Solar Energy

The Sun is the source of almost all energy used on Earth. Every hour the Earth receives more energy from the Sun than the world uses in a whole year. All energy stored in Earth’s reserves of coal, oil, and natural gas is matched by the energy from just 20 days of sunshine. Averaged over Earth’s surface, each square meter collects the approximate equivalent of almost one barrel of oil each year, or 4.2 kWh (kilowatt-hour) of energy every day.

If we combine this powerful energy source with other renewables, like wind, geothermal, hydropower, and biomass it seems unbelievable that human population depends on fossil fuels to meet our energy demands.

Solar power technology is one of the solutions to significantly reduce the carbon footprint (GHG – Green House Gases) that pollute our air and water, threaten our public health, and contribute to global warming and climate change. This abundant energy source with its financial and environmental benefits is poised to play a prominent role in our energy future as a feasible alternative to fossil fuels.

Solar energy supports all life on Earth and is the basis for almost every form of energy we use. The sun makes plants grow, which can be burned as “biomass” fuel or, if left to rot in swamps and compressed underground for millions of years, in the form of coal and oil. Heat from the sun causes temperature differences between areas, producing wind that can power turbines. Water evaporates because of the sun, falls on high elevations, and rushes down to the sea, spinning hydroelectric turbines as it passes. However solar energy usually refers to solar energy that can be used to generate heat, lighting, and electricity.

Why Solar

Almost all of the energy that drives the various systems (climate systems, ecosystems, hydrologic systems, etc.) found on the Earth originates from the sun. The interest of solar energy is continuously growing, and professionals recognize its immense energetic perspectives.

Abundant, Unlimited and Free

20 days of sunshine equivalent to all energy stored in earth’s reserves of coal, oil, and natural gas does not deplete when we use it.

Clean

A solar system is a clean power plant. A PV system will generally “make back” the amount of energy used in its manufacture in 18 to 36 months result in net-positive over system’s typical 25 year span.

Energy Security and Independence

Clean solar energy can help reduce a country’s dependence on imported energy great resource as backup energy supply in the event of traditional grid power outage a solar-energy system offers a degree of autonomy from the existing status quo of energy suppliers.
Reliable and Efficient

Solar energy systems often function for 20 years or more, requiring minimal maintenance rooftop installations avoid electricity losses in transmission and distribution.

Reduce Electricity Cost Volatility

With electricity cost rising during past 30 years, solar energy acts as natural against unstable and rising fossil fuel prices deterministic solar electricity pricing helps in budgeting the electricity cost accurately.

Lower Electricity Cost

Favorable power purchase agreement leads to lower electricity cost compared to utility commercial rates further subsidies through solar REC markets.

Net Metering

Sell excess electricity to utility and offset electricity costs leverage non-peak hours to pay for the full retail price

From sustainable point of view solar energy is the most attractive from all of the renewables. Solar power is free and clean. There are no side effects from obtaining it, no harmful emissions, no natural resources reduction, no waste production, and installation of the solar systems, in most cases on architectural structures, do not affect the scenery.

We can capture and convert solar radiation into useful forms of energy, such as heat and electricity, using a variety of technologies. The technical feasibility and economical operation of these technologies at a specific location depends on the available solar radiation or solar resource.

The major disadvantages of solar energy:

- The amount of sunlight that reaches the earth's surface is not constant and depends on location, time of day, time of year, and weather conditions.

- A large surface area is required to collect the solar energy at a useful rate

What is solar radiation

Solar energy is created at the core of the sun by nuclear fusion, where millions of tons of hydrogen are converted into helium. The process generates enormous heat that causes atoms to discharge photons. Then photons are being absorbed by gas molecules, causing nearby atoms to re-emit other photons. After countless repetitions the photon finally reaches the sun's surface. The last 20% of the journey to the surface of the Earth the energy is transported mostly by convection. It takes a photon approximately 100,000 years and circa $10^{25}$ absorptions, and re-emissions to travel from the sun's core to the surface. To reach the Earth sun's ray takes about 8 minutes.

Outside the Earth at the average earth-sun distance at the top of the atmosphere, solar radiation is calculated to has an intensity of circa 1367 W/m², defined as the Solar Constant, but only about 40% of the solar energy caught at the top of Earth's atmosphere passes through to the surface. Still this amount of energy is thousands times more than all energy generated on the Earth.
Solar radiation is the range of all possible frequencies of electromagnetic radiation emitted by the sun. Infrared radiation (IR) emitted by the Earth’s surface and its atmosphere is called terrestrial radiation. Components of solar and terrestrial radiation and their approximate wavelength ranges are as follows:

- **Ultraviolet**: 0.20 – 0.39 µm
- 0.20-0.29 µm (UVC);
- 0.29-0.32 µm (UVB);
- 0.32-0.39 µm (UVA)
- **Visible**: 0.39 – 0.76 µm
- **Infrared**: 0.76 – 100.00 µm (near-infrared: 0.76 – 4.00 µm)

Gamma rays, X-rays, and ultraviolet radiation 0.20 µm are selectively absorbed in the atmosphere by oxygen and nitrogen and turned into heat energy. The sun emits 7% of ultraviolet radiation in the range of 0.20 – 0.39 µm. UVC is absorbed by the concentration of ozone (O3) gas in the stratosphere, while UVB and UVA can be responsible for sunburn.

The colors within the visible light are violet, blue, green, yellow, orange, and red. Visible light stimulates the perception of color, and regulates the timing of animal activities such as migration, or photosynthesis of plants. In this zone the sun emits nearly 44% of its radiation.

Infrared solar radiation is emitted in 49% by the sun. Almost 37% is radiated between 0.76 and 1.5 µm (near IR) and only 12% at far IR. Infrared solar radiation with wavelengths greater than 700 nm (nanometer) is partially absorbed by carbon dioxide, ozone, and water present in the atmosphere in liquid and vapor forms. Roughly 30% of the sun's visible radiation (wavelengths from 400 nm to 700 nm) is reflected back to space by the atmosphere or the Earth’s surface.

Nearly 99% of solar, or short-wave radiation is in the range of 0.3 – 3.0 µm and the bulk of terrestrial, or long-wave radiation in 3.5 – 50 µm.

**Solar radiation and geographic location**

Every location on Earth receives sunlight at least part of the year, but the amount of solar radiation varies and depends on geographic location (including latitude and elevation), time of day, season, landscape, and weather, such as cloud cover.

Since the Earth is round, the sun strikes the surface at different angles ranging from 0º (just above the horizon) to 90º (directly overhead and gets all the energy possible). The more inclined the sun's rays are, the longer they travel through the atmosphere, the more scattered and diffuse. Polar regions never get a high sun. The total quantity of energy emitted from the sun’s surface is approximately 63,000,000 W/m². As solar radiation passes through the atmosphere some of it is absorbed, some diffused, and some reflected by gas molecules and suspended particles. The solar radiation that reaches the Earth’s surface without being scattered is called direct beam solar
radiation. Atmospheric conditions can reduce direct beam radiation from 10% on clear, dry days to 100% during cloudy days.

**Earth’s Energy Budget**

The Sun radiates about 1,300 watts per square meter energy outside the Earth’s atmosphere. Incoming solar radiation that reaches the upper atmosphere of the Earth in the amount of 174 petawatts (PW $10^{15}$) is called insolation. Approximately 30% of the insolation is reflected back to space, including 6% reflected by the atmosphere, 20% reflected by clouds, and 4% reflected from Earth’s surface. Roughly 70% of the insolation is absorbed by land, oceans, and clouds.

The solar spectrum at the Earth’s surface is in the range of all possible frequencies. The bulk of the emitted radiation comes from infrared solar radiation and visible light. The absorption of solar radiation by oceans and the atmosphere increases their temperature and results in distribution of thermal energy and water called atmospheric circulation or convection. Once the air reaches higher altitude with much lower temperature the water vapor is condensed into clouds that causing the rain. The water cycle is completed. The collision of low pressure regions with high pressure regions prompt to wind, storms or hurricanes.

The average temperature at the Earth’s surface would stay at the same level due to the absorption of the sun rays by the land masses and oceans. However as a result of the high emission of greenhouse gasses (GHG) the Earth’s temperature constantly and dangerously rises causing global warming.

Green plants use sunlight to synthesize foods from carbon dioxide and water in the process of photosynthesis while solar energy is converted into the chemical energy. The process generates organic compounds, such as biomass which is used to make fossil fuels. As a byproduct oxygen is created.

The annual insolation is determined as approximately $3,850,000$ exajoules EJ ($10^{18}$). The available wind energy is calculated as $2,250$ EJ and biomass as $3,000$ EJ. With our yearly global energy
consumption at nearly 500 EJ, there is unimaginably enormous amount of available renewable energy to be harvested.

The energy from the sun varies from place to place and depends on the geographic location, time of day, time of year, and weather conditions. Without an atmosphere 1.4 KW/m\(^2\) per hour is available, but with an atmosphere we can only count on 1KW/m\(^2\) per hour in the absence of clouds. Direct sunlight has a luminous effectiveness of about 93 lumens per watt of radiant flux and if not blocked by clouds, is experienced as sunshine. Bright sunlight provides illuminance of approximately 100,000 lux or lumens per square meter at the Earth's surface.

**Types of Solar Energy**

Solar energy can be converted into other forms of energy, such as heat and electricity. In the 1830s, the British astronomer John Herschel used a solar thermal collector box (a device that absorbs sunlight to collect heat) to cook food during an expedition to Africa. Today, the sun's energy is used in many ways.

Solar energy can be converted to thermal (or heat) energy and used to heat water and spaces. Sun's energy can be converted to electricity by photovoltaic (PV devices), also called 'solar cells' that change sunlight into direct current and solar power plants where electricity is generated indirectly by the steam produced by fluids heated by solar thermal collectors.

Solar Collectors transform short wavelengths into long wavelengths and trap this energy in the form of heat which is transferred and transported into a heat storage vault. Solar panels convert selected wavelengths of light into electricity.

Depending on the way solar technologies capture, storage, convert, and distribute sunlight they are called active or passive. The technology evolution for capturing solar energy began with passive solar centuries ago. Next was the origination of solar thermal technology and lastly photovoltaic development.

**Passive solar – capturing the Sun’s energy in building design and construction**

Passive solar technologies are using sunlight for useful energy without use of mechanical systems (as contrasted to active solar). Such technologies convert sunlight into usable heat (water, air, thermal mass), cause air-movement for ventilating, or future use, with little use of other energy sources. An example of passive solar energy is to use south-facing windows to provide the building with natural light and heat. Any home owner can use many solar applications in order to take advantage of passive solar energy. Passive solar techniques involve selecting materials with favorable thermal mass or light dispersing properties, orienting a building to the Sun or designing space that allows for the natural air circulation. Passive cooling is the use of the same design principles to reduce summer cooling requirements.

Active solar energy uses mechanical devices to capture, storage, and distribute energy of the sun. Active solar techniques involve the use of solar thermal collectors and photovoltaic panels with mechanical or electrical equipment. Thermal systems are often recognized as either passive thermal or active thermal systems, depending on whether or not they have a pump that actively circulates the fluid. A common application of a thermal system is to heat swimming pools, primarily because the fluid (swimming pool water) and pump (swimming pool filtration system) are already readily available.
Solar thermal – sunlight converted to heat
Thermal systems are generally less complicated than photovoltaic systems. The basic concept used by a thermal system is to use sunlight to directly heat a fluid that is used to transfer the thermal energy. Often the fluid is water, and on a structure this may or may not be connected to an internal storage tank such as a conventional hot water heater. Fluids other than water may be used in certain closed-loop systems to avoid freezing and enhance the fluid’s heat transfer characteristics.

Active Solar Space Heating uses mechanical equipment such as fans, pumps, and blowers to assist in collecting, storing, and distributing the heat throughout an conditioned space. These systems can be liquid-based or air-based. Liquid-based systems will use large water tanks or thermal mass for heat storage. Radiant distribution is handled with radiant slab systems, central forced air systems, or hot-water baseboards. Air-based systems use thermal mass or rock bins to hold the heated air for storage. The hot air is distributed through ducts and blowers.

Active Solar Water Heating uses pumps to circulate the water or heat-transfer fluid through the system to heat up the water. There are two types of active solar water heating systems: indirect and direct systems. Indirect systems use a heat transfer fluid that is usually a water-antifreeze mixture.

The heat-transfer fluid is pumped to a storage tank after it is heated in the solar collectors. This is where a heat-exchanger transfers the heat from the fluid to the household water. This type of system is also called a closed-loop system. Direct systems heat the household water in the solar collectors. When the water is heated, it is pumped to a storage tank and then piped to faucets. This system uses regular household water in the collectors and should only be used in areas that do not experience freezing conditions. This type of system is also called open-loop system.

Active Solar Pool Heating uses pumps to circulate the pool water through solar collectors for heating and then back to the pool. The pool is used as the storage medium for the heated water so there is no need for water storage tanks.

Photovoltaic – sunlight converted to electricity
Photovoltaic Solar Energy is the conversion of the sun’s energy directly into electrical energy. The sun’s energy is collected using photovoltaic solar panels. Solar panels convert sunlight into direct current (DC) electric power. DC power is then converted by inverter into alternating current (AC) to be compatible with power appliances and synchronized with utility power whenever the electrical grid is distributing electricity. The solar energy can be stored in batteries for use when there is no sunlight during the night or on cloudy days.

The photovoltaic cell was discovered in 1954 by Bell Telephone researchers examining the sensitivity of a properly prepared silicon wafer to sunlight. Beginning in the late 1950s, photovoltaic cells were used to power U.S. space satellites.