# *SOLAR ENERGY*

## *Educational text*

### Natural Solar Energy

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

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

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

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

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

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

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

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

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

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

*Greenhouse Effect*

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

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

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

*Photosynthesis*

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

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

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

*Fossil Fuels*

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

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

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

**Harnessing Solar Energy**

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

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

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

**Photovoltaics**

Photovoltaics is a form of active solar technology that was discovered in 1839 by 19-year-old French physicist Alexandre-Edmond Becquerel. Becquerel discovered that when he placed silver-chloride in an acidic solution and exposed it to sunlight, the platinum electrodes attached to it generated an electric current. This process of generating electricity directly from solar radiation is called the photovoltaic effect, or photovoltaics.

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

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

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

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

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

## Solar Energy and People

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

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

There are many pros and cons to using solar energy.

*Advantages*

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

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

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

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

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

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

*Disadvantages*

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

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

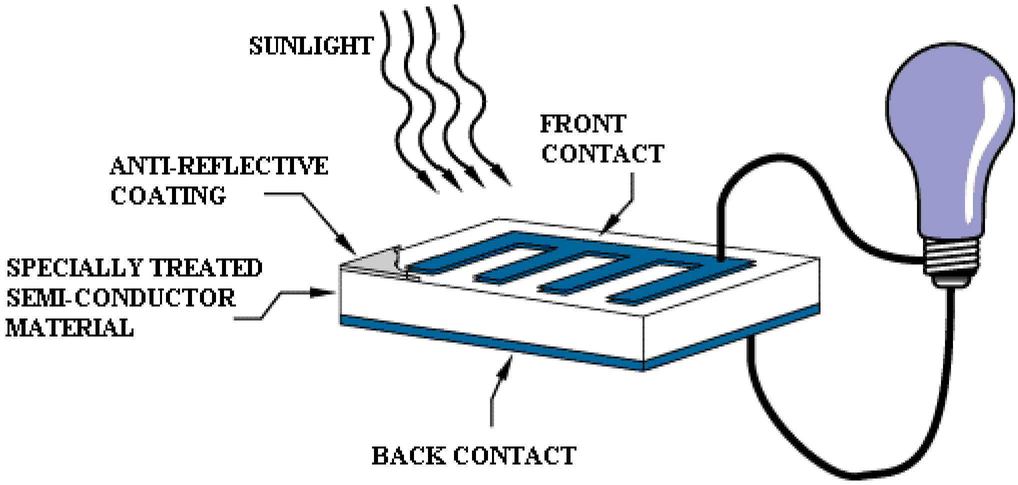
Both active and passive solar technology depend on factors that are out of our control, such as climate and cloud cover. Local areas must be studied to determine whether or not solar power would be effective in that area.

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

## How does it work

Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

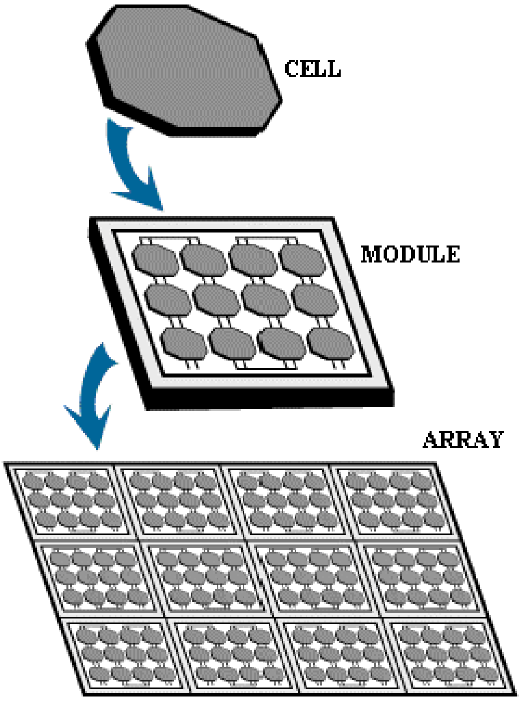
The photoelectric effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel Prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.

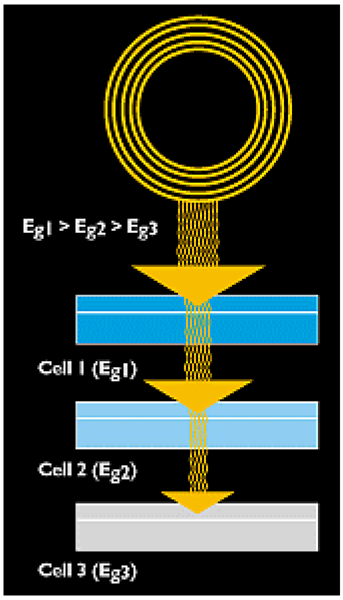



The diagram above illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or a tool.

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.

Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

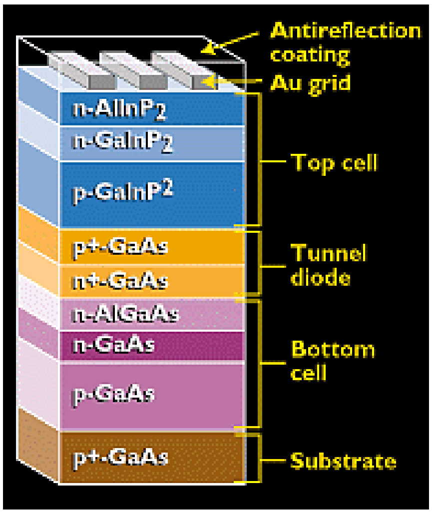



Today's most common PV devices use a single junction, or interface, to create an electric field within a semiconductor such as a PV cell. In a single-junction PV cell, only photons whose energy is equal to or greater than the band gap of the cell material can free an electron for an electric circuit. In other words, the photovoltaic response of single-junction cells is limited to the portion of the sun's spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used.

One way to get around this limitation is to use two (or more) different cells, with more than one band gap and more than one junction, to generate a voltage. These are referred to as "multi junction" cells (also called "cascade" or "tandem" cells). Multi junction devices can achieve a higher total conversion efficiency because they can convert more of the energy spectrum of light to electricity.

As shown below, a multi junction device is a stack of individual single-junction cells in descending order of band gap. The top cell captures the high-energy photons and passes the rest of the photons on to be absorbed by lower-band-gap cells.




Much of today's research in multi junction cells focuses on gallium arsenide as one (or all) of the component cells. Such cells have reached efficiencies of around 35% under concentrated sunlight. Other materials studied for multi junction devices have been amorphous silicon and copper indium diselenide.

As an example, the multi junction device below uses a top cell of gallium indium phosphide, "a tunnel junction," to aid the flow of electrons between the cells, and a bottom cell of gallium arsenide.

## *Advantages of photovoltaics*

- ✓ Do not pollute the environment
- ✓ The resource is inexaustible
- ✓ Does not need fossil fuels
- ✓ Does not emmit toxic chemicals

## *Disdvantages of photovoltaics*

- ✓ It is not very efficient
- ✓ It cannot be implemented everywhere.

## *Environmental issues*

Solar energy provides substantial benefits for our climate, our health, and our economy.

Each source of renewable energy has unique benefits and costs; this page explores the many benefits associated with these energy technologies. For more information on their potential impacts — including effective solutions to mitigate or avoid them entirely —

see The Environmental Impacts of Renewable Energy Technologies.

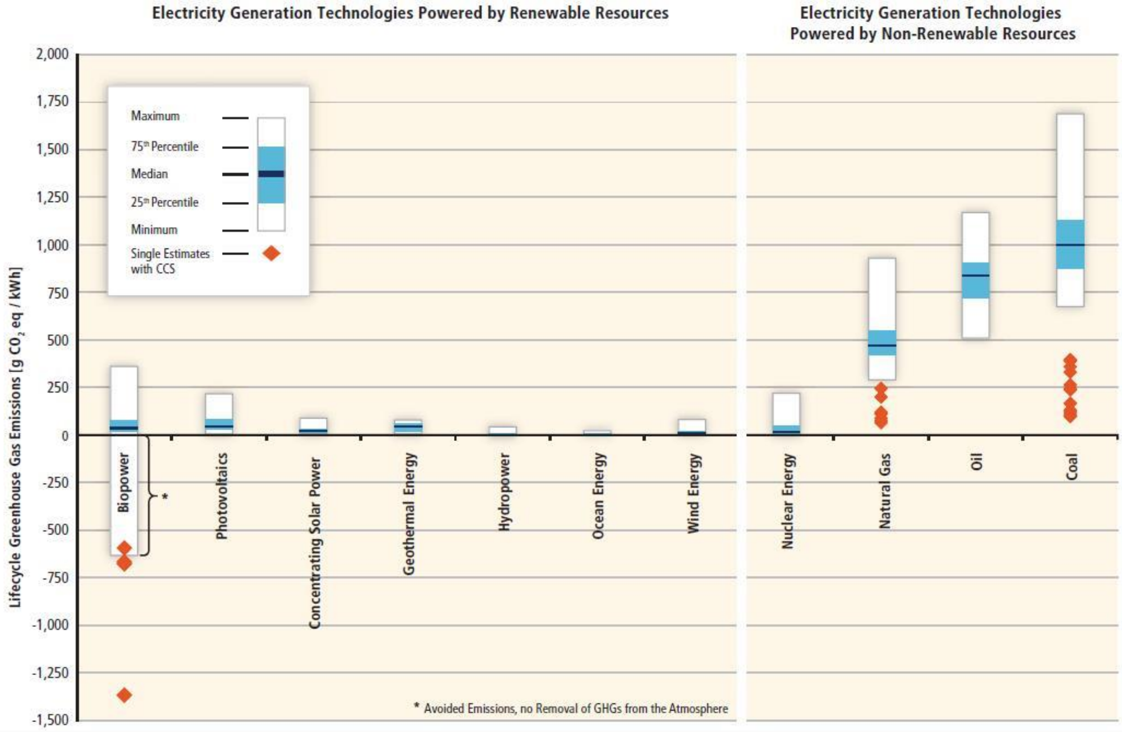
## Little to No Global Warming Emissions

Human activity is overloading our atmosphere with carbon dioxide and other global warming emissions, which trap heat, steadily drive up the planet's temperature, and create significant and harmful impacts on our health, our environment, and our climate.

Electricity production accounts for more than one-third of U.S. global warming emissions, with the majority generated by coal-fired power plants, which produce approximately 25 percent of total U.S. global warming emissions; natural gas-fired power plants produce 6 percent of total emissions. In contrast, most renewable energy sources produce little to no global warming emissions.

According to data aggregated by the International Panel on Climate Change, life-cycle global warming emissions associated with renewable energy—including manufacturing, installation, operation and maintenance, and dismantling and decommissioning—are minimal.

Compared with natural gas, which emits between 0.6 and 2 pounds of carbon dioxide equivalent per kilowatt-hour (CO2E/kWh), and coal, which emits between 1.4 and 3.6 pounds of CO2E/kWh, wind emits only 0.02 to 0.04 pounds of CO2E/kWh, solar 0.07 to 0.2,geothermal 0.1 to 0.2, and hydroelectric between 0.1 and 0.5. Renewable electricity generation from biomass can have a wide range of global warming emissions depending on the resource and how it is harvested. Sustainably sourced biomass has a low emissions footprint, while unsustainable sources of biomass can generate significant global warming emissions.




Source: IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp. (Chapter 9).

Increasing the supply of renewable energy would allow us to replace carbon-intensive energy sources and significantly reduce U.S. global warming emissions. For example, a 2009 UCS analysis found that a 25 percent by 2025 national renewable electricity standard would lower power plant CO2 emissions 277 million metric tons annually by 2025—the equivalent of the annual output from 70 typical (600 MW) new coal plants. In addition, a ground-breaking study by the U.S. Department of Energy's National Renewable Energy Laboratory explored the feasibility and environmental impacts associated with generating 80 percent of the country's electricity from renewable sources by 2050 and found that global warming emissions from electricity production could be reduced by approximately 81 percent.

## Improved Public Health and Environmental Quality

Generating electricity from renewable energy rather than fossil fuels offers significant public health benefits. The air and water pollution emitted by coal and natural gas plants is linked to breathing problems, neurological damage, heart attacks, and cancer. Replacing fossil fuels with renewable energy has been found to reduce premature mortality and lost workdays, and it reduces overall healthcare costs. The aggregate national economic impact associated with these health impacts of fossil fuels is between $361.7 and $886.5 billion, or between 2.5 percent and 6 percent of gross domestic product (GDP).

Wind, solar, and hydroelectric systems generate electricity with no associated air pollution emissions.

While geothermal and biomass energy systems emit some air pollutants, total air emissions are generally much lower than those of coal- and natural gas-fired power plants.

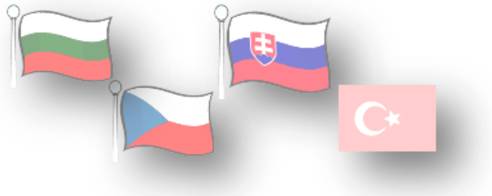
In addition, wind and solar energy require essentially no water to operate and thus do not pollute water resources or strain supply by competing with agriculture, drinking water systems, or other important water needs. In contrast, fossil fuels can have a significant impact on water resources. For example, both coal mining and natural gas drilling can pollute sources of drinking water. Natural gas extraction by hydraulic fracturing (fracking) requires large amounts of water and all thermal power plants, including those powered by coal, gas, and oil, withdraw and consume water for cooling.

Biomass and geothermal power plants, like coal- and natural gas-fired power plants, require water for cooling. In addition, hydroelectric power plants impact river ecosystems both upstream and downstream from the dam. However, NREL's 80 percent by 2050 renewable energy study, which included biomass and geothermal, found that water withdrawals would decrease 51 percent to 58 percent by 2050 and water consumption would be reduced by 47 percent to 55 percent.

## A Vast and Inexhaustible Energy Supply

Throughout the United States, strong winds, sunny skies, plant residues, heat from the earth, and fast-moving water can each provide a vast and constantly replenished energy resource supply. These diverse sources of renewable energy have the technical potential to provide all the electricity the nation needs many times over.

Estimates of the technical potential of each renewable energy source are based on their overall availability given certain technological and environmental constraints. In 2012, NREL found that together, renewable energy sources have the technical potential to supply 482,247 billion kilowatt-hours of electricity annually (see Table 1). This amount is 118 times the amount of electricity the nation currently consumes. However, it is important to note that not all of this technical potential can be tapped due to conflicting land use needs, the higher short-term costs of



those resources, constraints on ramping up their use such as limits on transmission capacity, barriers to public acceptance, and other hurdles.

| Table 1: Renewable Resource | Electricity Generation Capacity Potential (gigawatts) | Electricity Generation Potential (billion kilowatt-hours) | Renewable Electricity Generation as Percent of 2012 Electricity Use |
|---|---|---|---|
| Wind | | | |
| Land-Based | 10,955 | 32,784 | 809% |
| Offshore | 4,223 | 16,976 | 419% |
| **Subtotal** | **15,178** | **49,760** | **1,227%** |
| Solar | | | |
| Photovoltaics | 154,856 | 283,664 | 6,997% |
| Concentrating Solar Power | 38,066 | 116,146 | 2,865% |
| **Subtotal** | **192,922** | **399,810** | **9,862%** |
| Bioenergy | | | |
| **Subtotal** | **62** | **488** | **12%** |
| Geothermal | | | |
| Hydrothermal | 38 | 308 | 8% |
| Enhanced Geothermal Systems | 3,976 | 31,345 | 773% |
| **Subtotal** | **4,014** | **31,653** | **781%** |
| Hydropower | | | |
| Existing Conventional | 78 | 277 | 7% |
| New Conventional | 60 | 259 | 6% |
| **Subtotal** | **138** | **536** | **13%** |
| **Total** | **212,314** | **482,247** | **11,896%** |

Source: "U.S. Renewable Energy Technical Potentials: A GIS -Based Analysis", National Renewable Energy Laboratory. July 2012.

Today, renewable energy provides only a tiny fraction of its potential electricity output in the United States and worldwide. But numerous studies have repeatedly shown that renewable energy can be rapidly deployed to provide a significant share of future electricity needs, even after accounting for potential constraints.

## *Test – Photovoltaic power plants*

# ***Test:***

1. Where should solar parks be placed?

   (a) indoors

   (b) in places without lots of sun

   (c) in places with lots of sun

   (d) everywhere

2. Do photovoltaics use turbines?

   (a) yes

   (b) no

   (c) some of them

   (d) yes, but not for generating energy

3. What is the common trait of nuclear power plants, wind turbines, hydroelectric power plants and thermal power plants that solar parks do not have?

   (a) efficiency

   (b) environment pollution

   (c) turbines

   (d) large buildings

4. How can photovoltaics be harmful to the nature?
   (a) by collecting sun energy
   (b) they distrcat the birds
   (c) they cause no harm
   (d) the products with which they are created are sometimes toxic

5. What is the average efficiency of photovoltaics nowadays?
   (a) 20%
   (b) 10%
   (c) 50%
   (d) 99%

# *Self assessment:( Correct answers1c, 2b, 3c, 4d, 5a)*

# *Evaluating your needs:*

***If you did excellent on the test ( 5 )***, congratulations, you have perfect scientific knowledge, which can help to save the planet!

***If you did well on the test ( 4 )***, but you still want to brush up on your skills, try studying the material on your own.

***If you feel that you need guidance with studying (3)***, take part in a science course. This can be an efficient way to further your education.

***If you scored within (2-0),*** you have to search more information about renewable energy. You may want to have discussion with a teacher about sustainable energy resources.