Challenges in the Quest for Clean Energies

2. Solar Energy Technologies

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The global warming issues were discussed in Part 1 of this series of articles. This part describes the different solar energy technologies that are available for generating electricity to meet our daily power requirement. The article focuses on different kinds of materials that can be used to make the photovoltaic cells. The most common photovoltaic cells are made with monocrystalline or polycrystalline silicon. The next generation photovoltaic cells are thin film based. The high efficiency multijunction and concentrated solar cell technologies are also introduced in this article. The concept of power generation using solar thermal energy is explained. In the Indian scenario, there are about 250–300 sunny days in most parts of the country. A brief summary of the solar sector achievements in the country is given.

Previous articles:
1. Background, Vol.18, No.3, 2013.

Introduction

In Part 1 of this series we learnt that our energy intensive lifestyle has increased the greenhouse gases in the atmosphere that has led to many disastrous events in the world. Earth's surface temperature has gone up by a few degrees centigrade resulting in melting of ice and rising of the sea levels. For generating power, the main source of fuel has been petroleum and coal. Because of the burning of these fossil fuels the carbon dioxide in the atmosphere has gone up by almost 30% in the last century. In order to control the climate change due to the greenhouse gas emission, it is imperative that renewable sources like sunlight, wind, biomass and such are used to generate electricity. In this part of the series we will study the solar technology and how it can be used to generate power.

Keywords
Solar energy, photovoltaic cell, thin film, silicon.

Box 1.

Sun is a star, which is a large ball of burning gases. Its energy is due to the chemical conversion of hydrogen into helium through nuclear fusion. The protons liberated at the end of the last reaction above start reacting with each other again. This is how the chemical reactions in the sun are self-sustaining. Thus, the sun has burned for 5 million years and will continue to do so for many million years more. Sun converts 4 million tons of hydrogen into energy every second which is radiated into space.

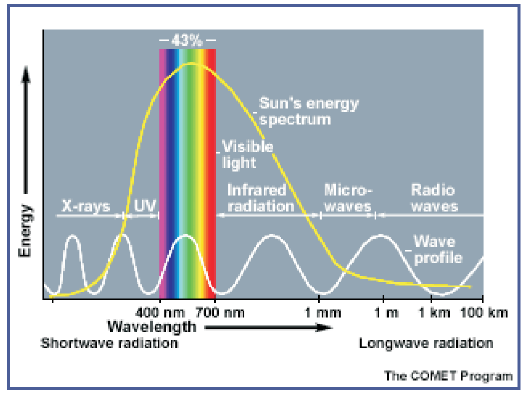

Figure A. The solar radiation spectrum.
Source: http://www.ucar.edu/learn/1_3_1.htm.

Sun is the center of the solar system; the heat and light on the planets including earth is because of the radiation from sun (*Box* 1).

The radiation from the sun that is received on the surface of the earth is mostly (~43%) in the visible region of the electromagnetic radiation spectrum with some amount of ultraviolet (UV) and infrared (IR) radiation, as shown in *Figure* 1. The wavelength range of sunlight is from 2×10^{-7} (6.2 eV) to 4×10^{-6} meters (3.1 eV). Wavelength, λ, of the radiation is related to its energy, E, through the equation $E = hc/\lambda$, where h is the Planck's constant and c is velocity of light. Lower the wavelength of radiation, higher is its energy. Thus, UV radiation has higher energy than visible or IR radiation.

Figure 1 shows the average solar energy that different parts of the world receive per square meter per day. It is estimated to be 0.012 PWh per square mile in a year (where P is peta = 10^{15}) and there is roughly 200 million square miles of earth's surface including the oceans. The current annual electricity demand across the world is in the range of 16 PWh and is likely to increase to about 36 PWh by 2030. Considering the vast area of the earth, we get almost 20,000 times more solar energy than our electricity requirement, for all practical purposes, forever. It makes a lot of

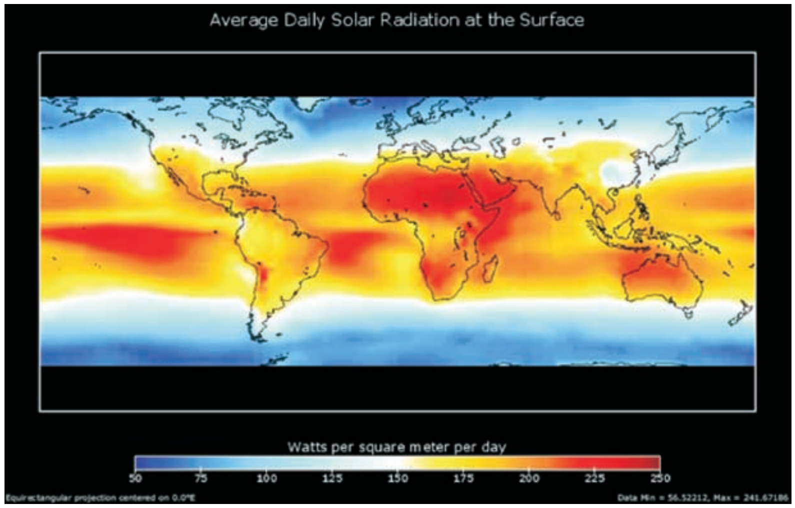

Figure 1. Average solar energy on the world in watts per square meter per day.
Source: http://international.cgdev.org/blog/solar-future-world-bank-southern-africa

sense to harness the solar energy for our benefit. The main advantages of the solar technology are:

• Sun shines bright on the surface of the earth which means the fuel required for generating power is free. There are no fluctuations in the price of fuel unlike in the case of fossil fuel run power generation plants.

• Most of the solar technology based power generators have no turning or moving parts to wear out or break down. Hence the system does not require outages for maintenance due to wear and tear of parts. However, some of the power generators use trackers to track the sun that have the moving parts in the form of motors.

• The solar power generators do not produce any noise. Modular systems can be quickly installed anywhere.

• There are no emissions of harmful or polluting gases. This is one of the safest ways of generating power without polluting the atmosphere.

Even with such critical advantages, solar photovoltaic power generating modules are not yet used extensively to exploit the solar radiation that the earth is receiving. Currently the cost of photovoltaic modules and their installation are high. The challenge for the technologists is to find a cost-effective way of converting the solar energy into usable energy for our applications.

Solar energy can be used in two ways to generate usable electricity. One is by using electronic devices called photovoltaics and the other by using thermal devices to convert the thermal energy of sunlight.

2. Photovoltaics

When solar radiation falls on a surface three things can happen: the radiation can get absorbed by the material, the radiation can get reflected off the surface or the radiation may pass through the material. If the electronic band gap of the material is very large compared to the wavelength of the incident radiation, then the radiation will pass through the material and if the band gap is in the same range as the energy of the radiation, then there can be absorption by the material. Thus, in order to absorb the solar radiation, we need to use materials that have the electronic band gap in the range of the solar radiation spectrum. Materials like silicon, GaAs, GaInP, CdTe, $CuIn_{1-x}Ga_xSe_2$ are a few examples of solar radiation absorbers.

Thus, in order to absorb the solar radiation, we need to use materials that have the electronic band gap in the range of the solar radiation spectrum.

First let us look at the construction of the solar photovoltaic cell (PV). The word 'photovoltaic' is made of two terms 'photo' meaning light and 'voltaic' meaning electricity. A PV cell contains a junction of two types of semiconductors (*Figure* 2). The junction is called a p–n junction, which is formed by putting together a p-type conductor layer and an n-type conductor layer.

The basic concept of the p–n junction is discussed in detail in an earlier article in *Resonance* [1]. Briefly, the free electrons on the n-type and free holes on the p-type initially move across the

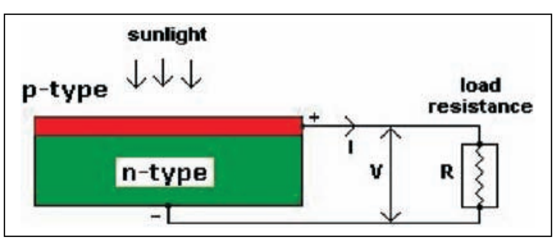

Figure 2. The solar PV circuit.

junction. When a free electron meets a free hole they cancel each other and disappear in the lattice leaving behind oppositely charged species on their 'own side'. Because of this movement, the free charge carriers near the junction tend to eat each other, producing a region depleted of any moving charges. This creates a neutral zone called the depletion zone. Any free charge that moves into the depletion zone finds itself in a region of no charge. Locally the free charge sees a lot of positive charges on the n-type side and a lot of negative charges on the p-type side. These exert a force on the free charge, pulling it back to its 'own side' of the junction away from the depletion zone. Once the depletion zone forms, the negative charge of the p-type conductor's extra electron and the positive charge of the n-type conductor's extra proton tend to keep the depletion zone free of free charges. A free charge now requires some extra energy to overcome the forces from the donor/acceptor atoms to be able to cross the zone and go over to the other side of the zone. The junction acts like a barrier for any charge flow (in other words, current) across it. The free charge carriers can pick up the extra energy in the form of photons from a light source or voltage from an electrical circuit depending on the properties of the materials used to make the junction.

For solar photovoltaic applications, it is clear that there is a need to have materials that absorb solar radiation, which provides the extra energy for the charge carriers to move through the depletion zone. The free charge carriers would then be collected by electrical conductors for application in the external circuit. The voltage produced in a single cell is not sufficient for most of the applications. An array of 36 cells is put together in a module. For larger applications, many such modules are connected in series and parallel to obtain the right power output. The output from the modules is dc in nature. An inverter and other electronic controls are needed to use the power from these modules (*Figure* 3).

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Regarding the materials at the cell level, the PV cells that are being used can be broadly categorized into two groups based on the basic material that is used to make the cells. They are silicon and non-silicon based PV cells.

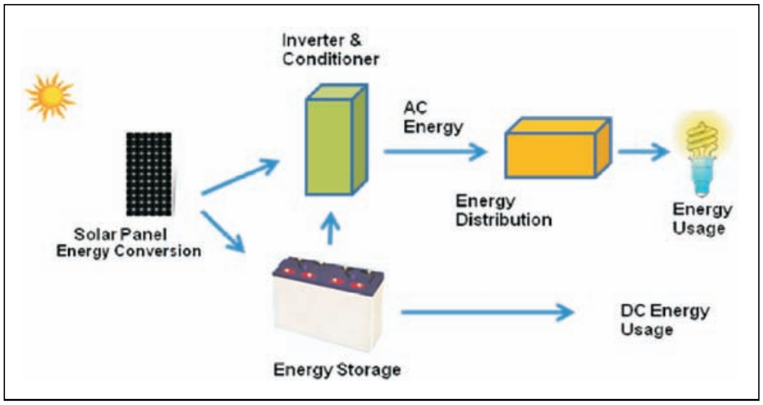

Figure 3. Components of a solar photovoltaic system.

2.1 *Silicon Based PV Cells*

As the name suggests the main material in the silicon based cells is silicon. Silicon is used in different forms like single crystal, polycrystalline and amorphous to make PV cells. This technology is well established and is found to be reliable. These PV cells have been the workhorses for a long time in solar industry amounting to about 85–90% of the global annual PV market. Let us study the technology involved in each of them.

Single Crystal Silicon PV Cells: Single crystals of silicon are grown from high purity silicon powder by Czochralski or float zone techniques. The impurities in the silicon play a major role in the efficiency of the cell. Purification of silicon is a critical step while growing silicon single crystals. The wafers of appropriate thickness (~140–200 micrometers) are cut from the crystal. In order to make the p–n junction, the crystals are grown with boron doping in the silicon. Boron doping makes silicon p-type conducting. Then phosphorus is doped onto the top surface of the wafer up to a controlled depth. Phosphorus doping makes silicon an n-type conductor. Thus in the same wafer, along its thickness, there are p- and n-type conductors forming a p–n junction. When sunlight falls on these cells, the charge carriers are produced. These charge carriers need to be collected from either side of the cell for passing current through the external circuit. Contact material is screen-printed on the two surfaces of the wafer that acts as a charge collector. The front contact pattern is specially

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The SC-Si PV cells have high efficiency of solar energy conversion. Each cell produces a voltage of 0.5–0.6 volts and 36 cells are needed to produce an open-circuit voltage of about 20 volts, which is sufficient to charge a 12 volt battery under most conditions.

designed to allow maximum light exposure of the Si material with minimum electrical (resistive) losses in the cell. The processes for making the single crystal silicon (SC-Si) solar PV cells are well established after many years of research and optimization.

In a single crystal, the arrangement of atoms in the material is uniform because the entire structure is grown from the same seed crystal. This uniformity is ideal for transferring electrons efficiently and for current flow through the material. The SC-Si PV cells have high efficiency of solar energy conversion. Each cell produces a voltage of 0.5–0.6 volts and 36 cells are needed to produce an open-circuit voltage of about 20 volts, which is sufficient to charge a 12 volt battery under most conditions.

Polycrystalline Silicon PV: The most popular commercial method of making polycrystalline silicon (poly-Si) cell involves a casting process in which molten silicon is directly cast into a mold and allowed to solidify into an ingot. Wafers are cut out of the solidified ingots for making the p–n junction. One surface of the wafer doped with P and the other side with B. The starting material can be refined lower-grade silicon, rather than the higher-grade semiconductor grade required for single-crystal material. This is where there is a cost advantage for poly-Si cells. The cooling rate is one factor that determines the final size of grains in the ingot and the distribution of impurities. These cells consist of several smaller crystals or grains that introduce boundaries. These boundaries offer resistance to the flow of electrons and encourage them to recombine with holes to reduce the power output of the solar cell. In order to reduce the reflective losses, the top surface of the cell is textured.

Amorphous Silicon PV: Amorphous silicon (a-Si) is like a glass with no order in the atomic arrangement. All amorphous materials contain many structural and bonding defects. In order to take care of the bonding defects, small amount of hydrogen is incorporated into a-Si. It is known that a-Si is a strong absorber of solar radiation but the mobility of the charge carriers is low. Because of the strong solar absorption capability, the thickness of the PV cell can be as small as 1 micrometer. The construction of the cell is slightly different here compared to SC-Si and poly-Si due to the low charge carrier mobility. Here instead of using a p–n junction for directing the free charge carriers, p-i-n junction is used. The basic scenario is that, a three-layer sandwich is created, with a middle intrinsic (i-type or undoped) layer between an n-type layer and a p-type layer. This geometry sets up an electric field between the p- and n-type regions that stretches across the middle intrinsic resistive region that assists in charge carrier mobility. The p- and n-type conductors are created by doping boron and phosphorus, respectively. Though a-Si PV cells are cheaper to manufacture compared to SC-Si and poly-Si, they are not very popular for higher capacity applications because of their long-term stability issues.

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Silicon-based solar cells are expected to dominate the PV market until at least 2020. The main limitation with these PV cells is that it is difficult to improve solar energy conversion efficiency through improved cell designs or manufacturing processes.

2.2 *Non-Silicon Based PV cells*

The materials that are used for making PV cells are cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), gallium arsenide (GaAs) and a series of modified GaAs materials. All these materials are used in the form of thin films. These materials have high solar radiation absorption capability because of their electronic band structure. The simplistic schematic diagram of the thin film PV cells is shown in *Figure* 4. All the materials used for making non-silicon PV cells are non-oxides

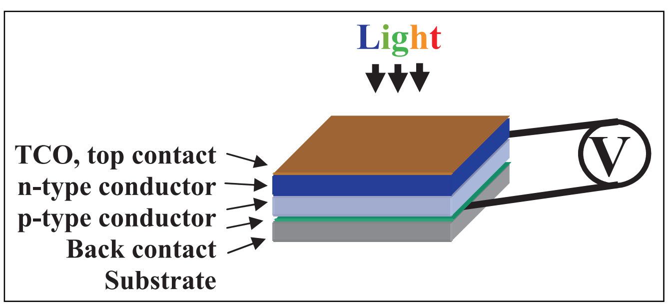


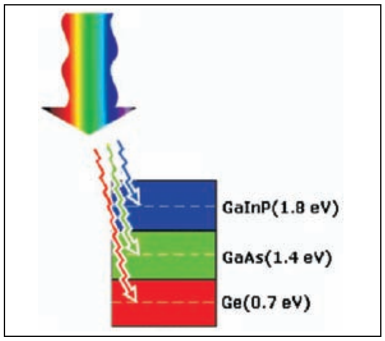
Figure 4. Schematic of the thin film PV cell.

The principle of these cells is that multiple PV cells with different band gap p-type absorbers are stacked one on top of the other. The different p-type materials absorb radiation of different regions of the solar spectrum.

and oxygen impurity can deteriorate the performance of the cell. The thin films are deposited using vacuum techniques and the cost of manufacturing these cells is high but the amount of material required and the hence the cost of raw materials is low. Other advantage is their stability and good performance at high ambient temperatures. Research is going on all over the world to find less expensive and large-scale production processes of these PV cells.

CIGS, CdTe PV Cells: As shown in *Figure* 4, a metallic (molybdenum is largely used) back contact is first deposited on a substrate. Substrate is generally glass but in recent times metal foils [2] and polymer sheets [3] are also being attempted. Since these PV cells are very thin, the substrate provides the required mechanical strength to the cell assembly. The p-type absorber material is deposited atop the back contact. This layer can be 1 micrometer thick or even less. Cadmium sulfide (CdS) is used as the n-type conductor in both CIGS and CdTe PV cells. Less than 200 nanometer thick film of the n-type conductor and less than 100 nanometer thick transparent conducting oxide (TCO) are deposited over the p-type conductor. The TCO layer acts as the front contact to collect the charge carriers from the n-type conductor. Indium doped tin oxide (ITO) or aluminum doped zinc oxide are the popular TCO materials for solar application. Silver wires are connected to the TCO for conducting the charge carriers through the external circuit.

Figure 5. Multijunction gallium-based solar cells.



Multijunction PV Cells: These are exotic, high efficiency solar PV cells. The principle of these cells is that multiple PV cells with different band gap p-type absorbers are stacked one on top of the other. The different p-type materials absorb radiation of different regions of the solar spectrum, as shown in *Figure* 5. The front cell that is exposed to the entire solar spectrum has the highest bandgap, the second cell has the second highest and so on. For example, in the gallium based 3-junction solar cells, the top layer is made of GaInP which has a bandgap of 1.8 eV. It absorbs radiation with energies higher than 1.8 eV and it is transparent to radiation with lower energies. Hence radiation with <1.8 eV passes through to the next cell which is a GaAs cell with a band gap of 1.4 eV. Here again radiation of higher energy than 1.4 eV is absorbed and lower energy radiation passes through to the next cell. Thus, in the multijunction cells most of the solar radiation can be utilized. The individual cells are connected in series. Because of this the current matching of the neighboring cells has to be good. There have been attempts to make 6-junction solar cells for better performance but there are some inherent problems of lattice matching at the cell interfaces. Since high vacuum techniques are used to deposit these thin film PV cells, their production costs are very high. These cells are mostly used for high-end applications like space.

Oxygen and nitrogen introduce an intermediate electronic band (which is partially occupied) in the band gap of the original material. The intermediate band absorbs low energy photons from the solar radiation.

Multiband PV Cells: This is a new type of solar PV cell that is still in the development stage. In single junction solar cells, one of the most important factors limiting power conversion efficiency is the loss of photons of the solar spectrum with lower energy than the bandgap of the material. These photons do not get absorbed by the p-type absorber and hence do not contribute to the cell power output. Materials like zinc telluride (ZT), zinc manganese telluride (ZMT), GaAs are known to absorb solar radiation efficiently. If oxygen, in the case of zinc compounds and nitrogen in the case of gallium compounds, is doped in very small quantities (<1–2%) into these materials, they become n-type conductors [4]. Oxygen and nitrogen introduce an intermediate electronic band (which is partially occupied) in the band gap of the original material as shown in *Figure* 6. The intermediate band absorbs low energy photons from the solar radiation. Thus, the efficiency of the cells

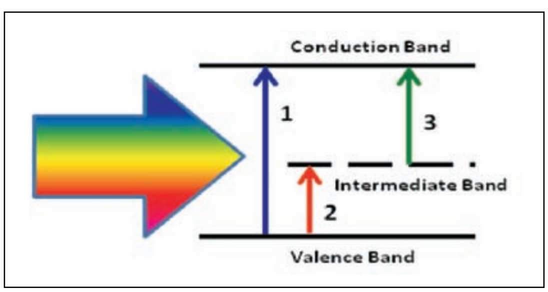


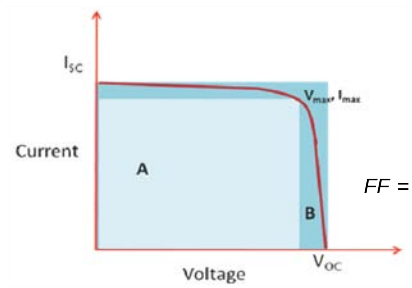
Figure 6. Schematic band diagram of a multiband cell material. The partially filled intermediate band is introduced by doping appropriate elements.

Box 2. Solar Cell Efficiency

Solar energy conversion efficiency in photovoltaic solar cells is measured by the ability of a cell to convert sunlight into usable electricity. The cell efficiency (η) is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In other words,

η = Maximum power output / (Incident radiation per unit area × Area of cell).

The maximum power output is a product of open circuit voltage (V_{OC}), short circuit current (I_{SC}), the fill factor (*FF*) of the cell. The fill factor is essentially a measure of the squareness of the I–V curve (see the *Figure* B).

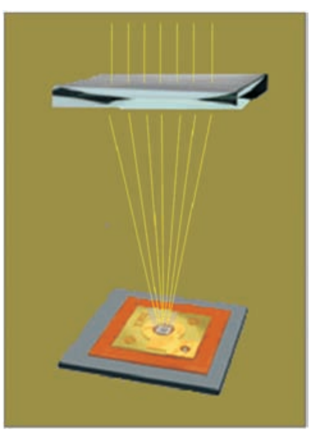


FF = area of Sq A/Area of Sq B

Figure B.

increases. Efficiencies (*Box* 2) of 35% have been achieved with GaNAs cells. The main drawback of these cells is the process of introducing controlled amount of anions on the surface of the absorber. Currently, pulse laser melting in controlled atmosphere is being used for doing this and the process is expensive.

Figure 7. Large amount of radiation is focused onto a small area by using a lens.



Concentrating Photovoltaic Cells (*CPV*): The concept behind the CPV is using lenses and mirrors to focus sunlight onto a small area. By using larger lenses, sunlight from a larger area can be used to generate power (*Figure* 7). SC-Si and multijunction solar cells are used in this configuration. In recent times, lenses that can magnify sunlight 2000 times are developed. This would reduce the solar cell area for the same power generation compared to other solar PV cells and thus reduce the amount of materials required for making the cells. However, there is a drawback with this configuration – along with the useful visible light the lenses also focus the infrared (heat) part of the sunlight. The PV cells get heated up and their efficiencies decrease. Hence efficient thermal management systems need to be attached to the PV cells to conduct away the heat. The lenses have to face the sun as much as possible. In order to do this, sun tracking sensors are attached to these lenses. The solar energy conversion efficiency of multijunction cells with the concentrators is found to be higher than 41%.

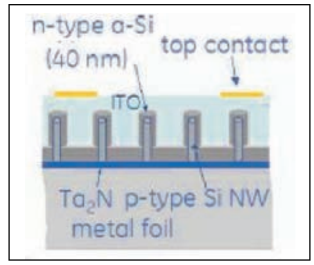
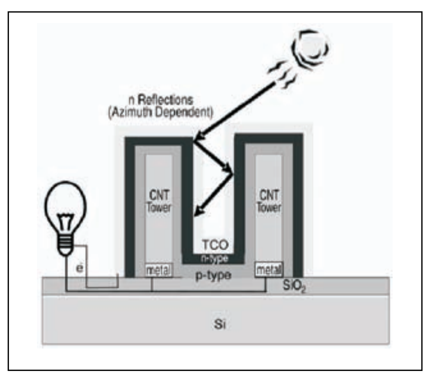


Figure 8. Schematic cross-sectional view of the demonstrated silicon nanowire solar cell.
Source: *Appl. Phys. Lett.* 91, 233117, 2007.

Nanotechnology Based Solar PV Cells: As in many fields of technology, nano-size materials are being tried for making solar PV cells. Two types of nanotechnology solar cells are fabricated at laboratory scales that have high efficiencies. These cells have a long way to go before they can be commercialized. In one of them, p-type silicon nanowires are grown on top of a conducting contact material like tantalum nitride [5]; n-type silicon is coated on top of the p-type nanowires to form the p–n junction. Indium tin oxide, which is a transparent conducting oxide, covers the entire cell and electrical connections are taken out from the top contact, as shown in *Figure* 8.

In another type [6], carbon nanotubes (CNT) are grown on top of metal strips. CNTs are good electrical conductors and act as current collectors. p-type conductor is deposited atop the CNTs and n-type conductor is deposited over the p-type conductor to form the p–n junction, as shown in *Figure* 9. TCO covers the whole cell and forms the front contact. The periodic array of CNT, offers multiple absorption opportunities of the radiation that falls on the cell because of reflection within the 3-d structure compared to flat PV cells.

Figure 9. Cross-sectional view of the CNT-based solar PV cell.
Source: *JOM*, Vol.59, No.3, pp.39–42, 2007.



Polymer/Organic Solar PV Cells: These PV cells are made of organic materials. They are very cost effective and simple printing techniques can be used to manufacture large area cells. The main drawback of these cells is the light conversion efficiency and their stability in ambient conditions for many years.

The polymer and dye-sensitized PV cells have been discussed in detail in prior articles [3,7]. There have been

Table 1. The efficiencies of the best in the class PV cells.

Type	Efficiency (%)
SC-Si	24.7
Poly-Si	19.8
a-Si12.7	
CdTe	16.4
CIGS	18.4
Multijunction	>25
Multijunction with concentrator	42.3
Multiband	~35

Multijunction PV cells have the highest efficiency. However, because of the high cost of fabrication of these cells, they are used mostly for space applications where efficiency and reliability are critical.

some recent advances like using nanomaterials, nanostructuring of the layers and using nanoparticle-organic hybrid materials. Currently, the record for the highest efficiency (*Box* 2) in this category of PV cells is 9% [8].

The solar energy conversion efficiencies of different types of inorganic PV cells are summarized in *Table* 1. These efficiencies are for cells best in the class. However, when the cells are put together to make the modules, the module efficiencies will be lower than the cell efficiencies because of losses at contacts. Of the well-understood cells, multijunction PV cells have the highest efficiency. However, because of the high cost of fabrication of these cells, they are used mostly for space applications where efficiency and reliability are critical. The silicon-based PV cells are extensively used for power generation. In fact, in many countries, government encourages and gives incentives for putting up solar panels on top of houses. *Figure* 10 shows one such town in The Netherlands.

Figure 10. PV on roofs in 'City of the Sun', Heerhugowaard, The Netherlands. Source: http://ec.europa.eu/research/energy/pdf/sra_photovoltaic_en.pdf.

Currently, the cost of electricity produced by the solar cells is very high because of the raw materials and the processing costs. As seen in *Figure* 11, with improvement in manufacturing processes, the cost per watt from different types of solar PV cells is decreasing. According to International Energy Agency (IEA), in many parts of the world, PV will achieve grid parity in terms of cost per kWh by 2020 and by 2050 PV will provide 11% of global electricity requirement [9]. In 1995, the SC-Si was the cheapest PV cell. But with the development of cost effective ways of making thin film PV, increased efficiency of concentrating PV and increasing cost of solar grade silicon powder, by 2020 silicon PV cells will be more expensive than thin films. Storing electricity in batteries so that power can be used at nights, adds additional cost to the solar plants.

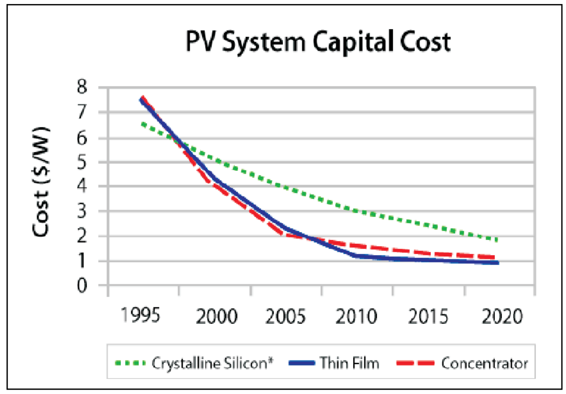


Figure 11. Cost per watt of solar power from different types of PV cells, predicted up to 2020.
Source: http://www1.eere.energy. gov/tribalenergy/guide/costs_solar_photovoltaics.html.

In addition, solar panel manufacturing process does have a pollution component in terms of the carbon-dioxide (CO_2) emission. It is estimated that 19–70 g of CO_2 is emitted for every kWh of electricity generated with thin-film and some of the silicon cells. Energy payback is a good way to measure this emission. It is an estimate of the number of years a PV system has to operate to recover the energy that was consumed in its production. Currently the energy payback time is estimated to be in the range of 5–15 years depending on the manufacturing process. Work is going on to reduce the energy payback time.

3. Solar Thermal

In this article we restrict our discussion to only the solar thermal systems that are used for electricity generation. The concept behind the usage of a solar thermal system is quite simple. The solar energy is directly collected and converted to electricity using a heat to electricity conversion device. Some kinds of heat engines or thermoelectric converters are the most common devices that are used. The heat from the solar radiation is concentrated onto a heat transfer fluid. In some cases water is directly heated using the solar radiation that is converted into steam. In more advanced systems, synthetic oil is used as a heat transfer fluid that produces steam from water. The steam is expanded in a Rankine cycle and finally converted to electricity. The efficiency

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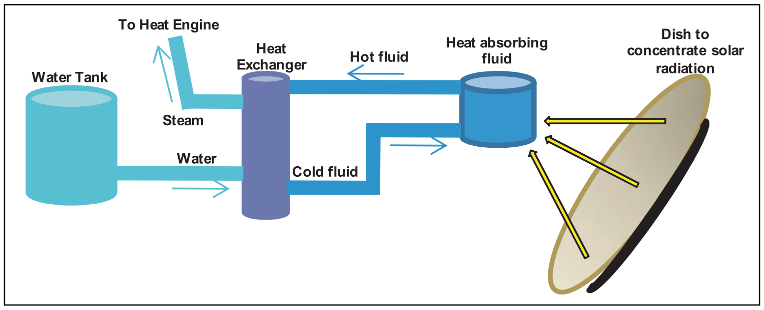

Figure 12. A schematic layout of different components of a solar thermal system.

of conversion depends on factors like the temperature and pressure of the steam. Higher the pressure and temperature higher is the efficiency of conversion into electricity. In order to increase the temperature and pressure of steam, the temperature of the heat transfer liquid needs to be higher. Hence more heat from the solar radiation will have to be focused on the fluid. This brings in a requirement to design the solar radiation concentrators.

Unconcentrated solar radiation can heat the fluid up to 200 C which is enough for heating water and room space in domestic applications. Concentrating solar radiation onto a small area using a parabolic trough or dish with mirrored surface can produce temperatures in the range of 400–650 C. A schematic diagram of a solar thermal steam producing system is shown in *Figure* 12. Instead of a concentrating dish it is possible to have parabolic troughs and long pipes, carrying the heat absorbing fluid, running at the focal point of the trough through the full length of the trough. Quite a bit of research and development has gone into designing the different components of the system.

Concentrating solar radiation onto a small area using a parabolic trough or dish with mirrored surface can produce temperatures in the range of 400–650 C.

In order to use the solar thermal plants at nights, the hot fluids are stored and used to generate steam. Some materials like the salts are used in molten form to store the heat. A 19.9 MW solar thermal plant has been set up in Spain (called the Gemasolar Power Plant) over a 185 hectare area. This plant uses an array of 2650 mirrors to reflect light onto a tower top that is 140 m high (*Figure* 13). The solar radiation heats up the salt to a temperature higher than 500 C and the molten salts are stored in special thermally insulated tanks that can preserve the temperature of the salts. The molten salt (a mixture of sodium and potassium ni-

Figure 13 . Gemasolar Power Plant in Spain.
Source : http://www.torresolenergy.com/TORRESOL/Press/torresol-energy-commissions-gemasolar-power-plant-in-spain.
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trates) is then used to generate steam and run steam turbines to generate electricity anytime of the day. It is estimated that Gemasolar will generate about 110 GWh of electricity per year reducing 30,000 tons of CO_2 emission and can power 25,000 homes. Thus, this is the first round-the-clock electricity generating station using solar power.

4. Indian Scenario

When we consider the Indian scenario, the average global radiation received is around 4.5–5.5 kWh per sq. meter per day in most parts of the country (*Figure* 14). With about 250–300 clear sunny days in a year in most parts of the country solar PV can be judiciously used to meet part of our ever-increasing energy demand. On an average, a house in urban location, with all its modern gadgets, consumes about 250–400 kWh electricity per month. With the roof area of a 11 square[1] house, it is possible to generate 250 kWh per day even with a 5% energy conversion efficient solar PV cells. Even with partial roof area coverage, it is possible to generate enough power to run households. Decentralized power generation for rural electricity needs can be achieved by setting up solar PV modules on rooftops of houses or even solar parks near the villages. This would ensure saving of cost on establishment and maintenance as well as transmission and distribution of energy. Attempts are made to use the solar PV modules to power the irrigation pumps in

[1] 1 square = 100 sq.ft

It is estimated that Gemasolar will generate about 110 GWh of electricity per year reducing 30,000 tons of CO_2 emission and can power 25,000 homes. Thus, this is the first round-the-clock electricity generating station using solar power.

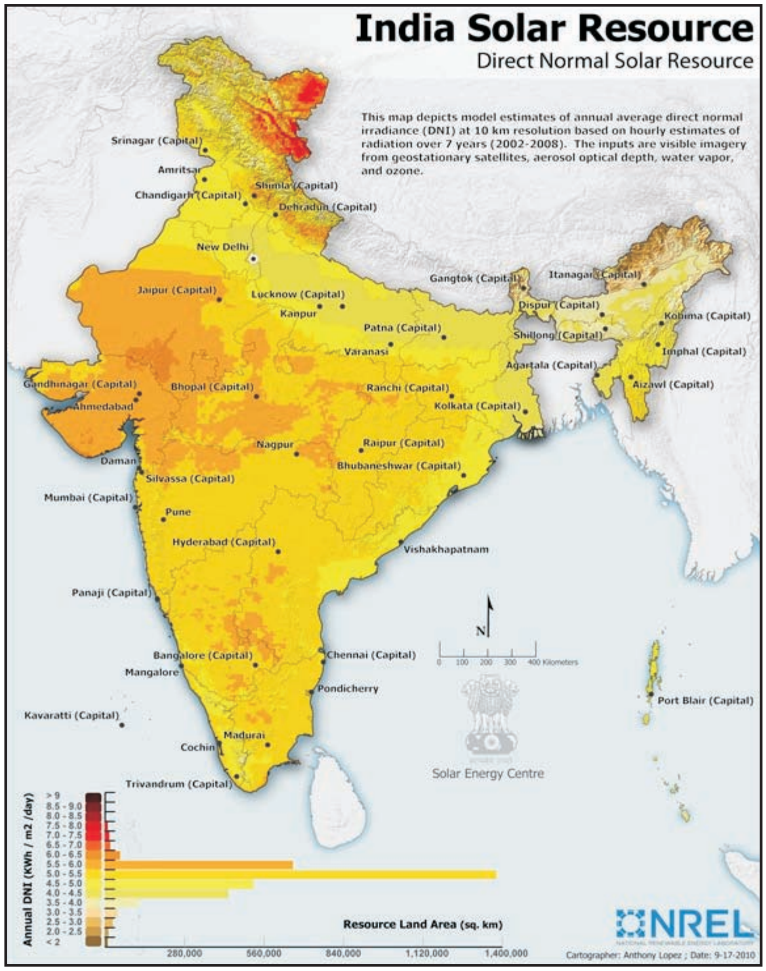

Figure 14. Solar direct irradiance map of India. Parts of Rajastan, Gujarat and Kashmir receive more radiation than the rest of the country.

Ministry of New and Renewable Energy has initiated the Jawaharlal Nehru National Solar Mission (JNNSM) under the brand 'Solar India'to encourage R&D, manufacturing and investment in the area of solar technology.

remote areas. Government of India is giving certain incentives in terms of tax and customs duty benefits to encourage the manufacturers of solar PV modules. In the silicon solar PV area, India is the second largest manufacturer in the world and 67% of the manufactured solar PV modules are exported. Ministry of New and Renewable Energy has initiated the Jawaharlal Nehru National Solar Mission (JNNSM) under the brand 'Solar India' to encourage R&D, manufacturing and investment in the area of solar technology. The mission of this scheme is to set up 20,000 MW grid-connected power generation capability and off-grid capability of 2000 MW by 2022. As of July 2012, about ~1140

MW capacity power plants have been installed around the country [10].

Solar thermal power generating plants are not yet set up in the country. Thermal systems mainly for water heating and cooking have been in use extensively all over the country. Solar steam generating system of 6 dishes with 16 sq. m area each is set up in Mount Abu in Rajasthan for use in kitchens, laundry, sterilization, etc [10].

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