PHOTOVOLTAIC SYSTEMS

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1. Introduction

Converting solar energy into electrical energy by PV installations is the most recognized way to use solar energy. Since solar photovoltaic cells are semiconductor devices, they have a lot in common with processing and production techniques of other semiconductor devices such as computers and memory chips. As it is well known, the requirements for purity and quality control of semiconductor devices are quite large. With today's production, which reached a large scale, the whole industry production of solar cells has been developed and, due to low production cost, it is mostly located in the Far East. Photovoltaic cells produced by the majority of today's most large producers are mainly made of crystalline silicon as semiconductor material.

Solar photovoltaic modules, which are a result of combination of photovoltaic cells to increase their power, are highly reliable, durable and low noise devices to produce electricity. The fuel for the photovoltaic cell is free. The sun is the only resource that is required for the operation of PV systems, and its energy is almost inexhaustible.

A typical photovoltaic cell efficiency is about 15%, which means it can convert 1/6 of solar energy into electricity. Photovoltaic systems produce no noise, there are no moving parts and they do not emit pollutants into the environment. Taking into account the energy consumed in the production of photovoltaic cells, they produce several tens of times less carbon dioxide per unit in relation to the energy produced from fossil fuel technologies.

Figure 1 photovoltaic cells

Photovoltaic cell has a lifetime of more than thirty years and is one of the most reliable semiconductor products. Most solar cells are produced from silicon, which is non-toxic and is found in abundance in the earth's crust.

Photovoltaic systems (cell, module, network) require minimal maintenance. At the end of the life cycle, photovoltaic modules can almost be completely recycled. Photovoltaic modules bring electricity to rural areas where there is no electric power grid, and thus increase the life value of these areas.

Photovoltaic systems will continue the future development in a direction to become a key factor in the production of electricity for households and buildings in general. The systems are installed on existing roofs and/or are integrated into the facade. These systems contribute to reducing energy consumption in buildings. A series of legislative acts of the European Union in the field of renewable energy and energy efficiency have been developed, particularly promoting photovoltaic technology for achieving the objectives of energy savings and CO2 reduction in public, private and commercial buildings. Also, photovoltaic technology, as a renewable energy source, contributes to power systems through diversification of energy sources and security of electricity supply.

By the introduction of incentives for the energy produced by renewable sources in all developed countries, photovoltaic systems have become very affordable, and timely return of investment in photovoltaic systems has become short and constantly decreasing.

In recent years, this industry is growing at a rate of 40% per year and the photovoltaic technology creates thousands of jobs at the local level.

2. Historycal overview

The photovoltaic effect has been discovered in the first half of the 19th the century. In 1839, a young French physicist Alexandre Edmond Becquerel observed a physical phenomenon or effect that allows the conversion of light into electricity. The solar cells' work is based on this principle of photovoltaic effect. In the following years, a number of scientists have contributed to the development of this effect and technologies through their researches, the most relevant among them are Charles Fritts, Edward Weston, Nikola Tesla and Albert Einstein, who has been awarded the Nobel Prize for his work on "photoelectric effect" in the year 1904.

However, due to high production rates, a greater development of this technology has begun only along with the development of semiconductor industry in the late fifties of the 20th century. During the sixties, the solar cells are used exclusively for supplying electricity to orbiting satellites in Earth orbit, where they prove themselves as very reliable and competitive technology. In the seventies there are improvements in production, performance and quality of solar cells, while the coming oil crisis helps to reduce production costs of solar cells and open up many possibilities for their practical implementation. Solar cells have been recognized as an excellent replacement for the supply of electricity at locations distant from the electricity grid. The energy is supplied to wireless applications, lighthouses' batteries, various signals, telecommunication equipment and other low power electricity dependent equipment. During the eighties, solar cells have become popular as an energy source for consumer electronic devices including calculators, watches, radios, lamps and other applications with small batteries. Also, after the crisis in the seventies, great efforts have been made in the development of solar cells for commercial use in households. Independent solar cells systems (off-grid) have been developed, as well as network connected systems (on-grid). In the mean time, a considerable increase in wide use of solar cells has been recorded in rural areas where electricity network and infrastructure have not been developed. Electricity produced in these areas is used for pumping water, cooling energy, telecommunications and other household appliances and everyday life needs.

Photovoltaic modules technology and market development has grown rapidly by introducing incentives for the production of electricity from renewable energy sources. Incentives are implemented in all developed countries, the leaders are the European Union, the United States, Japan, Australia, etc. The Republic of Croatia has also adopted a legislation which regulates the production of electricity from renewable energy sources according to the status of eligible producer of electric energy, based on incentive tariffs (feed-in tariffs) . *More in Chapter 8.*

As already mentioned, today the industry of photovoltaic modules and related equipment is growing at a rate of 40% per year, therefore, it is one of the fastest growing industry in the last decade. In the year 2010, the capacity of installed power has reached an enormous number of 17,5 GW.

3. Functioning of the photovoltaic cells

The word „photovoltaic“ consists of two words: photo, a greek word for light, and voltaic, which defines the measurement value by which the activity of the electric field is expressed, i.e. the difference of potentials. Photovoltaic systems use cells to convert sunlight into electricity. Converting solar energy into electricity in a photovoltaic installation is the most known way of using solar energy.

The light has a dual character according to quantum physics. Light is a particle and it is a wave. The particles of light are called photons. Photons are massless particles, moving at light speed. The energy of the photon depends on its wavelength and the frequency, and we can calculate it by the Einstein's law, which is:

$$E = h\nu$$

where:

E - photon energy

h - Planck's constant $h = 6.626\times10^{-34} Js$

ν - photon frequency

In metals and in the matter generally, electrons can exist as valence or as free. Valence electrons are associated with the atom, while the free electrons can move freely. In order for the valence electron to become free, he must get the energy that is greater than or equal to the energy of binding. Binding energy is the energy by which an electron is bound to an atom in one of the atomic bonds. In the case of photoelectric effect, the electron acquires the required energy by the collision with a photon. Part of the photon energy is consumed for the electron getting free from the influence of the atom which it is attached to, and the remaining energy is converted into kinetic energy of a now free electron. Free electrons obtained by the photoelectric effect are also called photoelectrons. The energy required to release a valence electron from the impact of an atom is called a „work out“ W_i, and it depends on the type of material in which the photoelectric effect has occurred. The equation that describes this process is as follows:

$$h\nu = W_i + E_{kin}$$

where:

$h\nu$ - photon energy

W_i, - work out

E_{kin} - kinetic energy of emitted electron

The previous equation shows that the electron will be released if the photon energy is less than the work output.

The photoelectric conversion in the PV junction. PV junction (diode) is a boundary between two differently doped semiconductor layers; one is a P-type layer (excess holes), and the second one is an N-type (excess electrons). At the boundary between the P and the N area, there is a spontaneous electric field, which affects the generated electrons and holes and determines the direction of the current.

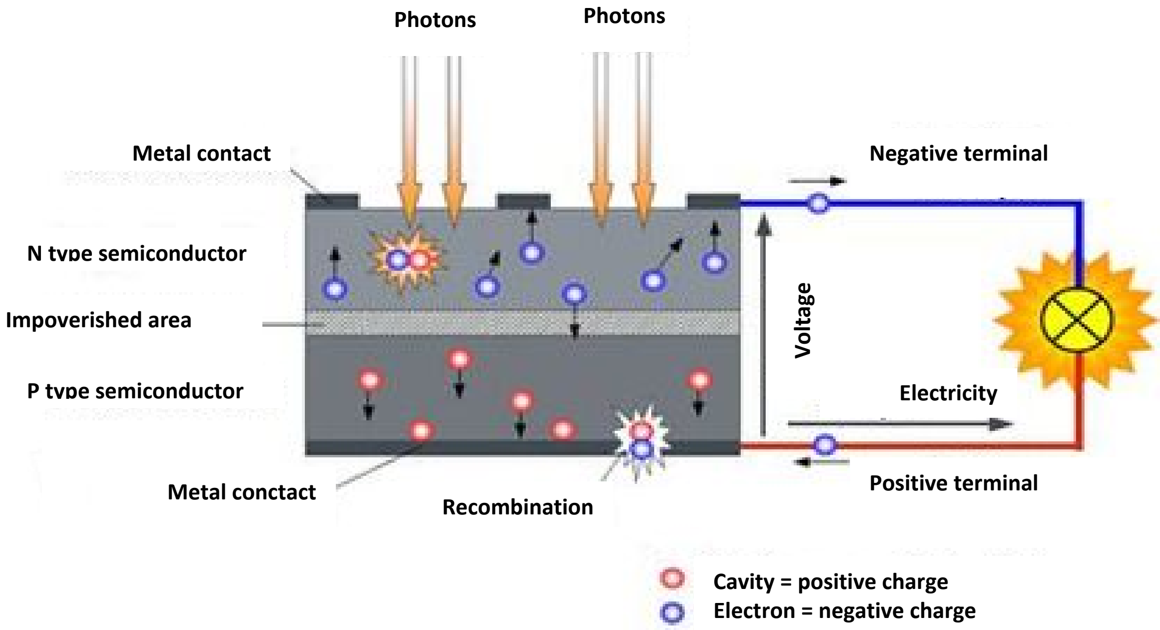


Figure 2 Functioning of the photovoltaic cell

To obtain the energy by the photoelectric effect, there shall be a directed motion of photoelectrons, i.e. electricity. All charged particles, photoelectrons also, move in a directed motion under the influence of electric field. The electric field in the material itself is located in semiconductors, precisely in the impoverished area of PV junction (diode). It was pointed out for the semiconductors that, along with the free electrons in them, there are cavities as charge carriers, which are a sort of a byproduct in the emergence of free electrons. Cavities occurs whenever the valence electron turns into a free electron, and this process is called the generation, while the reverse process, when the free electron fills the empty spaces - a cavity, is called recombination. If the electron-cavity pairs occur away from the impoverished areas it is possible to recombine before they are separated by the electric field. Photoelectrons and cavities in semiconductors are accumulated at opposite ends, thereby creating an electromotive force. If a consuming device is connected to such a system, the current will flow and we will get electricity.

In this way, solar cells produce a voltage around 0,5-0,7 V, with a current density of about several tens of mA/cm^2 depending on the solar radiation power as well as on the radiation spectrum.

The usefulness of a photovoltaic solar cell is defined as the ratio of electric power provided by the PV solar cells and the solar radiation power. Mathematically, it can can be presented in the following relation:

$$\eta = \frac{P_{el}}{P_{sol}} = \frac{U \cdot I}{E \cdot A}$$

where:

P_{el} - Electrical output power
P_{sol} - Radiation power (sun)
U - Efective value of output voltage
I - Effective value of the electricity output
E - Specific radiation power (for example W/m^2)
A - Area

The usefulness of PV solar cells ranges from a few percent to forty percent. The remaining energy that is not converted into electrical energy is mainly converted into heat energy and thus warms the cell. Generally, the increase in solar cell temperature reduces the usefulness of PV cells.

Standard calculations for the energy efficiency of solar photovoltaic cells are explained below.

Energy conversion efficiency of a solar photovoltaic cell (η "ETA") is the percentage of energy from the incident light that actually ends up as electricity. This is calculated at the point of maximum power, Pm, divided by the input light irradiation (E, in W/m2), all under standard test conditions (STC) and the surface of photovoltaic solar cells (AC in m2).

$$\eta = \frac{P_m}{E \times A_c}$$

STC - standard test conditions, according to which the reference solar radiation is 1.000 W/m^2, spectral distribution is 1.5 and cell temperature 25^0C.

4. Types of solar photovoltaic cells

Electricity is produced in solar cells which, as noted, consist of more layers of semiconductive material. When the sun's rays shine down upon the solar cells, the electromotive force between these layers is being created, which causes the flow of electricity. The higher the solar radiation intensity, the greater the flow of electricity.

The most common material for the production of solar cells is silicon. Silicon is obtained from sand and is one of the most common elements in the earth's crust, so there is no limit to the availability of raw materials.

Figure 3 photovoltaic cell

Solar cell manufacturing technologies are:

- monocrystalline,
- polycrystalline,
- Bar-crystalline silicon,
- thin-film technology.

Cells made from crystal silicon (Si), are made of a thinly sliced piece (wafer), a crystal of silicon (monocrystalline) or a whole block of silicon crystals (multicrystalline); their efficiency ranges between 12% and 19%.

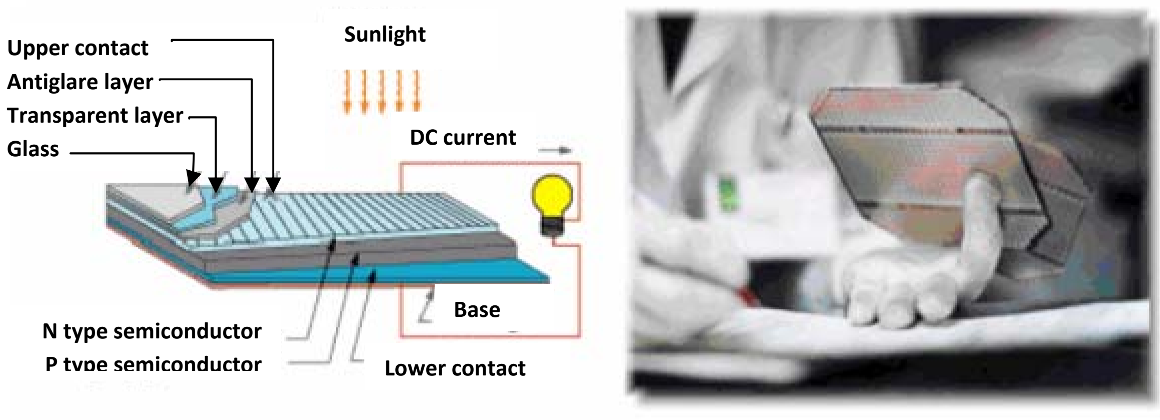


Figure 4 ***Typical monocrystalline cells***

- Monocrystalline Si cells: conversion efficiency for this type of cells ranges from 13% to 17%, and can generally be said to be in wide commercial use. In good light conditions it is the most efficient photovoltaic cell. This type of cell can convert solar radiation of 1.000 W/m^2 to 140 W of electricity with the cell surface of 1m^2. The production of monocrystalline Si cells requires an absolutely pure semiconducting material. Monocrystalline rods are extracted from the molten silicon and sliced into thin chips (wafer). Such type of production enables a relatively high degree of usability. Expected lifespan of these cells is typically 25-30 years and, of course, as well as for all photovoltaic cells, the output degrades somewhat over the years.

- Multicrystalline Si cells: this type of cell can convert solar radiation of 1.000 W/m^2 to 130 W of electricity with the cell surface of 1m^2. The production of these cells is economically more efficient compared to monocrystalline. Liquid silicon is poured into blocks, which are then cut into slabs. During the solidification of materials crystal structures of various sizes are being created, at whose borders some defects may emerge, making the solar cell to have a somewhat lower efficiency, which ranges from 10% zo 14%. The lifespan is expected to be between 20 and 25 years.

- Ribbon silicon has the advantage in its production process in not needing a wafer cutting (which results in loss of up to 50% of the material in the process of cutting). However, the quality and the possibility of production of this technology will not make it a leader in the near future. The efficiency of these cells is around 11%.

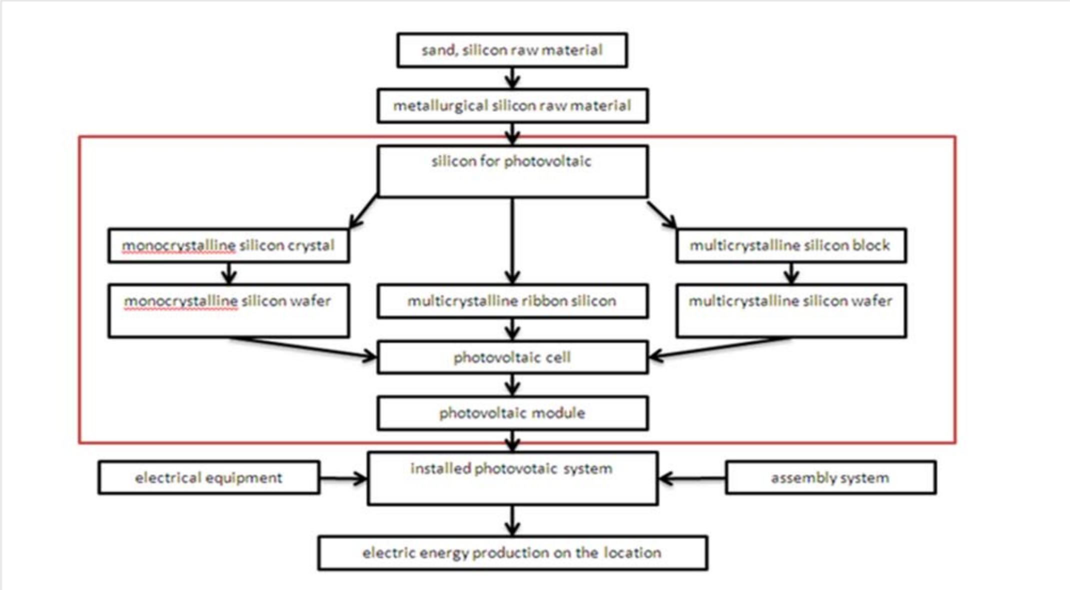


Figure 5 Scheme of the silicon processing for the solar photovoltaic systems production

- In the thin-film technology the modules are manufactured by piling extremely thin layers of photosensitive materials on a cheap substrate such as glass, stainless steel or plastic. The process of generating modules in thin-film technology has resulted in reduced production costs compared to crystalline silicon technology, which is somewhat more intense. Today's price advantage in the production of a thin-film is balanced with the crystalline silicon due to lower efficiency of the thin-film, which ranges from 5% to 13%. The share of thin-film technology on the market is 15% and constantly increasing, it is also expected an increase in years to come and thus reduce the adverse market ratio in relation to the photovoltaic module of crystalline silicon. Lifespan is around 15-20 years. There are four types of thin-film modules (depending on the active material) that are now in commercial use:

1. Amorphous silicon (a-Si)

Amorphous Si Cells: Cell efficiency is around 6%, a cell surface of $1m^2$ can convert 1.000 W/m^2 of solar radiation to about 50 watts of electric energy. Progresses in research of this type of module have been made and it is expected a greater efficiency in the future.

If a thin film of silicon is put on a glass or another substrate it is called amorphous or thin layer cell. The layer thickness is less than 1 microns, therefore the lower production costs are in line with the low cost of materials. However, the efficiency of amorphous cells is much lower compared to other cell types. It is primarily used in equipment where low power is needed (watches, pocket PCs) or, more recently, as an element in building facades.

Figure 6 thin-film, amorphous silicon

2. Cadmium Tellurium (CdTe)

Figure 7 CdTe thin-film

Cadmium tellurium (CdTe) cells: Cell efficiency is around 18%, a cell surface of $1m^2$ can convert solar radiation of 1.000 W/ m^2 to 160 W of electricity in laboratory conditions. Cadmium teleurid is a fusion of metal cadmium and tellurium semimetal. It is suitable for use in thin photovoltaic modules due to the physical properties and low-technology manufacturing. Despite these advantages it is not widely used due to cadmium toxicity and suspected carcinogenicity.

3. Copper indium gallium selenide (CIS, CIGS)

CIS cells have the highest efficiency among the thin-film cells, which is about 20%. This cell type can convert solar radiation of 1.000 W/m^2 to 160 W of electricity with the cell surface of 1 m^2 in laboratory conditions.

Figure 8 CIS thin-film

4. Thermo sensitive solar cells and other organ cells (DSC)

The development of these organic cells is yet to come, since it is still testing and it is not increasingly commercialized. Cell efficiency is around 10%. The tests are going in the direction of using the facade integrated systems, which has proven to be high-quality solutions in all light radiation and all temperature conditions. Also, a great potential of this technology is in low cost compared to silicon cells.

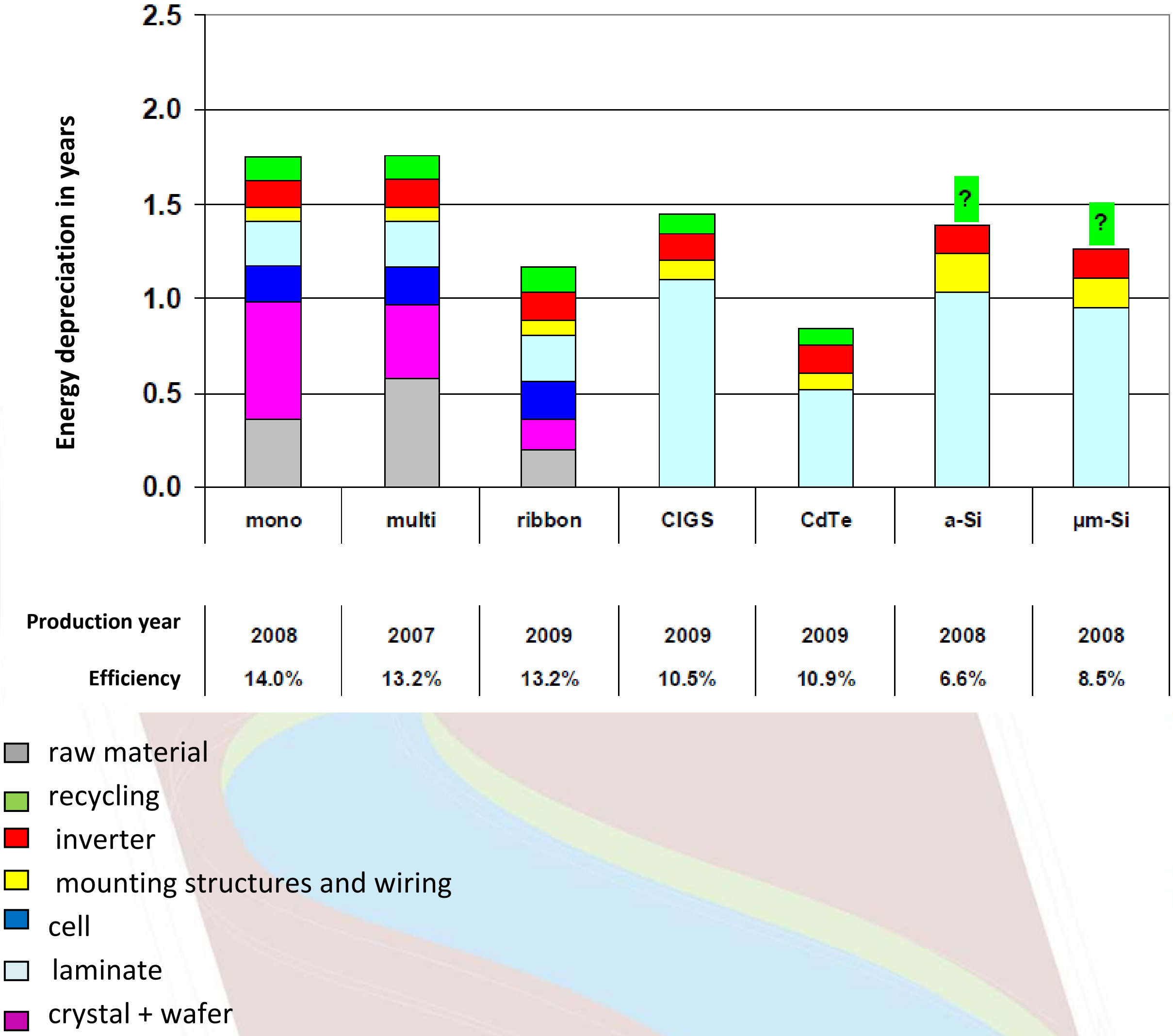
There are other types of photovoltaic technologies that are still developing, while others are to be commercialized.

Regardless of the lifespan, the warranty period of today's most common commercial photovoltaic modules is 10 years at 90% power output, and 25 years at 80% power output.

5. Energy depreciation of photovoltaic cells

The period of energy depreciation of photovoltaic cells is the time period that must pass using a photovoltaic system to return the energy that has been invested in the construction of all parts of the system, as well as the energy required for the breakdown after the lifetime of a PV system. Of course, the energy depreciation time is different for different locations at which the system is located, thus it is a lot shorter on locations with a large amount of irradiated solar energy, up to 10 or more times shorter than its lifetime. South Istria has approximately 1.700 kWh/m^2 annual radiation, while the northern part of Istria has somewhere around 1.500 kWh/m^2.

Figure 9 Roof photovoltaic system's energy depreciation at the location having the annual radiation of 1.700 kWh/m2, optimally inclined photovoltaic module



The figure shows the available data on the energy depreciation for the various technologies of photovoltaic cells, with their respective efficiencies in given years of production.

In relation to the south of Istria, which is shown in Figure 9, the energy depreciation in the city of Zagreb is, for example, about 20% longer, in southern Dalmatia is 10 to 15% shorter than in Istria, which corresponds to solar radiation intensity-insolation map, shown in Figure 13.

6. Photovoltaic system types

Photovoltaic systems can be generally divided into two basic groups:

1. Photovoltaic systems not connected to the network, stand-alone systems (off-grid)
2. Photovoltaic systems connected to public electricity network (on-grid)

There are lots of different subtypes of photovoltaic systems according to type and method of connecting to the network, or a way of storing energy on independent systems.

6.1 Network-connected photovoltaic systems (on-grid)

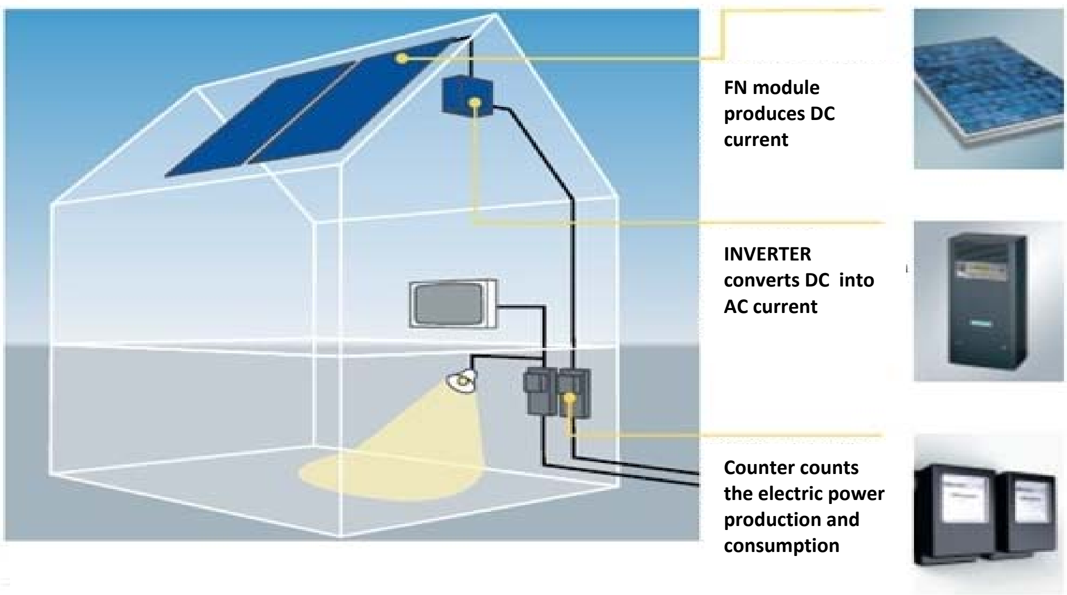


Figure 10 Network-connected photovoltaic system

The main components of PV systems are photovoltaic modules, photovoltaic inverter, mounting subframe and measuring cabinet with protective equipment and installation. Photovoltaic modules convert solar energy into DC current, while photovoltaic inverter adjusts the produced energy in a form which can be submitted to the public grid. The AC voltage is supplied to the electricity network through the protection and measuring equipment.

Photovoltaic inverter is usually located indoors, although there are inverters for outdoor installation, where it must not be directly exposed to sunlight. Inverters produce high-quality AC current of corresponding voltage and are suitable for a network-connected photovoltaic systems. Network inverters operate like any other inverter, with the difference that the network inverters must ensure that the voltage they supply is in phase with the network voltage. This allows the photovoltaic systems to deliver the electricity to the electrical network.

Electrical connection is usually located in the electrical control box, which is located in a separate room, but can also be placed in the measurement and terminal box, which then connects to the electrical control box. The meter is installed at the point of connection, a single phase, two-tariff, electronic system for single-phase, and a three phase, two-tariff, electronic system for two-phase and three phase systems. In such installations it is regularly proposed to setting up a fuse in front of and behind the counters in order to permit replacement of the meter at a no-load condition. The exact conditions of connection are synchronized with the local distributor of electric energy - HEP ODS. Power OFF buttons must be provided both on the side of photovoltaic modules as well as on the side of network connection.

The output voltage of the inverter must be in accordance with the Regulation on standardized voltages for low voltage electricity distribution network and electrical equipment. Standard sizes of the nominal voltage is 230V, up to 400V between phase and neutral conductor, between phase conductors, the quad-phase network nominal frequency of 50 Hz, and, under normal conditions, it should not differ from the nominal value by more than ± 10%.

Due to the large exposures to lightning, besides being connected to the lightning protection installation, the photovoltaic modules are protected by arresters and bias as well. Arresters are installed immediately after the module in order to prevent the impact of bias on the installation of the building.

6.2 Network-connected home systems (possibility for own consumption)

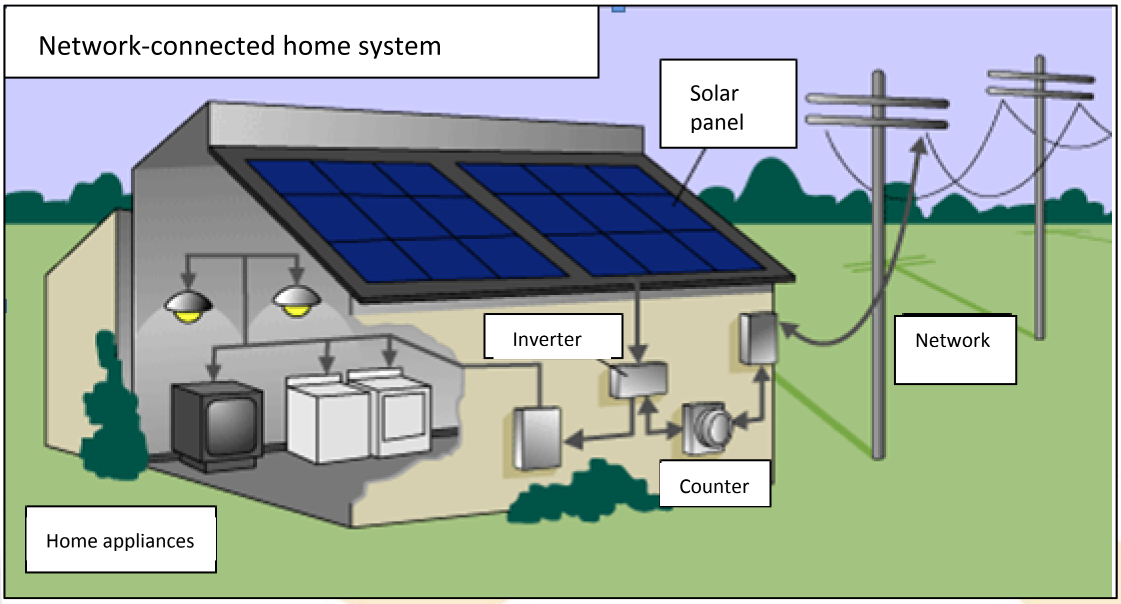


Figure 11 Network-connected home photovoltaic system

These are the most popular types of solar photovoltaic systems that are suitable for home and commercial installations in developed and urban areas. Connection to the local electricity network allows selling to the local distributor of electric energy any excess of electricity generated and not used in the household consumption, because the PV system is connected to the network via a home installation in parallel operation with the distribution system. Also, the home is supplied with electricity from the grid when there is no sunny weather. The inverter, as already discussed, is used to convert direct current (DC) produced by the photovoltaic modules into alternating current (AC) located in the electrical grid and used to drive all the household appliances.

This system gives two choices to the user: to sell the entire electricity produced to the local distributor, delivering all the electricity in the network (especially if there is a price incentive for electricity produced from renewable sources according to the status of eligible producer of electric energy - feed-in tariffs) or the electricity produced can be used to meet the current needs of households and sell any surplus in the electricity grid. It is necessary to mention that the local distributor in Croatia, ODS-HEP, is currently trying to avoid the second solution and prefers supplying of all the electricity produced into the network, without the possibility for the own consumption.

The increase of interest in this type of connecting the photovoltaic system to the grid is expected to happen with convergence of prices of the electricity produced in a conventional way with the price of the electricity produced from renewable energy sources. So far, the incentive feed-in tariffs are favoring network installations only, although the photovoltaic system produces the most electricity at midday, when the sun is up, and can thus meet the energy needs and thereby relieve the power system.

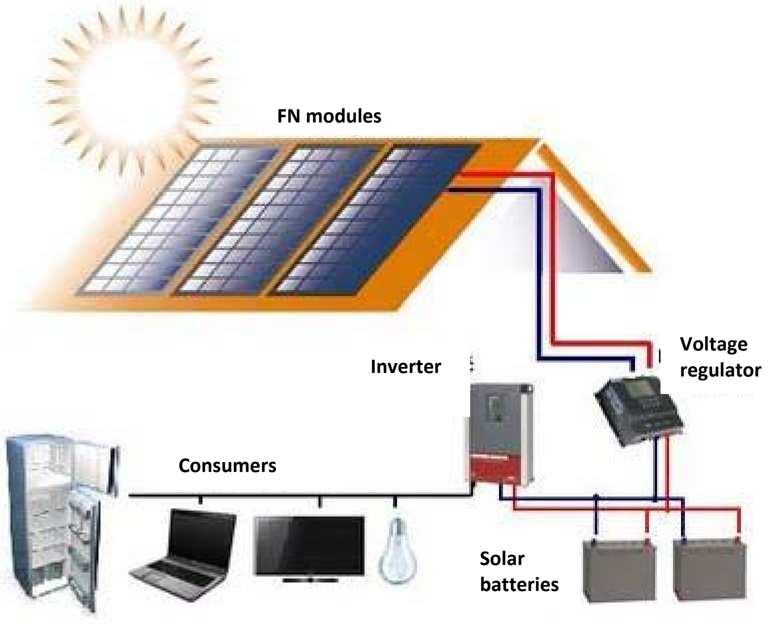
6.3 Network-connected solar power plants (farms)

Figure 12 Solar farm

These systems, also connected to the network, are generating large amounts of electricity by a photovoltaic installation on a localized area. The power of such photovoltaic power ranges from several hundred kilowatts to tens of megawatts, recently up to several hundred megawatts. Some of these installations can be located on large industrial facilities and terminals, but more often on large barren land surfaces. Such large installations are exploiting existing facilities to produce electricity at the location and thus compensate part of the electric energy demand in the area.

To have a feeling of size, talking about solar farms, it is worth to mention an example of a large-scale solar farm in the former military airport in Germany: 40 MWp power, thin film technology, surface area 110 hectares, which is equivalent to an area of 200 football stadiums, the expected annual production of 40 million kWh of electricity, saving 25.000 tonnes of CO_2, and cost about 130 million €.

6.4 Standalone systems (off-grid) or isolated systems



These systems are used in rural areas where there is no electricity network and infrastructure. The systems are connected to a reservoir of energy (battery) by a control over the filling and emptying. The inverter can also be used to provide alternating current for standard electrical equipment and appliances.

Figure 13 Standalone photovoltaic system

Typical stand-alone photovoltaic installations are used to ensure the availability of electricity in remote areas (mountain resorts, islands, rural areas in the developing areas). Rural electrification means either small home solar photovoltaic installations covering basic electricity needs of an individual household, or bigger solar photovoltaic network that provides enough electricity for several households.

6.5 Hybrid systems

A solar photovoltaic system can be combined with other energy sources, such as biomass generator, wind turbines, diesel generator, all to ensure a constant and sufficient supply of electricity, since it is known that all renewable energy sources, including photovoltaic systems, are not constant in energy production. It means that, when there is no sun, the system does not produce electricity, although the need for energy is constant, and therefore must be met from other sources. The hybrid system can be connected to a network, stand-alone or as a support network.

6.6 Independent systems for economic purposes

Use of electricity produced in solar photovoltaic systems in remote installations far from electrical networks is very common. An example is telecommunication equipment, especially for bridging the rural areas with the rest of the country with built electric grid. CDMA mobile stations are powered by photovoltaic or hybrid systems. Other photovoltaic installations, such as for traffic signs and lights, are today competitive because the cost of bringing electricity infrastructure in these remote places quite high.

7. Solar radiation

The sun is the central star of the solar system in which the Earth is. It has a form of a large glowing ball of gas, the chemical composition of mostly hydrogen and helium, but also other elements that are in it to a lesser extent, like oxygen, carbon, iron, neon, nitrogen, silicon, magnesium and sulfur.

Energy from the Sun comes to the Earth in the form of solar radiation. Nuclear reactions take place in the interior of the Sun, during which hydrogen is transformed into helium by a fusion process, accompanied by the release of large amounts of energy, where the temperature reaches 15 million °C. Part of this energy comes to Earth in form of heat and light, and allows all processes, from photosynthesis to the production of electricity in photovoltaic systems.

Under optimal conditions, the earth's surface can obtain 1.000 W/m2, while the actual value depends on the location, i.e. latitude, climatological location parameters such as frequency of cloud cover and haze, air pressure, etc.

Considering the sunlight and the productivity of photovoltaic systems, it is necessary to understand the following concepts:

- Irradiation, average density of the radiant solar radiation power, which is equal to the ratio of the solar radiation power and surface of the plane perpendicular to the direction of this radiation (W/m^2),
- Radiation, which represents the quantity of solar radiation that is radiated on the unit surface at a given time (Wh/m^2) or (J/m^2). Besides expressing it in hourly values, it is often expressed as daily, monthly or yearly radiation, depending on the time interval.

The solar radiation weakens on its way through the earth's atmosphere due to the interaction with gases and vapors in the atmosphere and arrives at the Earth's surface as direct and diffused. Direct sunlight comes directly from the sun, while scattered or diffused radiation reaches the earth from all directions. Considering direct and diffused radiation on a flat surface, we are talking about the total radiation. In case of an inclined surface, the rejected or reflected radiation has to be added to the direct and diffused radiation. Rejected radiation can be reflected from the ground or water.

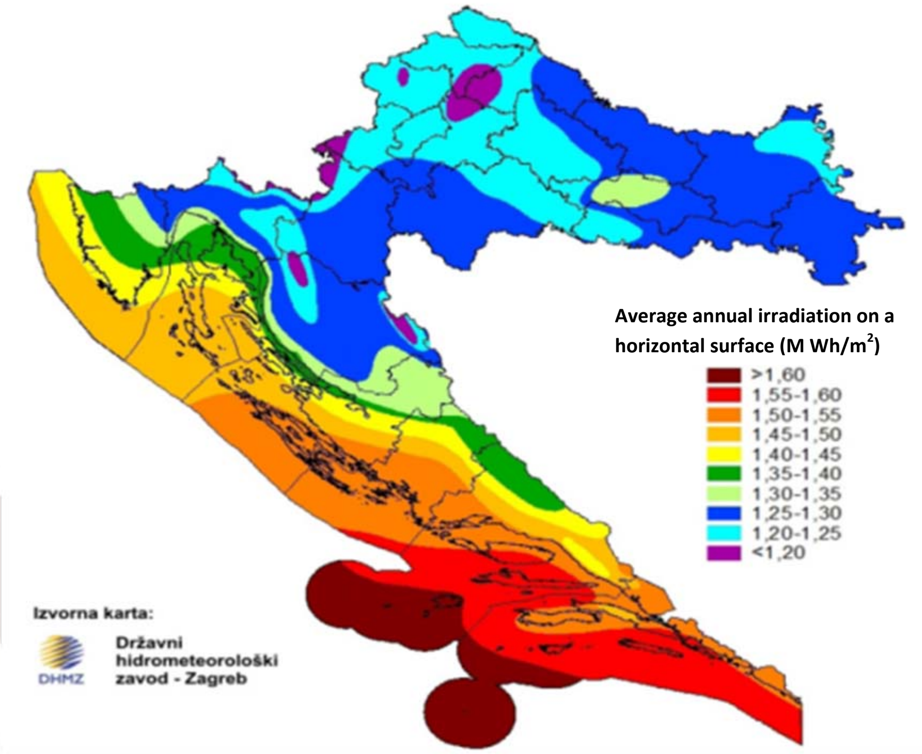


Figure 14 Average annual radiation to a horizontal plane in Croatia

The largest component of solar radiation is direct, and the maximum radiation should be on a surface perpendicular to the direction of the sun's rays. The greatest radiation at any given moment is only possible if the plane is constantly referred to the movement of the sun in the sky.

Photovoltaic modules can be mounted in various ways, fixed at a certain angle, or may be moving to better monitor the angle of inclination of the sun during the day for greater energy yield and better results in the production of electricity. Optimal value of the inclination angle of the surface has to be determined for fixed mounted photovoltaic module. The optimum angle of inclined PV module's surfaces is the angle at which it is inclined in relation to a horizontal surface in order to obtain the highest possible annual irradiation. An optimum angle of inclination for a period or certain months in the year can also be calculated.

The greatest energy yield of a fixed module system is achieved by placing the modules at the optimal annual angle. As the sunlight radiation is a highly seasonal dependent variable, the average daily radiation values to an inclined surface range from about 1 kWh/m^2 in December up to 7 kWh/m^2 in June, which means that we obtain a higher energy yield in summer by setting a module at a lower angle, and vice versa.

Figure 15 Photovoltaic modules with active monitoring of the Sun motion, Tracker

Influence of shading on solar power plant - the maximum electric energy is produced when sunlight directly crosses the PV modules. Shadows created by objects on the roof, wood or other surrounding buildings and skyscrapers substantially affect electricity production. The shade also negatively affects the stability of the system because modules located partially in the shade do not have a linear production of electricity, resulting in voltage changes and inverter disturbances. If only one cell in a module is located in the shade, it can reduce the power of all modules by 75%.

8. Legislative and institutional framework for producing of electric energy from RES

There are two basic acts governing the issue of electricity generation from renewable energy sources (RES) and high-efficiency cogeneration - Energy Act (Official Gazette 68/01, 177/04, 76/07) and Act on Electric Energy Market (Official Gazette 177/04, 76/07). Energy Act stipulates that the RES usage is in the interest of the Republic of Croatia, defines the eligible producer (EP) as an energy entity that in a single production facility produces energy from RES. The Act states that all issues related to the use of renewable energy are regulated by special Regulations. The Regulations on the use of renewable energy sources and cogeneration (OG 67/07) sets out the terms of using renewable energy and cogeneration plants, defined groups of RES and cogeneration plants, establishes the conditions for registration of projects and facilities for the use of RES, the registration of eligible producers, and defines all steps the energy subject must take in order to obtain the approval for the construction of new plants. the The Ministry of Economy, Labour and Entrepreneurship (MELE) is responsible for maintaining the Register. Based on the Energy Act the tariff system for electricity production from RES and cogeneration has been declared. Eligible producers are entitled to an incentive price, which is defined by the tariff system, and the price depends on the type and size of plants. The eligible producer is entitled to an incentive price based on the electricity purchase contract that is signed with the Croatian energy market operator (HROTE).

According to the Act on Electric Energy Market, the transmission system operator or the distribution system operator shall provide redeeming of the total electricity produced by the eligible producer under prescribed conditions. The status of eligible electricity producer is based on a decision of the Croatian Energy Regulatory Agency (HERA) in accordance with the conditions and procedures prescribed by the Regulation on granting the status of eligible producer (OG 67/07).

Besides MELE and HERA, the key institution in the system of encouraging the production of electricity from renewable energy sources and cogeneration is the Croatian Energy Market Operator (HROTE). The Act on Electricity Market defines its obligations, including signing the contract with all suppliers, collecting fees for the stimulation of renewable energy and cogeneration, as well as calculation and allocation of funds collected from fees to eligible producers.

9. New solar photovoltaic panel technologies and development possibilities

Since 2004 Europe is the leader in the global photovoltaic market installations. In 2010 Europe holds about 40% of the global market, while the countries that have developed the best support systems for photovoltaic installations are Germany, Italy Spain, France, Czech Republic.

So far, the market is dominated by crystalline silicon cells, while an increasing share of thin film technology is expected in the future. Thin-film technology enables significant savings in materials, more flexible installation of photovoltaic cells since they can be bent. Furthermore, thin film technology solar cells have a significantly shorther return of invested energy period, while, on the other hand, the effectiveness is somewhat lower.

Silicon as base material is absolutely dominating, with a share of 98,3%, out of it mostly crystalline silicon technology with a 93,7% share in total production. Until recently (year 2000), monocrystalline silicon production technology was predominant, obtained by the so called Czochralski process or technology of the floating zone. The production of monocrystalline silicon is more expensive, but the cell efficiency is greater. Today this technology is losing a step in comparison with the technology of multicrystalline silicon (Mc-Si). The advantages of multicrystalline silicon are lower capital investment for production of wafer (a thin slab of a semiconductor material), higher efficiency due to the use of square silicon wafers, which provide greater active surface of the module compared with a circular or quasi-circular shape of monocrystalline wafer. In Mc-Si technology it is easier to produce larger cell size of 150×150 and 200×200 mm, which simplifies their incorporation into modules. The Mc-Si technology had a share of 57.2% in the total production of solar cells in year 2003.

Ribbon silicon has the production process advantage in avoiding the need for cutting wafer, which resulted in loss of up to 50% of the material in the process of cutting. However, the quality and the possibility of production is not at a level on which this technology could take the lead in the near future. The biggest technological disadvantage of crystalline silicon is in its semiconducting character with a so-called indirect band gap, which is why it needs a relatively large thickness of the active layer in order to largely benefit from solar radiation. Semiconductors with a so-called direct band gap are applied in thin-film technology and their thickness can be much smaller, with significantly lower consumption of materials, which promises low cost and the ability to produce large quantities of cells. Unfortunately, although long awaited, these thin film solar cells technologies, with amorphous silicon, CIS, CdTe and other, have not yet demonstrated its market ability and will need significant investment to become competitive to crystalline silicon due to cost, low efficiency, stability, or environmental acceptability of the module. The share of thin-film technology (amorphous silicon, CdTe, CIS), despite significant efforts in research, has remained relatively modest so far. However, strong increase in production of solar cells from crystalline silicon can cause a rise in prices and shortages of raw silicon, giving the possibility for a greater penetration of these technologies in the future.

Although photovoltaic systems are commercially available and widely extended, further research and development of photovoltaic technology is essential to allow it to become a major source of electricity. Considering future directions in the research of solar photovoltaic cells, as far as crystalline silicon solar cells concern, a technology that has dominated since the beginning of photovoltaics developing, there are six important features to take account of:

1. The reduction of specific consumption of silicon materials in the final module
2. New and improved silicon raw material, which has a more favorable price-quality ratio
3. Increasing the efficiency of cells and modules, and, in long-term, using of new and integrated concepts
4. New and improved materials in all parts of the production chain
5. High throughput, high yield, integrated industrial processing
6. The discovery of new safer technologies for a reduced negative effect on the environment as well as achieving a longer lifetime of the module

When it comes to thin film technology, which is relatively new and has great potential for development, there are a few guidelines:

1. Reliability and a better balance between cost and quality of production equipment
2. Reducing the costs of packaging for rigid and flexible modules
3. More reliable modules through better procedures for quality assurance (improvements in testing and improving module efficiency assessment)
4. Recycling materials and old modules
5. Replacement of the rare chemical elements such as indium, gallium, tellurium

It is crucial for all the photovoltaic cells technologies and for the entire photovoltaic industry to ensure a greater decrease in price in the next several years. This goal will be accomplished as soon as conditions for new technological innovations and improvements, that will increase the efficiencies of photovoltaic cells and prolong their lifespan, are provided at all social levels. Indirectly, it will lead to a reduction of production costs.

Specific efficiency targets by the year 2020, issued by EPIA (European Photovoltaic Industry Association), are:

1. Commercial crystalline silicon cells:
   - Mono-crystalline silicon, cells must achieve efficiency of 22%, although some present commercial cells have already its efficiency in the range 19-22%,
   - Multi-crystalline silicon, cells must achieve an average efficiency of 20%.

2. Commercial modules in thin-film technology
   - Amorphous silicon (a-Si), must reach the efficiency of 10-16%,
   - Cadmium tellurium (CdTe), must reach the efficiency of 15-20%,
   - Copper indium gallium selenide (CIS, CIGS), must reach the efficiency of 16-22%.

9.1 Concentrating Photovoltaic Systems

Research on concentrating photovoltaic systems has begun in the seventies of the twentieth century. Today, small, medium and high concentrating photovoltaic systems are in use, and are able to increase the solar radiation from 2 to even 300 times.

Concentrating photovoltaic systems use optical lenses to concentrate large amounts of solar radiation on a small area of photovoltaic modules to generate electricity. They also regularly use the system to actively track the movement of the sun. Unlike traditional photovoltaic systems, concentrating systems are often cheaper to produce, because the concentration of solar radiation allows a much smaller area of photovoltaic cells for the same energy produced.

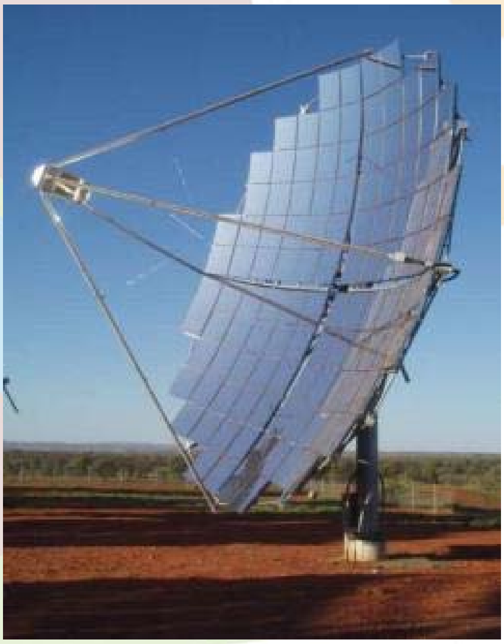


Figure 16 Concentrating Photovoltaic System

As it is well known from the photoelectric effect, photovoltaic cells produce the more electricity the more they are exposed to sunlight. The problem occurs with the cell efficiency, because its effectiveness decreases by the temperature increase.

This means that, if you would like to increase the production by increasing solar radiation, lowering of the consequently increased temperature should be ensured. Another problem with concentrating photovoltaic systems is the optical lenses and sun movement tracking system price, which often exceeds the savings in the number of cells in relation to traditional photovoltaic systems.

Challenges at concentrating photovoltaic system's functioning are how to operate with maximum efficiency at concentrating radiation, which means how to ensure adequate system cooling. Also, one of the disadvantages is the inability to concentrate diffused radiation, when direct radiation is not available, such as during cloudy weather. The conclusion is that such systems are optimal and cost-effective only on those locations that have the necessary direct solar radiation on an annual basis.

9.2 Carbon nanotube (CNT)

Carbon nanotube (CNT) is a nano structure which consists in carbon atoms (C) in the form of an empty cylinder. The ends of cylinders are usually sealed by semi-fullerene structures.

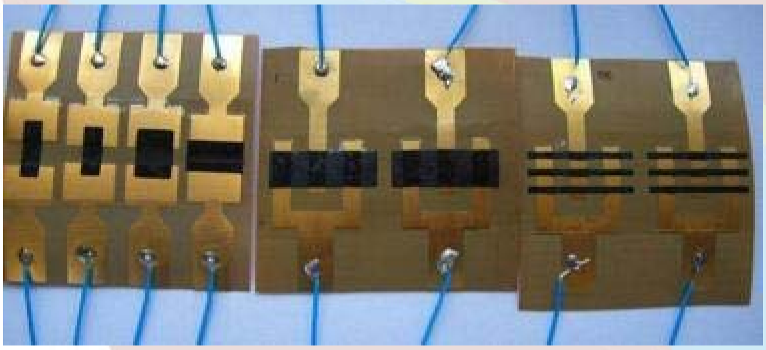


Figure 17 CNT photovoltaic cell

The ratio of length to diameter in nanotubes construction is up to 132.000.000:1, more than any other material.

There are three types of carbon nanotubes - the so-called "armchair" (chair), zig-zag and spiral (helical) nanotubes. These three types have different symmetries. Carbon nanotubes can be long several hundred nanometers. Some of them are considered special forms of fullerenes. To produce macroscopic materials that are built from carbon nanotubes, carbon nanotubes are arranged in bundles next to each other in order to form a triangular lattice. These are Single-Walled Carbon Nanotubes (SWNT).

The second type is Multi-Walled Carbon Nanotubes - MWNT, made by placing the tube of a smaller diameter in a tube of a larger diameter and then again in a third tube that has a larger diameter, etc. Carbon nanotubes are already used in some commercial technologies such as displays.

Carbon nanotubes are one of the most mentioned building blocks in nanotechnology. They have a hundred times greater resistance to stretching in relation to steel, thermal conductivity is better than the purest diamond has, electrical conductivity is similar to copper.

Previous studies have succeeded to produce nanotubes that respond to the light of a certain spectrum range, but never responsive to the entire visible spectrum. Nanotubes are filled with three types of chromophores that change shape when they are illuminated with light color. Each species responds to a single color: red, green or blue. Modifying the form of chromophores alters the electrical conductivity of nanotubes, which can be measured and converted into digital information.

Although CNT has the potential in relation to photovoltaic systems, a cell which efficiency is greater than 6,5% has not yet been produced. CNT technology is still in the initial stage of research and there is plenty of room for future improvements.

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