

Solar collectors fall into two general categories: non-concentrating and concentrating. In the non-concentrating type, the collector area (i.e. the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation). In these types the whole solar panel absorbs the light.

Flat plate and evacuated tube solar collectors are used to collect heat for space heating or domestic hot water.

Flat plate collectors

Flat plate thermal system for water heating deployed on a flat roof.

Flat plate collectors, developed by Hottel and Whillier in the 1950s, are the most common type. They consist of (1) a dark flat-plate absorber of solar energy, (2) a transparent cover that allows solar energy to pass through but reduces heat losses, (3) a heat-transport fluid (air, antifreeze or water) flowing through tubes to remove heat from the absorber, and (4) a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel or copper, to which a black or selective coating is applied) backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. Fluid is circulated through the tubing to transfer heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger. Some fabricates have a completely flooded absorber consisting of two sheets of metal stamped to produce a circulation zone. Because the heat exchange area is greater they may be marginally more efficient than traditional absorbers.[1]

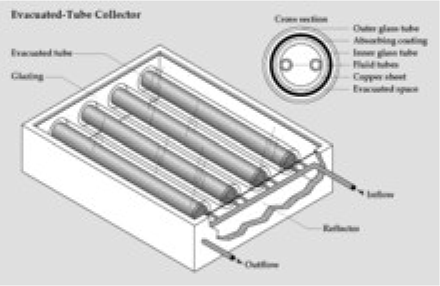
As an alternative to metal collectors, new polymer flat plate collectors are now being produced in Europe. These may be wholly polymer, or they may include metal plates in front of freeze-tolerant water channels made of silicone rubber. Polymers, being flexible and therefore freeze-tolerant, are able to contain plain water instead of antifreeze, so that they may be plumbed directly into existing water tanks instead of needing to use heat exchangers. By dispensing with a heat exchanger in these flat plate panel, temperatures need not be quite so high for the circulation system to be switched on, so such direct circulation panels, whether polymer or otherwise, can be more efficient, particularly at low light levels. However, polymer collectors suffer from overheating when insulated, as stagnation temperatures can exceed the melting point of the polymer. For example, the melting point of polypropylene is 160°C, while the stagnation temperature of insulated thermal collectors can exceed 180°C.

In areas where freezing is a possibility, metal collectors must be carefully plumbed so they completely drained down using gravity before freezing is expected so that they do not crack. Other collectors are part of a sealed heat exchange system, rather than having the potable water flow directly through the collectors. A mixture of water and propylene glycol (which is used in the food industry) can be used as a heat exchange fluid to protect against freeze damage, down to a temperature that depends on the proportion of propylene glycol in the mixture. The use of glycol lowers the water's heat carrying capacity only marginally, while the addition of an extra heat exchanger may lower system performance at low light levels.

A pool or unglazed collector is simple form of flat-plate collector without a transparent cover. It is used for pool heating and can work quite well when the desired output temperature is near the ambient temperature (that is, when it is warm outside). As the ambient temperature gets cooler, these collectors become ineffective.

Most flat plate collectors have a life expectancy of over 25 years.

Evacuated tube collectors



Evacuated (or vacuum) tubes panel.

Evacuated tube collectors have multiple evacuated borosilicate glass tubes which heat up solar absorbers and, ultimately, solar working fluid (water or an antifreeze mix—typically propylene glycol) in order to heat domestic hot water, or for hydronic space heating. The vacuum within the evacuated tubes reduce convection and conduction heat losses, allowing them to reach considerably higher temperatures than most flat-plate collectors. Two types of tube collectors are distinguished by their heat transfer method: the older type pumps a heat transfer fluid (water or antifreeze) through a U-shaped copper tube in each of the glass collector tubes. A newer type uses a sealed heat pipe that contains a liquid that vapourises as it is heated. The vapour rises to a heat-transfer bulb positioned outside the collector tube in a manifold through which water (in direct systems) or heat transfer fluid (HTF in indirect systems) is pumped. The vacuum that surrounds the outside of the tube reduces heat loss to the outside, therefore the greater efficiency of evacuated tube collectors. Therefore they can perform well in colder conditions. The advantage is largely lost in warmer climates, except in those cases where very hot water is desirable, for example commercial process water. The high temperatures that can occur may require special system design to avoid or mitigate overheating conditions though some have built in temperature limitation.

The advantage over the flat-plate collectors is that the constant profile of the round evacuated tubes means that the collector is always perpendicular to the sun's rays and therefore the energy absorbed is approximately constant over the course of a day - provided the inner collecting tube is circular in section and not of the flat fin type. The question what to do with the "lost" sun shining through the gaps between evacuated tubes (gaps which can be as wide as the tubes' absorptive surface themselves) can be addressed either by adding specially curved metal reflectors under the evacuated tubes or by reverting to the use of flat plate collectors which are designed not to offer any gaps in the collector's heat interception profile. The gaps allow for snow to fall through the collector, minimizing the loss of production in some snowy conditions, though the lack of radiated heat from the tubes prevents effective shedding of accumulated snow.

Evacuated tube collectors are made of a series of modular tubes, mounted in parallel, whose number can be added to or reduced as hot water delivery needs change. They have rows of parallel transparent glass tubes, each of which contains a collector tube (in place of the collector plate to which metal tubes are attached in a flat-plate collector). In some cases, the tubes are covered with a special light-modulating coating. In an evacuated tube collector, solar heat passing through an outer glass tube heats the absorber tube contained within it. The absorber can either consist of copper (glass-metal) or specially-coated glass tubing (glass-glass). The glass-metal evacuated tubes are typically sealed at the manifold end, and the collector is actually sealed in the vacuum, thus the fact that the absorber and heat pipe are dissimilar materials creates no corrosion problems. Some systems use foam insulation in the manifold. Soda-lime glass is used in the higher quality evacuated tubes manufacture. Newer technology evacuated tube systems use a coated glass-and-metal absorber. The glass is a boron silicate material and the aluminum absorber plate and copper heat pipe are slid down inside the open top end of the tube. In lower quality systems moisture can enter the manifold around the sheet metal casing, and may eventually be absorbed by the glass fibre insulation and finds its way down into the tubes. This can lead to corrosion at the absorber/heat pipe interface area or freezing ruptures of the tube itself if the tube absorbs water.

The high stagnation temperatures can cause antifreeze to break down, so care must be used if selecting this type of system in temperate climates. Tubes come in different levels of quality so the different kinds have to be examined as well. High quality units can efficiently absorb diffuse solar radiation present in cloudy conditions and are unaffected by wind. They also have the same performance in similar light conditions summer and winter.

Comparisons of flat plate and evacuated tube collectors

A long standing argument exists between protagonists of these two technologies. Some of this can be related to the physical structure of evacuated tube collectors which have a discontinuous absorbance area. An array of evacuated tubes on a roof has 1) open space between collector tubes and 2) (vacuum-filled) space occupied between the two concentric glass tubes of each collector tube. Consequently, a square meter of roof area covered with evacuated tubes (collector gross area) is larger than the area comprising the actual absorbers (absorber plate area). If evacuated tubes are compared with flat-plate collectors on the basis of square meterage of roof occupied, a different conclusion might be reached than if the areas of absorber were compared. In addition, the way that the ISO 9806 standard [2]specifies the way in which the efficiency of solar thermal collectors should be measured is ambiguous, since these could be measured either in terms of gross area or in terms of absorber area

Solar thermal collector

Solar Thermal Collector Dish

A solar thermal collector is a solar collector designed to collect heat by absorbing sunlight. The term is applied to solar hot water panels, but may also be used to denote more complex installations such as solar parabolic, solar trough and solar towers. These complex collectors are generally used in solar power plants where solar heat is used to generate electricity by heating water to produce steam which drives a turbine connected to an electrical generator. A collector is a device for converting the energy in solar radiation into a more usable or storable form. The energy in sunlight is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. The solar energy striking the earth's surface depends on weather conditions, as well as location and orientation of the surface, but overall, it averages about 1,000 watts per square meter under clear skies with the surface directly perpendicular to the sun's rays.

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