

**Solar Electric and Solar Thermal Energy:
A Summary of Current Technologies**



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Power Terminology

1. GWh – Gigawatt hour: The gigawatt is equal to one billion (10^9) watts or 1 gigawatt = 1000 megawatts.
2. kV – kilovolt
3. kWh – kilowatt hour
4. PV – Photovoltaic
5. MV –Megavolt: A *megavolt* is 1 million volts in electronics and physics.
6. MW – Megawatt: a megawatt is equal to one million (10^6) watts
7. MWe – Megawatt electrical

List of Abbreviations

PV-Photovoltaic
CSR-Central Receiver System
CPV-Concentrated photovoltaic
DG-distributed generation
DC-direct current
AC-alternating current
IEA- International energy Agency
NASA- National Aeronautics and Space Administration
BC-Before Christ

Abstract

Energy is the most valuable resource and foundation of civilization. It is also our heritage for future generations. Preserving this resource for future requires a thorough understanding of energy resources, optimal operation and sustainable usage. Solutions that previously seemed impossible or too expensive, today, are technically and economically achievable. Application of new capacity generated by renewable energy sources, new management systems, advanced technologies and improving productivity can contribute to economic growth.

Solar energy is one of the most important sources of energy as it is free and no other country can charge for the use of the sun. Solar energy, on the other hand can be important because this energy is infinite.

Solar energy received by the earth in one hour is more than the energy used by world's population in one year. World attention to solar energy has risen recently due to technology development and lower cost of installation and operation along with environmental concerns about fossil fuels. According to experts, solar energy will soon become the favorite energy used. Increasing the efficiency of photovoltaic systems and reduced costs of associated equipment has impacts on this explosive growth.

Addressing the issues related to solar energy and renewable energy is important for everyone. This report investigates the nature of solar energy; various ways of exploiting it; and examining the state of the art technologies used to provide power from this profitable energy.

Key words:

Energy, renewable energy, fossil fuel, sun, solar energy, solar cell

1 Introduction

1.1 Nature of Solar Energy

The sun is a main source of renewable energy that could provide a limitless source of energy supply in many parts of the world. Lack of sun can easily end life. Without the Sun, the Earth's temperature will drop suddenly and Earth will be cold and dark, so no plant life and no human on earth will exist (NASA). The sun is the cause and origin of the various energy sources which are exist in the nature, such as fossil fuels which are stored deep in the earth; waterfalls and wind energy; plant, animal, and human growth; all organic matter that can be converted to heat and mechanical energy; along with sea waves, gravitational and tidal power occurs upon earth moves around the sun and moon.

Solar energy is produced through deep nuclear fusion reactions. In a fusion process, two atomic nuclei collide at very high speed and create a new form of nucleus. It can be done due to the extremely high temperature and high density in the sun's core. Although the positive charges tend to repel each other, they stay together due to the high temperature and density of the sun's core. (NESTA, National Earth Science Teachers Association)

The most common fusion in the sun is called the proton-proton chain. This process begins when the simplest form of the hydrogen nucleus (contain one proton) close together just for a moment. First a nucleus composed of two subatomic particles is created (deuterium formation) then deuterium fuses with another proton and a triple subatomic particle is created (helium nuclei). Two helium-3 nuclei fuse together and a nucleus with four subatomic particles is created (alpha particle form) also an electrically neutral subatomic particle called a neutrino produced in this process (nave, 2000). Finally, the nucleus, which is helium, consists of two protons and two neutrons. The Helium mass is slightly less than the mass of the four protons which it has been made from. This lost mass is converted into energy. The amount of this energy can be calculated by the famous formula $E=mc^2$ discovered by German physicist, Albert Einstein. In this equation, E represents energy, m the mass, and c is the speed of light. (nave, 2000)



Figure 1: Equation of Mass Energy Equivalence
Source: Jha 2010

1.2 History of Solar Energy

The use of solar energy dates back to the seventh century BC .it was used for heating, cooking, lighting or making fires. ¹

- Ancient Greeks and Romans was the first people who built their houses with solar heating and sunlight benefits.
- Seventh century BC: Ancient people used the magnifying glass to focus sunlight in order to light fires.
- Third century BC: Romans and Greeks used mirrors to light their torches.
- The second century BC: The Greek scientist, Archimedes, used reflected solar radiation from the sun and focused through a bronze shield.
- In the fourth century AD: Roman bathes were designed to heat water by using sunlight.
- In the thirteenth century: Pueblo Indians in North America built their cliff homes facing south to take advantage of sun heat during the winter.
- In 1767: Swiss scientists built the first solar collector.
- In 1816: Scottish minister Robert Stirling patented his invention to pre-heat the engine heater. Later this invention was used in the generation of electricity by solar heating.
- In1839: French scientist Edmund Becquerel discovered the photovoltaic effect. While he was working with electrolysis cell with two metal electrodes in the electrolyte dilution. he found out that when he placed it in the sun, the electricity generation rate would be increased.
- In 1860: French mathematician August Mouchet began to work on the solar steam engine. After 20 years, he and his assistant, Abel Pire, built a prototype of modern engines that are currently used in parabolic linear collectors.
- In 1837: Willoughby Smith discovers the photoconductivity of selenium.
- In1876: William Grylls Adams and Richard Evans Day discovered that selenium generates electricity when it is placed in the sun.
- In 1880: Samuel P. Langley invented a bolometer, a device to measure the power of solar thermal radiation.
- In 1883: Americans Charles Fritts, thought the idea of making solar cells from selenium wafers.
- In 188: Heinrich Hertz discovered that ultraviolet radiation provides the minimum voltage required for spark between two electrodes.
- In 1891: The first solar water heater was patented by American Clarence Kemp.
- In 1904: Wilhelm Hallwachs discovered that copper and copper oxides are photosensitive together.
- In 1905: Albert Einstein, with his theory of relativity, outlined the photoelectric effects.
- In 1908: William J. Bailey, mad a collector with copper coils and an insulated box

¹ For full detail go to: https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf

- In 1916: the photoelectric effects have been proved experimentally by scientists.
- In 1918: Polish scientist Jan Czochralski discovered how to grow single crystal silicon.
- In 1921: Albert Einstein received the Nobel Prize for his theory of the photoelectric effect.
- In 1932: photovoltaic effect in cadmium sulfide was detected.
- In 1954: three American scientists developed the first silicon photovoltaic cell.
- In mid-1950s: the world's first commercial office building which worked with solar water heater was designed.
- In 1963: Japan installed a 24 watt panel on a lighthouse.
- 1964: NASA's first satellite with a capacity of 470 MW fed by photovoltaic cells launched in space.
- In 1969: solar furnace using 8parabolic mirrors built in Odeillo, France.
- 1970: Elliot Berman designed cheaper solar cells; extensive use of photovoltaic becomes possible.
- In 1976 AD: NASA Lewis Research Center for the first time began to install 83 photovoltaic systems across the world to provide light in clinics, water pumping and etc.
- In 1981: the first solar plane flew from France to England.
- 1986: the largest solar thermal power plant at that time was launched in California.
- In 2001: thin film photovoltaic was made.
- In 2002: the largest rooftop solar systems were installed in California.
- In 2008: the largest solar park using thin film systems was established in Germany.
- In 2013: 930 megawatts of photovoltaic (PV) systems were installed in United States, which represents the largest quarter ever for residential PV installations ever.

2 Large-scale Solar Thermal Technology Systems

Solar thermal systems include those that are based on low temperature thermal collectors. These systems use heat from the sun for the final heat consumption. This technology system consists of two groups of flat solar collectors and a low concentration solar collector (concentrator collectors).

Thermal systems have a storage unit to provide heating at night. Most solar thermal systems are used for heating water in commercial buildings, swimming pools, water, large homes, apartment buildings and hotels. Also, a large part of the demand is for space heating/ cooling of buildings and supplying power for absorption heat pumps² with solar thermal technologies.

Some of the basic concepts of thermal systems are as follows:

- Working fluid is used to transfer the absorbed heat for suitable usage a heat transfer fluid such as oil, water or air is needed.
- Absorbent surfaces: dark surfaces made from different technologies to maximize the absorption of thermal energy. In solar power plants, absorbent surfaces are exposed where the sun is shine or is concentrated.
- Thermal storage system: stores solar energy to use at night or on a cloudy day. In solar water heaters, hot water storage tanks are used and in power systems, thermal energy is stored in reservoirs containing oil and sand.³

2.1 Flat- plate Collector

Flat plate collectors absorbs heat from the sun using a dark, flat ,metal plate to transfer the energy using heat-absorbing fluid, such as water or air. A flat –plate collectors consists of the following components:

- Glazing sheet that may include one or more layers of glass or transparent plastic.
- Heat absorbing riser tubes
- Absorber sheet (can be straight, wavy, fluted and usually in dark color) to which tubes and pipes are attached.
- Manifold or header: for draining the fluid flow and transferring the heat; it is usually installed at the top and bottom of the collector.
- Insulation to reduce heat loss, usually around or in the back of the collector and the tubes.
- Special frame to hold the collector components and keep them safe from dust, moisture and other external factors.

² Energy.gov, *Absorption Heat Pumps*, 2012

³ For more information go to: <http://www.sun.org.ir>

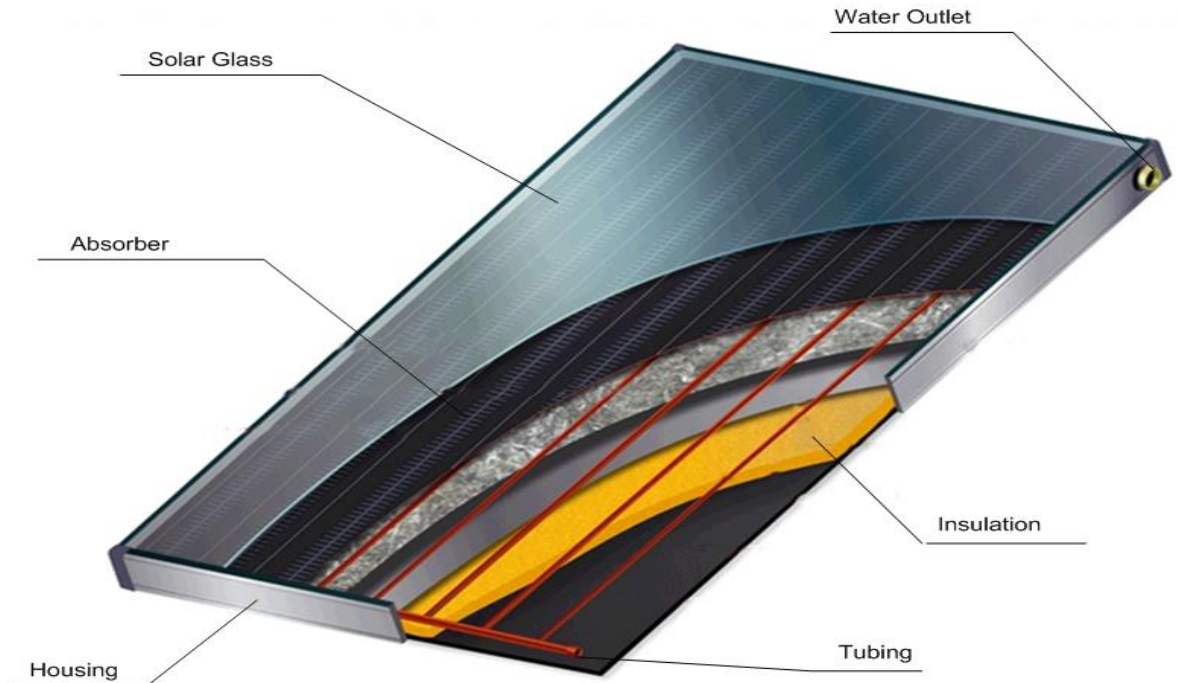


Figure 2: Anatomy of a solar flat plate collector

Source: (Solar fred, 2010)

Flat-plate collectors based on fluid bed type, structure and function are divided in to three categories, namely:

- Trickling-water collector
- Liquid-based collector
- Air-based collector

Trickling-water Collector

It was built and installed on a roof of a house for the first time in 1950s by Dr.Harry E.Tompson. (Canivan)

Water from the upper manifold trickles down to sloped corrugated collector .The water absorbs heat from the heated corrugated sheet while passing through valleys by gravity. Heated water goes down and collected to be use or stored.

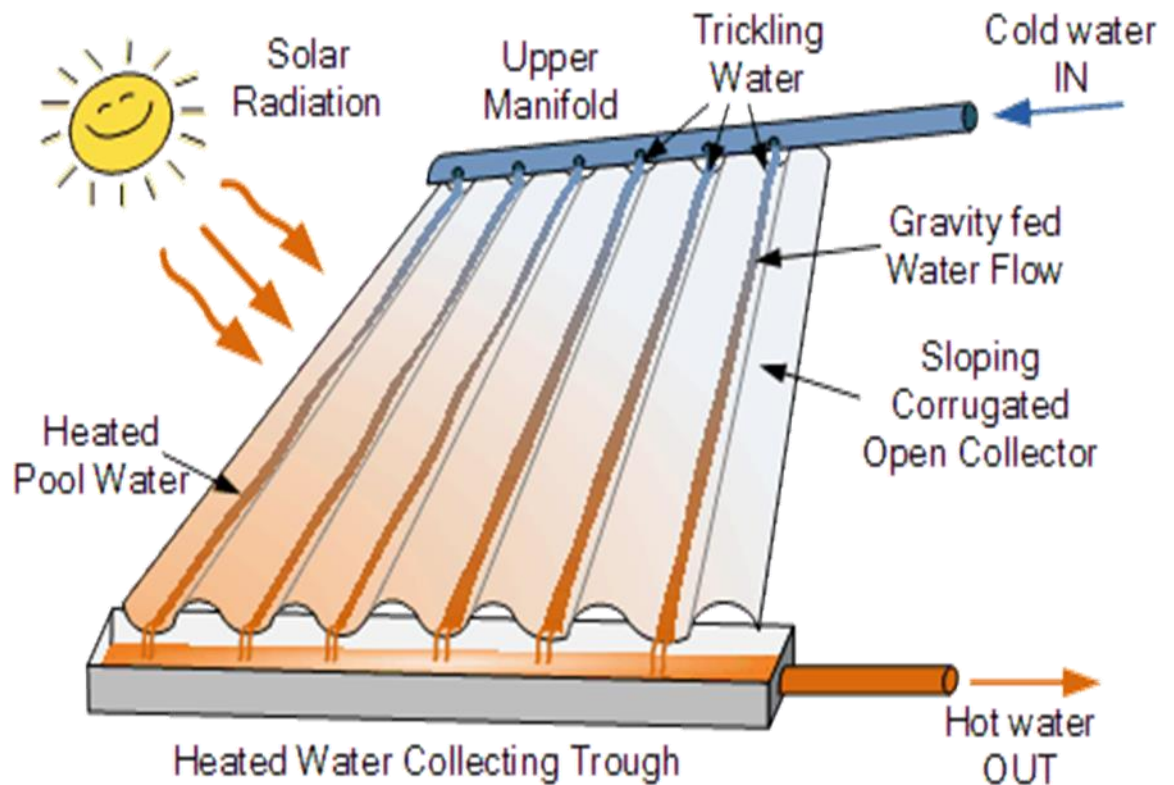


Figure 3:Trickling-down water collector
Source: Alternative Energy Tutorials

Liquid-based Collector

The working fluid on these collectors is usually water, oil or liquid with a low freezing point. Freezing of the water in the collector and the corrosion are the major problems in these types of collectors.

Flat plate collectors, collect direct and diffuse solar radiation so they don't need tracking systems. Although they having large heat absorbing-surface, they produce less heat with lower temperature in compare with concentrator collectors.

They are suited to warm up the water and air as they are less expensive than concentrator collectors.

Air-based Collector

In this type of collector, air or gas is used as a medium to transfer the heat. The advantage of this collector over the other types of liquid collectors is that there is zero corrosion and zero air frost. Having less weight than liquid-based collectors is another advantage of this type of collector as they don't have pressurized piping. Nevertheless, difficulty to regulate and low heat storage capacity of air are the main reasons why air-based collector are not that much common.

2.2 Concentrator Collector

With the help of advanced geometric design, direct solar radiation and part of diffused solar radiation are concentrated with concentrator collectors. With this type of collector, reflection surface are used to increase solar radiation. In order to achieve high temperatures, solar radiation will be concentrated in the focal area, for this purpose, concentrator collector must be able to track the sun during the day. Focusing on the focal area boosts given energy per unit.

Heat dissipation is reduced due to decreases in absorption surface, so higher temperatures and more heat is produced. Concentrator collector is not designed to use in cloudy conditions.

In comparison with flat-plate collector they have higher costs of regulation. Although they have a lower efficiency in low temperature, their efficiency is good in high temperature. The intensity of intake solar radiation by concentrator can get about 70-80 times more than flat collectors also they don't need insolation however it is crucial for flat collector. (suna)

3 Non-power Plant Applications of Solar Energy

There are a number of small scale solar energy technology options available for home and small businesses usage. These include:

- Solar water heating
- Solar heating and cooling
- Passive solar heating
- Active solar heating system
- Solar cooling system
- Solar desalinization
- Direct solar dryer
- Indirect solar dryer
- Solar cooker
- Solar furnace

These systems use flat-plate collection technologies and each is described in the following pages.

3.1 Solar Water Heater

These use solar energy to heat the water. They are composed of three parts: a collector, circuit piping, and heat storage tanks.

In most modern water heater, water and antifreeze solution moves between the tank and the collector in a closed cycle by circuit piping. The collector absorbs the sun's heat energy and transfers it to the working fluid. Heated fluid moves toward the storage tank where it passes through a heat exchanger and transfers its heat to the water in storage tank; after cooling down it goes back to the collector again so without mixing with consumable water, it always moves in closed cycle.

Solar water heaters fit into two categories, open and closed circuit systems. In both categories, they can work in thermosyphon (natural flow – a passive heat exchange) or a pump (forced heat exchange). The important part of the solar water heaters is the collector, in which the plate is heated by solar radiation and transferred its heat to the working fluid. This plate is always a dark color and has a special coating that maximizes energy absorption and minimizes heat dispersion. To achieve high temperatures, the plate and tube are set inside an insulated box covered with glass to optimize the greenhouse effect.

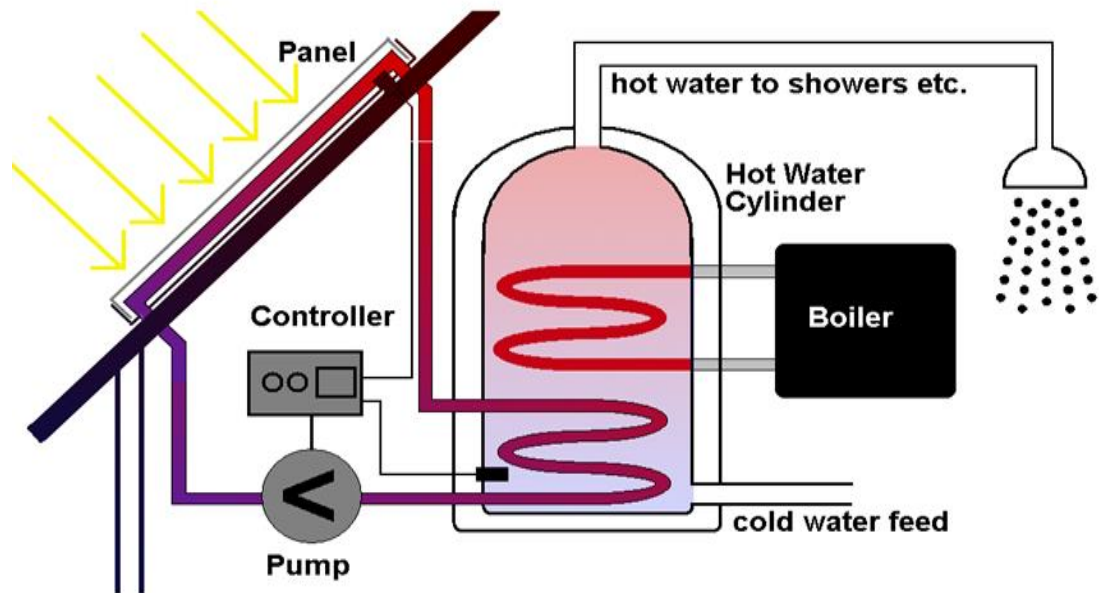


Figure 4: Solar water heater diagram
 Source: *Sunvelope*, 2011

3.2 Solar Heating and Cooling

Since a high percentage of energy consumption belongs to daily heating and cooling of buildings, it is important to design and implement buildings in order to make best use of solar energy. Supplying energy demand of the building is possible through *passive* and *active* forms. The supply of solar energy in the passive form is highly depending on quality of architecting the building; however, in the active form, it is necessary to access solar collector and another source of energy in order to transfer the heated fluid.

Passive Solar Heating System

In this system, energy of natural sources like the sun is used to heat up the building. It means that, with this type of system, the building must be designed to reduce dependency on fossil fuel, with zero to very little usage of fossil energy. There are different methods for achieving passive solar heating:

- Direct gain method
- Drum wall
- Solar chimney design
- Attached green house
- Pool on the roof

The following graphic illustrates some of the design considerations for passive solar hearing.

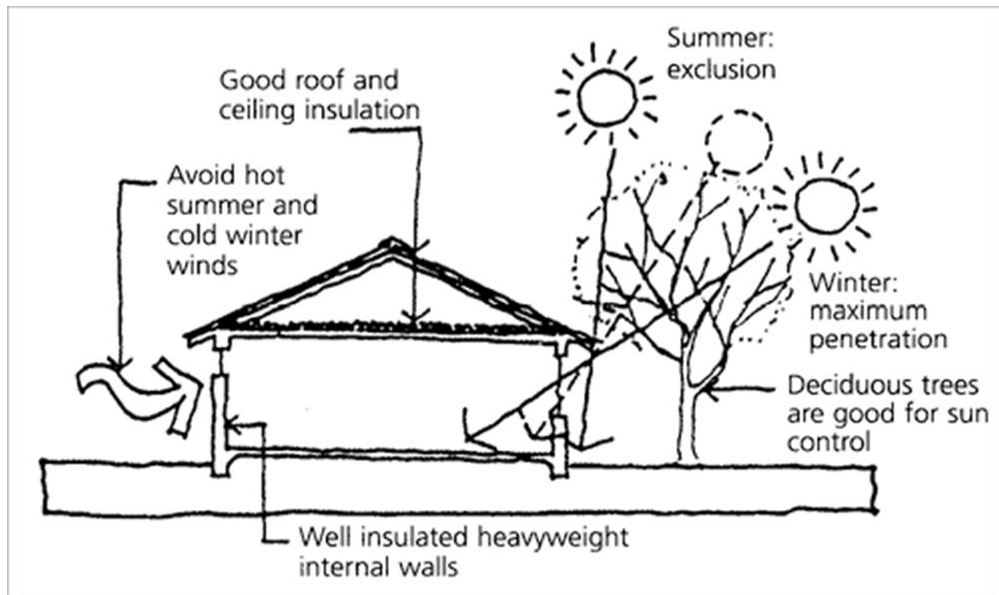


Figure 5: Passive solar heating

Source: Evans and Evans, 2007

Active Solar Heating

In the active system, different elements are used to supply heat for a building. Components used in these systems include collectors, thermal energy storage, fluid flow channels, pumps, piping, valves, dampers, manual or automatic control systems, auxiliary fuel systems and heat exchangers.

3.3 Solar Cooling System

Although solar heating systems are relatively inexpensive, solar cooling is difficult and expensive. In general, there are two solutions for solar cooling:

- Convert solar energy into electrical or mechanical energy and enable its use in compression chiller systems, or
- Convert solar energy into thermal energy and use it in the operation of an absorption chiller system.

3.4 Solar Desalinization

Principles of solar water purifier are simple. Plastic or glass cover on the top surface of the device plays a key role in the performance of this system.

The sun's rays passing through the brine pool and increased the temperature of the water inside to heat; produced steam hit the inner surface of the cover glass which has a temperature lower than the temperature of seawater desalination and began to distill. By collecting the distilled water, fresh water is obtained.

Solar desalination performances can be divided into two terms: Direct and Indirect methods. In direct method solar thermal energy is just used however in indirect method electrical energy is used as an alternate energy. Solar desalination must be designed according to the climate and weather condition of the interest regions.

3.5 Solar Dryer

This technique uses direct or indirect solar thermal energy with natural or forced air flow causes drying of the substances.

Direct Solar Dryer

It has easy and inexpensive application with no possibility of controlling the heat temperature. In this way, if fruits and vegetable overexposed by the sun, their color will be change and they lose plenty of their vitamins.

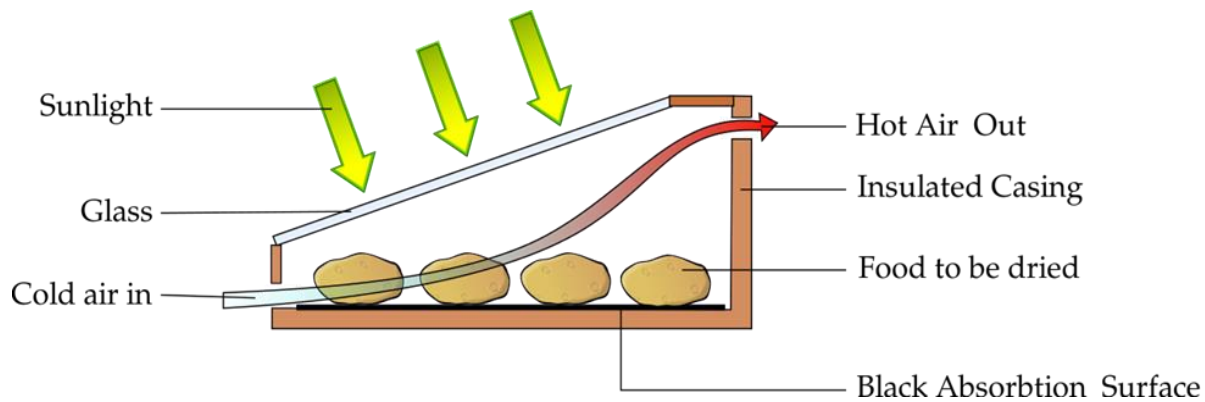
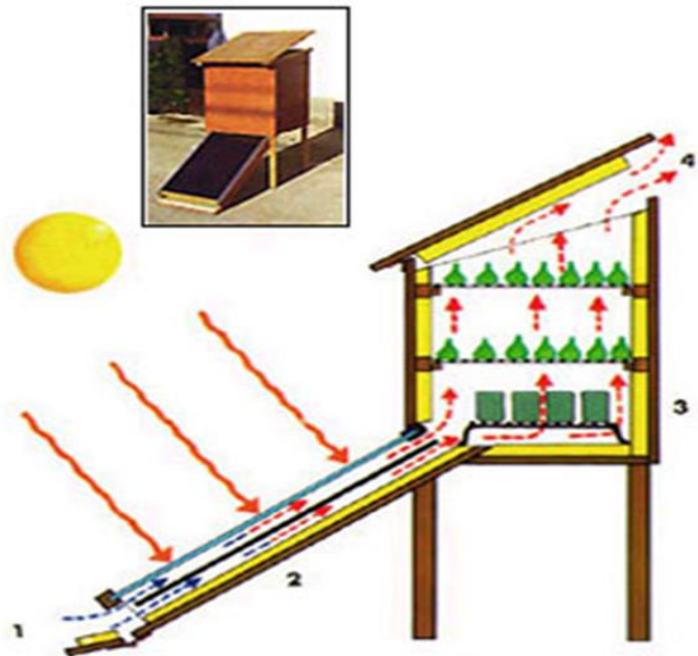


Figure 6: A schematic of a direct solar dryer
 Source: A. K. Karthikeyan, 2013

Indirect Solar Dryer

In this system, the temperature can be controlled and food is not directly exposed by the sunlight so color remains constant. This device fits the needs of the villages in the drying of fruits and vegetables, as well as in industrial dried rice and vegetable production.

Figure 7: Indicator solar dryer
 Source: Terra Fundacion



3.6 Solar Cooker

This technology uses direct sunlight to cook foods and vegetables. There are three common types of solar cookers:

- Solar Parabolic Cooker,
- Solar Panel Cookers and
- Solar Box Cooker

The **Solar parabolic cooker** is also called a concentrator cooker, this included a parabolic dish which is used to cook foods by putting them on the focal point of the dish. This type of cookers is a bit complicated to construct and needs direct supervision as the concentrator requires frequent adjustment in order to achieve maximum effectiveness. Cooking is accomplished more quickly as this type of cooker can reach high temperature rapidly.

A **solar panel cooker** consists of a reflective panel, transparent glass bowl and darkened pan. It is usually simpler and more economical to build also it is adaptable in most of situation. Food cooked in this cooker usually contains more moisture so it is good to use for soups, stews, etc.

The **solar box (oven) cookers** are the most common type of cookers. This technology is like traditional oven with food placed in an insulated box. The box cooker can be made of any kind of material, like wood or plastic and then covered by transparent glass or plastic to permit solar rays inside the box and, at the same time, prevent trapping the solar rays that have been converted to heat energy. For effective and higher temperature cooking, reflector panels can be added to concentrate the sun rays toward the cooking pot. These cookers can easily achieve temperature above 100° C so it is possible to use them for frying. (Vickery, 2014)

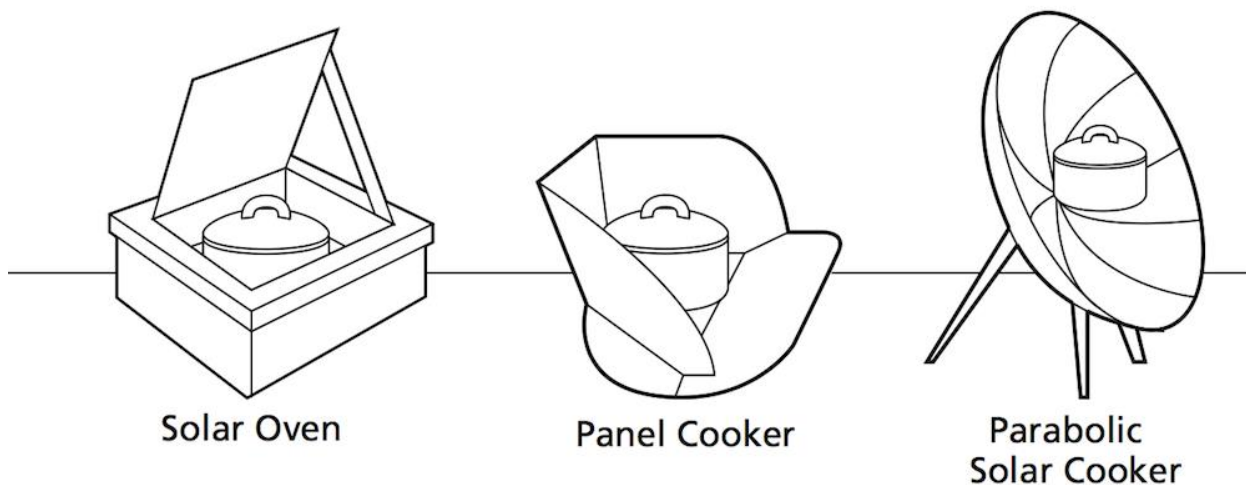


Figure 8: Solar cookers designs
Source: Vickery, 2014

3.7 Solar Furnace

This type of power plant captures sunlight and uses it to produce high temperature for industrial purposes. It is done by concentrating sunlight via curved mirrors on the focal point of the furnace. The most common solar furnace includes one flat mirror and one parabolic mirror. Sunlight is radiated to the flat mirror and then reflects back to the parabolic mirror so temperature in the focal point goes up.

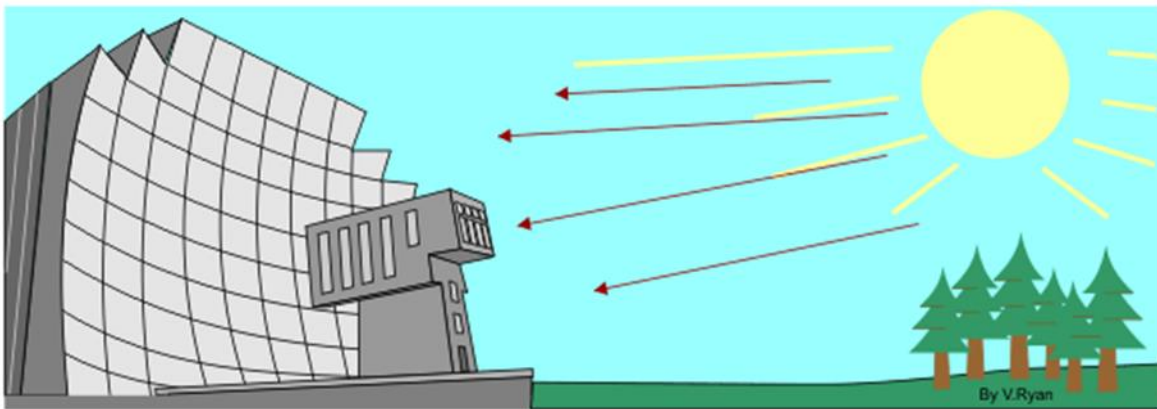


Figure 9: Solar furnace

Source: (Ryan, 2005)

4 Solar Power Plant Technology

Solar thermal power plants are divided into 5 categories:

- Parabolic trough
- Central receiver system (CRS)
- Parabolic dish/stirling dish
- Solar chimney
- Fresnel collector

4.1 Parabolic Trough Power Plant

This power plant uses long parallel rows of concentrators. The concentrator consists of a parabolic reflective surface made from glass to form a mirror that is placed on an arched structure. The receiver is made from specially coated absorber tubes covered by Pyrex glass set along the focal line. Distal parts of the receiver located on the two fulcrums are mounted on the main structural beams. Tracking systems are single-axis devices tracking the sun from east to west so that the sun's rays reflected on the absorber tube for the entire tracking time.

A heat transfer fluid (oil) with a temperature of about 400 ° C flows through the absorber tube, when it reaches the heat exchanger; it converts water into steam. Superheated steam passes

through a turbine, generating electrical energy. This type of power plant with heat storage is capable of generating electricity even after sunset.

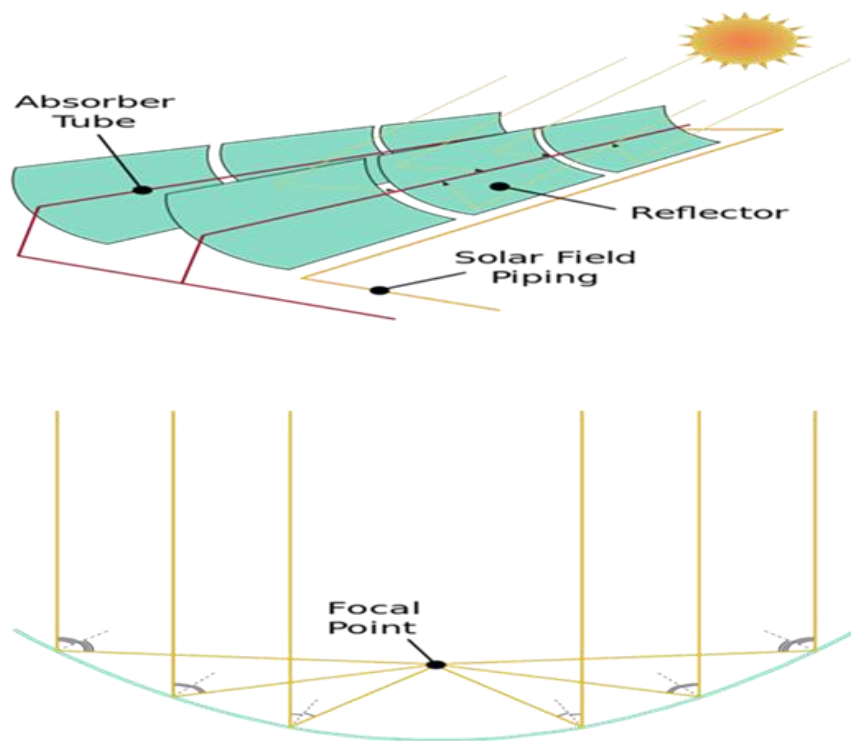


Figure 10: A diagram of a parabolic trough solar farm (top) and an end view of how a parabolic collector focuses sunlight onto its focal point. Source: Andrew Buck, 2008

The main components of a parabolic power plant include:

- Parabolic reflectors
- Receiver; to absorb reflected radiations and heat the heat transfer fluid.
- Steel made supporter and foundation
- Electric power production systems
- Heat transfer equipment
- Equipment to transfer heat loss to the outside environment

4.2 Central Receiver System (CRS) Power Station

This system includes a set of mirrors (heliostat) that each separately concentrate solar energy and reflect it to the central receiver on the top of the tall tower. Energy collected in the central receiver is transferred to the heat exchanger mounted on the tower, where water is converted to super-heated steam. This steam drives a generator turbine that is installed at the bottom of tower to produce electricity.

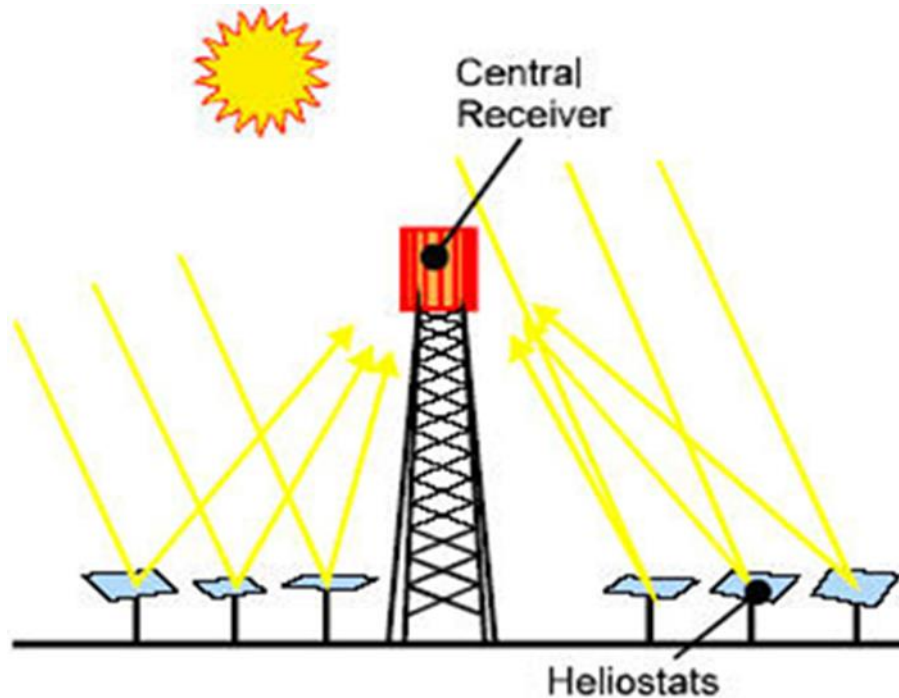


Figure 10: Diagram illustrating the central receiver principle
Source: (Solar PACES)

The main components of a CRS power station:

- Heliostat, solar radiation collector system
- Central receiver, which absorbs heat from solar radiation and make it usable.
- Thermal energy transfer system absorbs heat passed through receiver and moves it around. In the basic design, water and steam is used as an absorbent and heat transporter fluid, however in the more developed designs, molten sodium and potassium have been used.
- The power conversion system
- Energy storage system

4.3 Stirling Dish Power Plants

These power plants use sunlight beamed on surface of the parabolic concentrator and accumulated on the focal point. For these systems to be effective, the collectors must always track the sun. So they need dual-axis tracking mechanisms. In such systems, sunlight is concentrated on the focal point and a Stirling engine converts the concentrated thermal energy in to mechanical energy. Then an alternator uses this mechanical energy to generate electricity.



Figure 11: Stirling dish power plant

Source: TCS Power

The main components of Stirling dish power plants include:

- Concentrator surfaces that focus the rays of the sun at the focal point.
- Stirling engine converts concentrated thermal energy in to mechanical energy and generate electricity via an alternator.
- Tracking system and control system tracks the sun making sure that the receivers are always pointing toward the sun surface to focus the light on the receiver of Stirling engine. Control system uses different information coming from different sensors and the Stirling engine to issue right control signal in any command mode.
- Structural and foundation: to keep the concentrators, Stirling engines and other components safe from withstand inertia loads, wind and earthquakes; strength foundation and structural are needed.

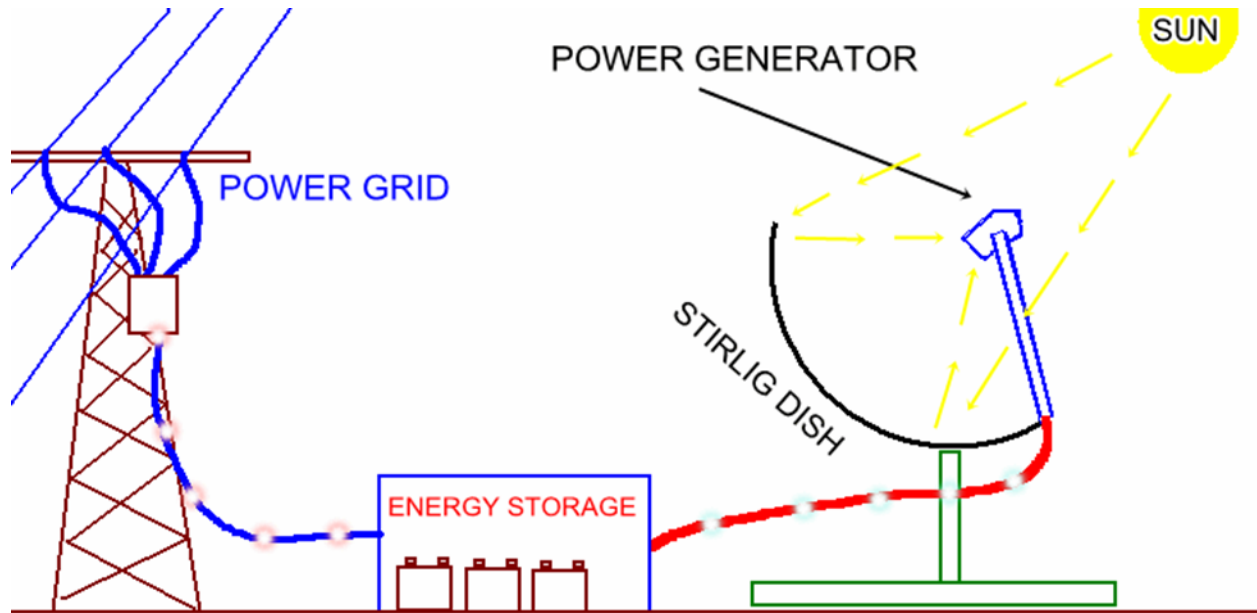


Figure 12 Stirling power plant diagram
 Source: love4earth.es.t

4.4 Solar Chimney Power Plant

This kind of solar power system is the combination of solar air collector and air steering column that produces inducted air stream. The air stream causes the turbine to rotate and generate electricity.

Application of Solar Chimney Power Plant

Sun warms up the air under the photoconductive collector roof that surrounds the central tower (chimney). The junction of central tower with collector roof is constructed to be resistant against air infiltration. Warm air is lighter than cold air, so it will rise up through the tower.

Steady air flow causes conversion of air to mechanical energy through the turbines, then electrical energy produced via generators. In order to produce electricity 24 hours per day, water pipes or water container under the collector roof are used. These pipes or container only need to be filled once.

The main components of solar chimney power plant

- The semi-transparent roof (e.g. glass) installed at a several meters above the ground.
- An elevated chimney, located in the center of collector roof.
- Wind turbines, installed in the junction of chimney with roof.
- Piece of coated land

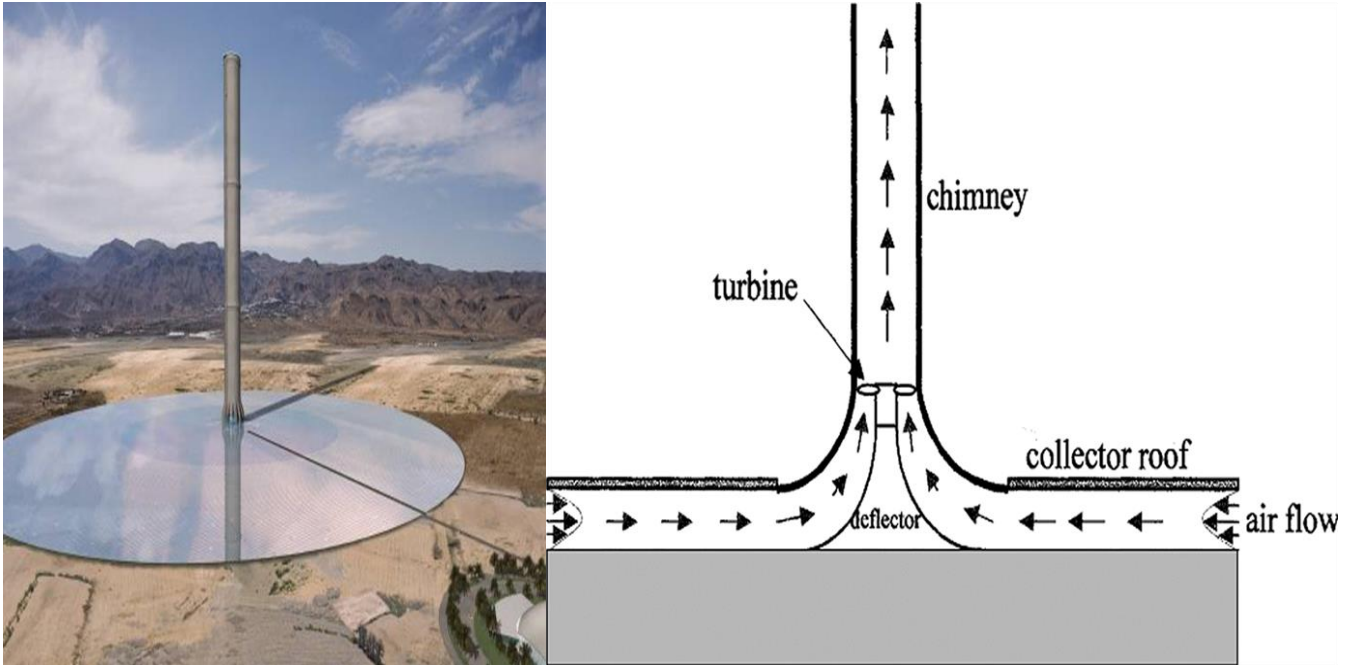


Figure 13: Solar Chimney power plant

Source: Left ASME, 2012, Right – Renewable Energy World, 2003

4.5 Fresnel Solar Power Station

In this type of power plant, the Fresnel collector is used to concentrate sun light on the receiver tube. Like the parabolic power plant, collectors are installed in linear order, north to south. Collectors include plenty of long, narrow flat mirrors. The angle of each mirror is set to best concentrate the sunlight reflection on the receiver. There is a secondary reflector as a parabolic pair in the receiver to collect the reflected energy and concentrate it on the receiver tube so, the fluid (e.g. oil) in the receiver tube will be heated. The hot fluid then goes through a heat exchanger to power up a steam generator.

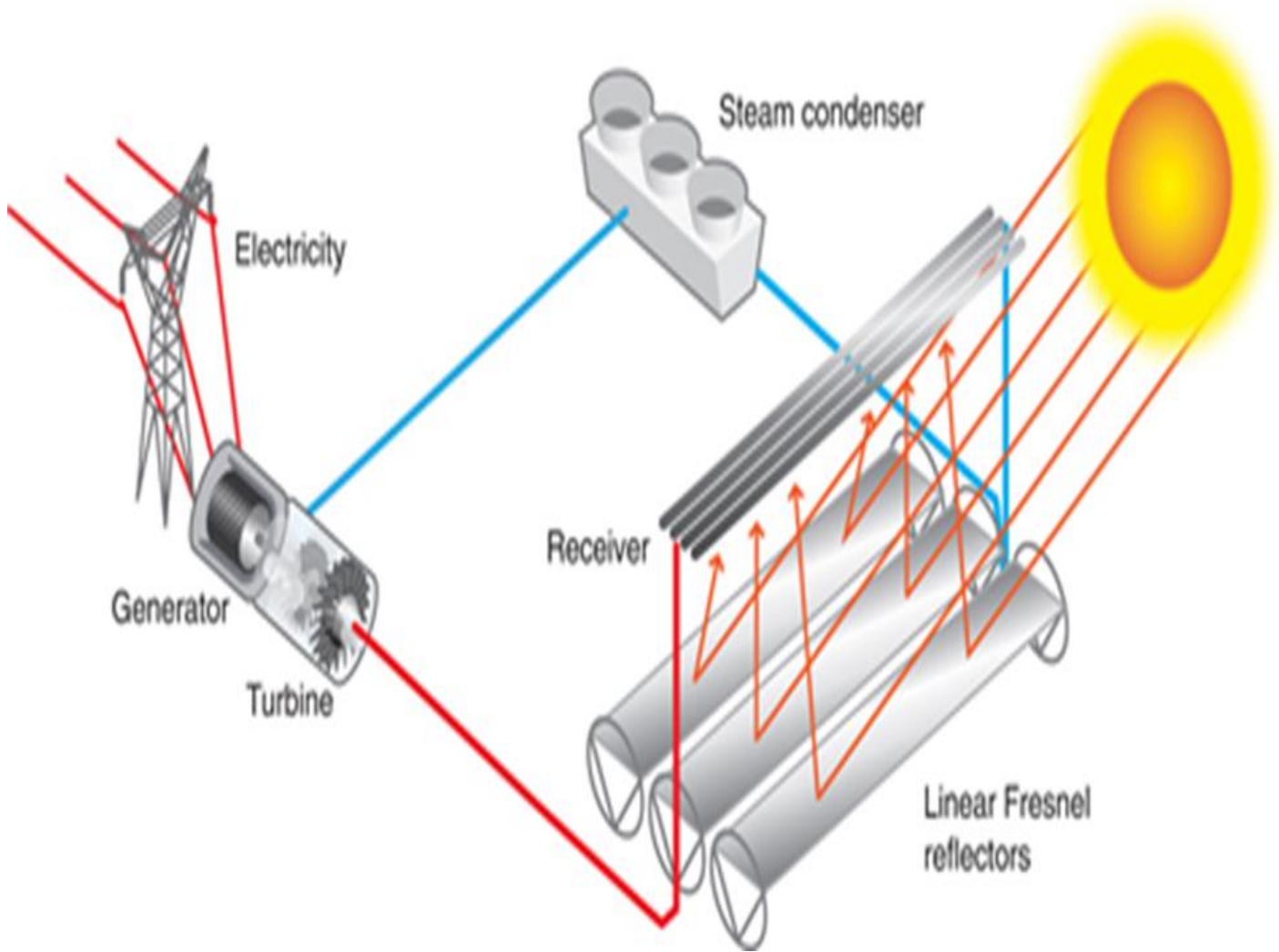


Figure 14: Fresnel Solar Power Station
Source: (DOE/NREL, 2000)

5. Photovoltaic (PV) Power Systems

Some materials are able to absorb photons of light and release electron, this phenomenon is called photoelectric effect. Photovoltaic cells convert sunlight directly into electrical energy without using any mechanical or chemical mechanism.

Photovoltaic cell operation is based on the principal of semiconductor technology. When two semiconductors, such as silicon and gallium arsenide, are put into contact with each other and exposed to light, electricity will flow between them. This was first noted by Edmund Becquerel in 1839 (SEIA). Actual development of PV technology began in the 1950s and gained greater impetus through the National Aeronautics and Space Administration (NASA) space program during the 1960s (NASA). Now researchers are trying to increase conversion efficiencies and mass production strategies in order to cost down the producing of PV modules.

Photovoltaic energy offers several advantages over other energy sources

- It consumes no conventional fossil fuels,
- Creates no pollution
- Is a widely available and reliable source of energy-
- Has no associated storage or transportation difficulties
- Is eminently reliable and practicable for wide scale power production

However, this technology can be limited because of the movement of the sun, especially in extreme latitudes.

A variety of materials may be used in the manufacture of solar cells, each of which has different cost efficiency. In fact, PV cells must be designed to convert different wave lengths of sunlight that reaches the earth's surface into useful energy with high efficiency.

The materials used to make solar cells can be classified into three generations:

- The first generation of PV technologies: *crystalline silicon cells*.
Silicon is one of the most abundant elements on the earth and it is very suitable for use in photovoltaic systems. Depending on how silicon wafers are made, crystalline silicon cells are divided into two general categories: mono-crystalline silicon and poly-crystalline silicon. Other crystalline categories include gallium arsenide cells.
- Second generation of PV technologies: *Thin film solar cells*.
After more than 20 years of research and development, thin film solar cells have started to spread. Compared to silicon wafers, thin films reduced the cost of electricity quite significant. Three main types of thin film solar cells, which have already been commercialized, are:
 - Amorphous silicon (aSi/ μ c-Si)

- Cadmium telluride (Cd-Te)
- Copper–indium–selenide (CIS) and Copper- indium –gallium- selenide (CIGS)
- The third generation of PV technologies: *In development*.
These technologies are still and still being developed and tested. They include:
 - Concentrated photovoltaic (CPV)
 - Organic solar cells
 - Dye-sensitized solar cell
 - Polymer solar cells
 - Liquid-crystal solar cells

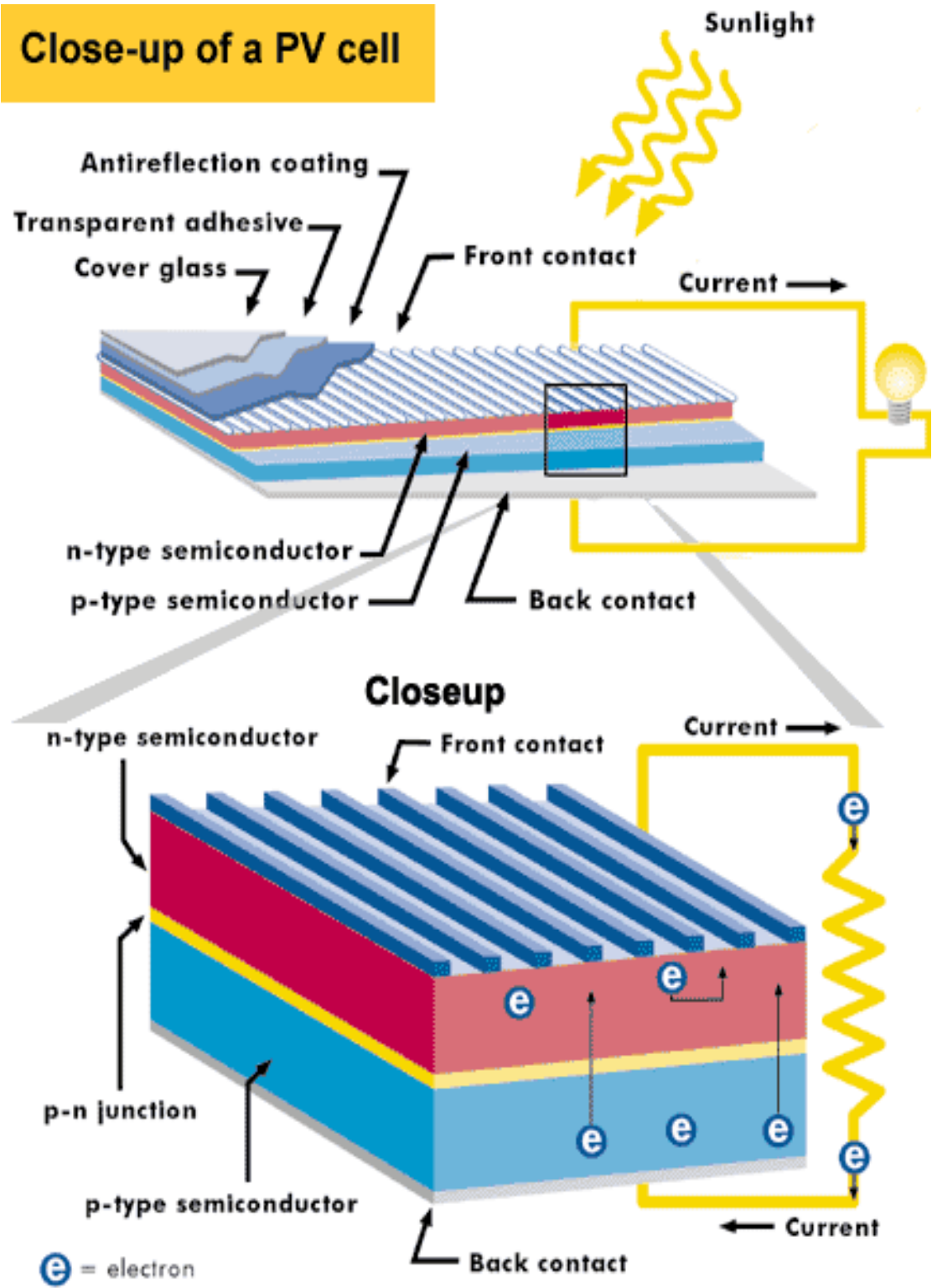


Figure 15: Crystalline Silicon Cell Structure
 Source: Four Peaks Technologie, 2011

Layers of a Solar Cell

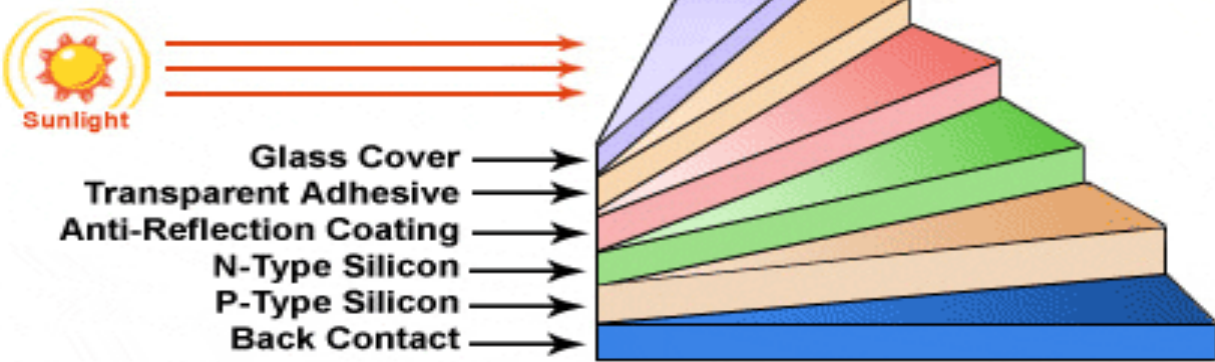


Figure 16: Layers of a solar cell

Source: Dako Power, cc 2008

5.1 Photovoltaic Systems Applications

Photovoltaic systems are applicable for public consumption and agriculture. It can be connected to the power grid or works as stand-alone systems (autonomous) with the fixed or mobile structure in small or large scale from providing energy required for small calculators to large power plant. Possibility to track the sun and maximizing electricity generation from the sun light during the day are the key advantages of using mobile system however due to the high risk of failures in mechanical systems, using this technology for small and sporadic scale are not recommended. This technology has been used only in few PV power plants around the worlds.

5.2 Methods for Using Photovoltaic Energy

Grid Connected

In this method, electrical energy from photovoltaic systems is transferred directly to the national power grid. Voltage and frequency of the electrical energy produced by the photovoltaic system can be adjusted to meet the voltage, frequency and phase characteristic of the national power grid using electrical equipment to convert direct current (DC) to alternating current (AC), such as inverters connected to the network and etc.)

Centralize/decentralize form of grid connected PV system boosts energy power of distribution network (injected voltage and current prevents voltage drop of power distribution network during the day.)

By implementing grid connected PV system, each member of national power grid represents as a small distributed generation (DG). In addition to providing enough supply of electrical energy required by the consumer; a consumer surplus can be injected to distributed network grid.

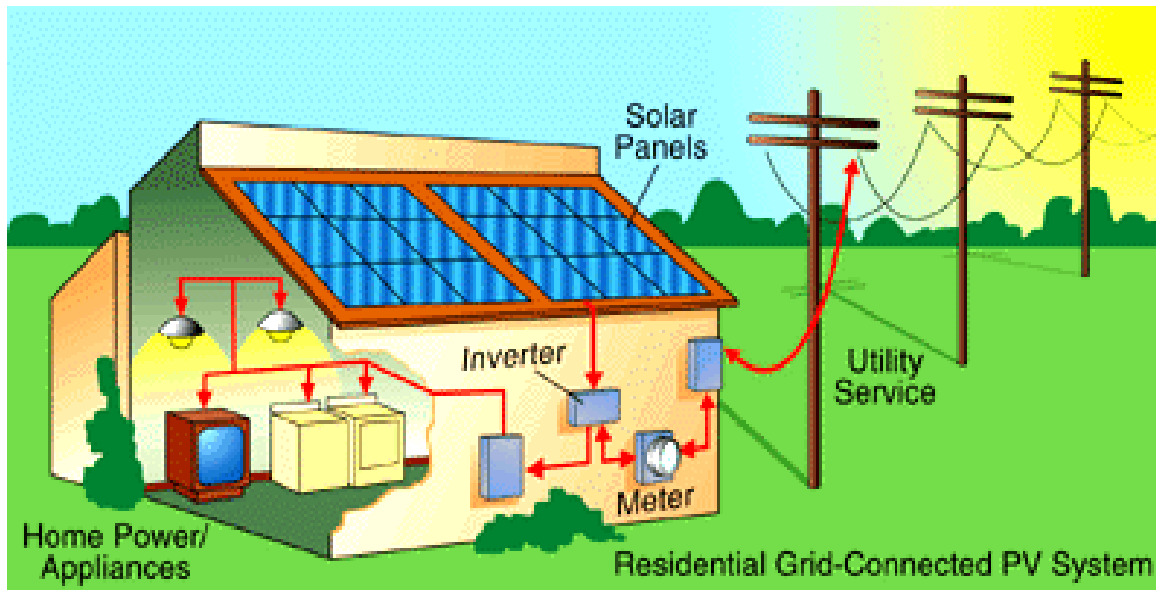


Figure 17: grid-connected small solar electric systems

Source: *Encyclopedia of Science*.

Stand-alone PV System

A stand-alone system provides energy for telecommunications, residential house, nomadic tents and rural cottages needs, in general areas lacking electricity network. These systems produce a high proportion of the world's off-grid power generation. In many countries (especially developing countries) these systems can be used to provide electrical energy requirements of villages without electricity these system, For example, Indonesia has been providing electricity for rural households in this way, since 2007⁴. (RENDEV, 2009)

The major benefits of these systems, particularly in deprived and rural areas are:

- No need for fuel and problems to providing it, especially in hard to reach areas.
- No need for constant repair and maintenance with proper lifetime.

5.3 Photovoltaic Power System Applications

In addition to stand-alone power systems, photovoltaic energy can be used in other ways. These are described below:

Water Pumping

Solar/photovoltaic energy is used effectively for water. Solar pumps are applicable in domestic use, irrigation, livestock watering, aquaculture, forests watering, meadows, fountains, etc. Increasing demands in this sector reflects the capabilities and functionality of the system.

⁴ http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/rendev_solar_energy_applications_in_indonesia.pdf



Figure 18: Application of solar water pumping system
Source: (Dr. Solar)

Solar Lighting

Solar powered lighting can be used in residential areas and schools, between road stations, tunnels, marine lanterns, park lights, etc. The advantage of this technology is providing light during the night which is important factor for large and industrial cities. Without access to electricity, lighting is limited to oil lamps or dynamo lights. Solar lights are a perfect solution for areas without access to electricity for lighting. Tens of thousands of examples of these systems are installed globally every year.



Figure 19: Solar lighting
Source: Offthegrid, 2004

Portable Solar Generators

Portable Solar Generators, including the solar vehicles, non-industrial electrical applications in devices such as toys, solar calculators, etc. Ease of transportation and installation are the main benefits of these systems, which plays an important role in its development.



Figure 20: The winning car in the 1996 World Solar Challenge
 Source: PVSRC

Cathodic Protection

Corrosion of raw material, chemical, oil and gas pipes must be prevented or slowed down in order to prevent leakages from the pipes and environmental pollution. Stand-alone energy systems can be used to generate a protective electric current to protect these pipelines.

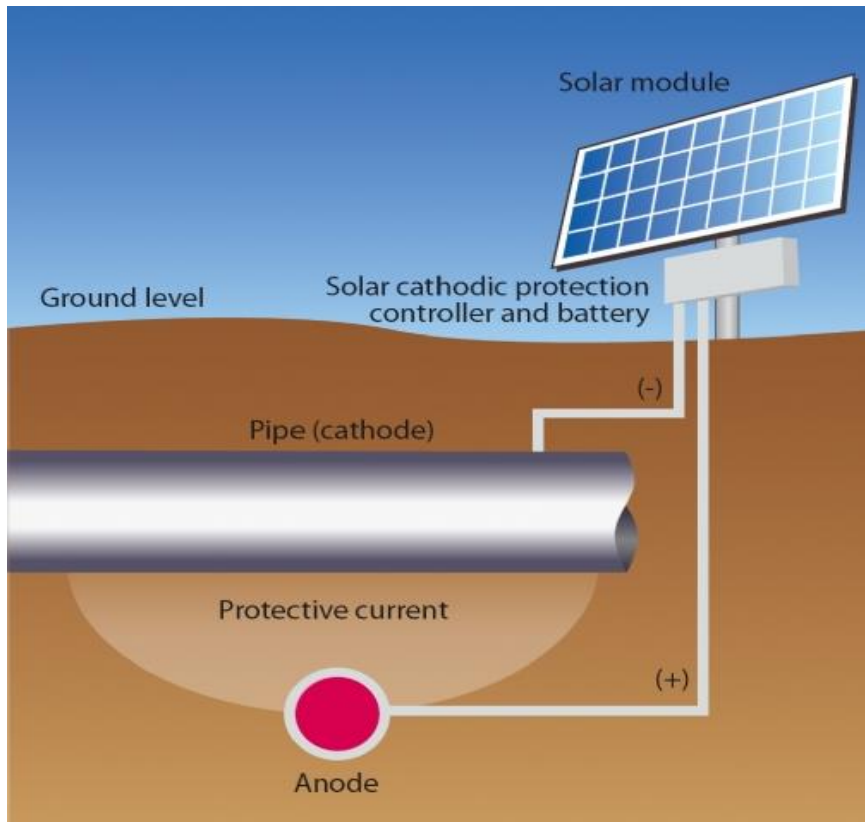


Figure 21: Cathodic Protection Controller (CP)
 Source: Sollatek

6. Global Solar Energy Statistics

6.1 Concentrating Solar Power (CSP)/Concentrated Solar Thermal (CST)

CSP and CST are CSP refer to technologies that use concentrated sunlight to heat up the receiver and transform the heat to mechanical energy via turbine or other engines and then generate electricity. (IEA)CPS and CST are used interchangeably .

The key feature of CST is that by storing solar energy it can discharge electricity to the grid at the time that sun is not shining. The parabolic trough (PT) is the most common type of CST systems, accounting for 90% of total installed CST technologies worldwide. (Probyn, 2012)

The high cost of investment causes increase in electricity cost and is one of the down sides of this technology. In addition, to perform optimally, CST technologies require higher radiation rates as compared with PV system. These technologies usually need water as a cooler, which is often hard to find in locations with high solar accessibility.

Spain and United State are primary investors and also world leaders in the CST sector with respectively about 1 GW and 500 MW installed, and more under construction or development. Recently, developing countries have shown great interest in this technology due to their high intensity of solar resources. For example, India plans to develop 500 MW of CST plants for the Jawaharlal Nehru National Solar Mission in the first phase of the three-phase project. The South African government awarded three CST concessions in December 2011 with total capacity of 200 MW. (Probyn, 2012) Other projects in developing countries include the

- Thai Solar TSE1 and TSE2 plants in Thailand.
- Solarium Mymensingh plant in Bangladesh (18 MW).
- GeoBase Gwanda Solar Plant in Zimbabwe (120 MW)
- Ouarzazate Solar phase 1 in Morocco (160 MW)

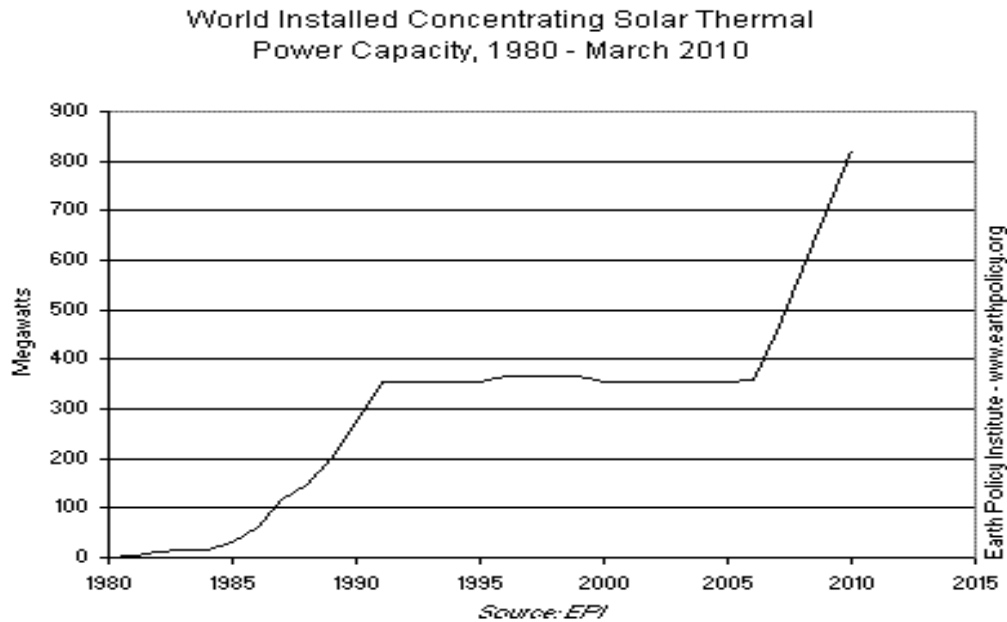


Figure 22: World installed concentrating solar thermal power capacity
Source: EPI, 2010

CSP could account for up to 25% of total energy demand by 2050 according to Greenpeace International, the European Solar Thermal Electricity Association and the International Energy Agency's (IEA) Solar PACES group. (IEA, n.d.)

6.2 Solar photovoltaic (PV)

After years of fast progress in the PV market in Europe, 2013 was a year of sparkling of PV system in Asia and America due to decrease of the cost. Representing 50% of all the installation in 2013 in China and Japan, Asian countries ranked number one in PV marketplace. The United State also shows great progress while the market in the Europe has broken down for the second consecutive year. Asia installed 22.9 GW, Europe 11.2 GW and the Americas 5.3 GW. (IEA, PVPS 2014)

Total of 35 GW of PV were installed in The International Energy Agency's Photovoltaic Power System Program members countries (IEA PVPS) during 2013 (2012: 25 GW). This raised the global total installed PV capacity higher than 137 GW (roughly 140 GW) at the end of 2013.

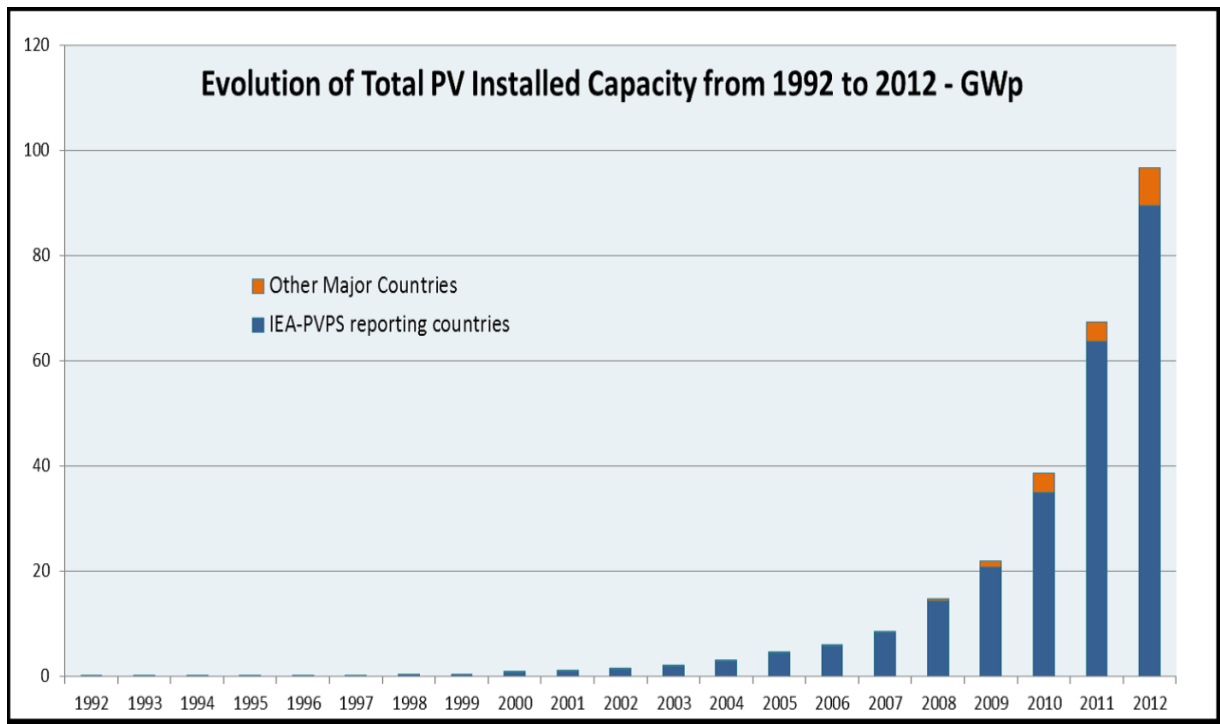


Figure 23: Evaluation of total PV installed capacity from 1992 to 2012

Source: IEA

PV contribution to the total supply of electricity increased significantly and it has become a reliable source of electricity in several countries. Around 8% of total electricity demand in Italy, more than 6% in Germany and close to 6% in Greece comes from PV contribution.

While overall world PV contribution was almost 0.87% in 2013, in 17 countries this contribution achieves more than 1%, Australia and Japan passed 1.5% and overall European contribution has reached 3%. (IEA PVPS, 2014)

Rapidly growing interest in PV comes from its adaptability for different market sectors, from small scale of rural electrification to large scale power plants (today above 300 MW in size) it also suggests a new business plan and market design for the near future.

7. Conclusion

Statistics indicate that the production, conversion and consumption of different types of energy are the main factors for destruction and pollution of the environment among the man-made factors. However, not only the world's energy consumption will remain constant, but forecasts indicate that consumption will continue growing due to increasing population, the desire for prosperity and increasing per capita GDP (gross domestic product) in the world. (The World Bank)

Consequences of energy consumption are increasing the amount of carbon dioxide emissions and also SOX and NOX emissions. Studies show that there are two main solutions to mitigate this issue:

- Increasing energy efficiency
- Increase the share of renewable energy in the global energy mix

For many years, the majority of the industry relies on fossil fuels (coal, oil and natural gas). Fossil fuels are non-renewable resources that need for thousands of years to create, therefore, fossil fuels cannot always respond to all human needs and sooner or later it will end.

So we must find an alternative to the fossil fuel. Solar energy can be a great alternative; especially that it is a free and unlimited source. It will help us to have clean and sustainable energy to power our world without any damage to our environment. It will help us to have zero dependency on costly and damaging fossil fuel. There is no doubt that as future solar power technology costs continue to decline, fossil fuel costs will dramatically increase.

So attention must be focused on renewable energies as a low risk investments and solar energy becomes the preferred target of investors.

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Appendix

General Knowledge about the Sun

- The sun is made of gas which is most sensitive to the magnetic force, called plasma.
- The Sun's radius (distance from the center to its surface), is about 695,500 kilometers, roughly 109 times the radius of the Earth.
- The sun has a surface temperature of 5800 K (9980.3° F). The solar core temperature is more than 15 million degree Kelvin ($2.7000e+7^{\circ}$ F).
- The sun mass is 99.8% of the total mass of the Solar System, which is 333,000 times the mass of Earth.
- The average density of sun is about 90 pounds per cubic foot, or about 1.4 grams per cubic centimeter. This value is about 1.4 times the density of water and less than a third the average density of the earth.
- Like most of stars, the majority of the atoms of the Sun, are from the chemical element of hydrogen. After hydrogen, helium is the most common element found in the sun. The rest of the mass of the sun is composed of atoms of seven other elements. There are 98,000 atoms of helium, 850 atoms of oxygen, 360 atoms of carbon, 120 atoms of neon, 110 atoms of nitrogen, 40 atoms of magnesium, 35 atoms of iron and 35 atoms of silicon in the sun for every 1 million atoms of hydrogen. So about 94 percent of the atoms are hydrogen and 0.1% of them are other than hydrogen and helium.
- The mass of the lightest element of the sun, hydrogen is about 73.46 percent, 24.85 percent helium, 0.77% oxygen, 0.29% carbon, 0.16 % iron, 0.12 % sulfur, .12% neon, 0.09% nitrogen, 0.07% silicon, and 0.05% magnesium of the total mass of the sun.
- According to scientific estimation, about 4.5 million years since the birth of this fireball has been passed and up to next 5 billion years from now, it can still be regarded as a great source of energy.
- Due to reflection, scattering and absorption by gases and aerosols in the atmosphere, only 47% of the energy of the sun reaches the Earth's surface.
- The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year.