1 Introduction to World Energy Consumption

At present, human world energy consumption is made up of about 88% fossil fuels (gas, coal and oil), 6% hydroelectricity, 6% nuclear power and tiny fraction from biomass and other solar energy sources [1]. Fossil fuels are causing environment pollution and becoming gradually exhausted. Nuclear energy obtained from nuclear fission is inquisitively dangerous and limited due to deficiency of heavy elements. Similarly, nuclear fusion has short comings in controlling the reaction and the formation energy. Therefore, seeking a renewable energy source has become a fashionable work. The amount of solar energy from the sun to the earth is gigantic, i.e. $3 \times 10^{24}$ J per year, about $10^4$ times more than what mankind consumes currently. Solar energy emitted by the sun and reaching the earth’s surface is a form of electromagnetic radiation that is available over a wide spectral range (300-2100 nm). In order to be used the radiation needs to be converted into an energy form suitable for our needs.

1.1 Concept of Renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible. Since the industrial revolution, fossil fuels like petroleum, coal, oil, natural gas and other non-renewable energy sources have been used as the primary energy source of power for commercial and domestic applications. However, fossil fuels are finite source of energy and with rapidly increasing energy consumption with population and concerns of excessive use and depletion of these sources of energy, have alarmed the need for
sustainable and renewable energy. Burning fossil fuels release number of particulate matter like carbon, nitrogen and sulphur into the atmosphere which combines with air to form acidic components causing acid rain, affecting natural and human resource. Also, combustion of fossil fuels and other human activities have increased greenhouse gases like carbon-dioxide, methane, chlorofluorocarbon’s in the atmospheres which are believed as the major factors for the cause of global warming. In addition to these effects, there are environmental risks associated with extracting, transporting and utilizing fossil fuels which can bring hazardous impact on surrounding habitat and environment.

Continuing consumption of fossil fuels might also have affect economically by generating a shortfall of these energy resources with the growing demand and the pollutant was summarized in Table 1.1. Thus there is a need for conservation of fossil fuels to protect our environment by utilizing sustainable, renewable and clean energy resources.

**Table 1.1: Effect of Pollutants on Human beings**

<table>
<thead>
<tr>
<th>Types</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Pollutants</strong></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>Heart disease, strokes, pneumonia, pulmonary tuberculosis, congestion of brain and lungs</td>
</tr>
<tr>
<td>SOₓ</td>
<td>Acute respiratory infection (chronic pulmonary cardiac disorders)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Chronic respiratory infection (chromic bronchitis, emphysema and pulmonary oedema)</td>
</tr>
<tr>
<td>HC</td>
<td>Lung and stomach cancer</td>
</tr>
<tr>
<td>Pollutants</td>
<td>Effects</td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
</tr>
<tr>
<td>SP</td>
<td>Tissue destruction of the respiratory epithelium (deleterious effect on the lining of the nose, sinus, throat and lungs) cancer</td>
</tr>
<tr>
<td>Pb and PbOx</td>
<td>Brain damage, cumulative poisoning (absorbed in red blood cells and bone marrow)</td>
</tr>
</tbody>
</table>

**Secondary pollutants**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAN and NO₂</td>
<td>Attacks of acute asthma and allergic respiratory infections (chronic bronchitis and emphysema)</td>
</tr>
<tr>
<td>O₃</td>
<td>Chest constriction, irritation of mucous membrane, headache, coughing and exhaustion</td>
</tr>
</tbody>
</table>

**Aerosols**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₄²⁻ and NO₃⁻</td>
<td>Asthma, infant mortality and acute respiratory infections</td>
</tr>
</tbody>
</table>

**Others**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldehydes, olefins, nitroamines PAH</td>
<td>Respiratory tract carcinoma</td>
</tr>
<tr>
<td>Acrolein</td>
<td>Irritation to eyes</td>
</tr>
</tbody>
</table>

### 1.2 Renewable Energy Scenario

In India the potential of renewable energy source is about 81.200 MW out of which only 5594 MW (6.9%) has been harnessed so far. The potential and capacity harnessed so far is given in Table 1.2 [2].
Table 1.2: Potential & Installation of Renewable Energy System

<table>
<thead>
<tr>
<th>S. No</th>
<th>Renewable Energy Sources</th>
<th>Potential (MW)</th>
<th>Potential Harnessed So Far (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wind</td>
<td>45,000</td>
<td>2980</td>
</tr>
<tr>
<td>2</td>
<td>Small Hydro Upto (25 MW)</td>
<td>15,000</td>
<td>1693</td>
</tr>
<tr>
<td>3</td>
<td>Bio Mass</td>
<td>3,500</td>
<td>727</td>
</tr>
<tr>
<td>4</td>
<td>Gasifier</td>
<td>16,000</td>
<td>62.0</td>
</tr>
<tr>
<td>5</td>
<td>Urban &amp; Industrial Waste</td>
<td>1,700</td>
<td>46.5</td>
</tr>
<tr>
<td>6</td>
<td>Solar Photovoltaic (S.P.V)</td>
<td>20 (Sq km)</td>
<td>86.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>81,200</td>
<td>5,594</td>
</tr>
</tbody>
</table>

India’s need for power is growing at a prodigious rate, annual electricity generation and consumption in India have both nearly doubled since 1990, and it’s projected 2.6% (low end) to 4.5% (high end). Annual rate of increase for electricity consumption (through 2020) is the highest for any major country. India is currently the seventh greatest electricity consuming country (accounting for about 3.5% of the world total annual electricity consumption) but will soon overtake both Germany and Canada in that regard. India now faces an electricity shortages conservatively estimated at 11% and as high as 18% during peak demand periods [3].

1.3 Renewable Energy Technologies

There are many of the renewable energy technologies in the world. Such as Solar energy, Wind energy, Biomass and biogas energy, Geothermal energy, Tidal energy, Ocean thermal energy etc., Some of them are described in detailed below.
1.3.1 Solar Energy

Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy could be used, it will be one of the most important supplies of energy specially when other sources in the country have depleted energy comes to the earth from the sun. This energy keeps the temperature of the earth above than in colder space, causes current in the atmosphere and in ocean, causes the water cycle and generate photosynthesis in plants. The solar power where sun hits atmosphere is $10^{17}$ Watts, where as the solar power on earth’s surface is $10^{16}$ Watts.

The total worldwide power demand of all needs of civilization is $10^{13}$ Watts. Therefore the sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require [4]. Electricity can be produced from the solar energy by photovoltaic solar cells, which convert the solar energy directly to electricity. The most significant applications of photovoltaic cell in India are the energisation of pump sets for irrigation, drinking water supply and rural electrification covering street lights, community TV sets, medical refrigerators and other small power loads.

1.3.2 Wind Energy

Wind energy, which is an indirect source of solar energy conversion, can be utilized to run windmill, which in turn drives a generator to produce electricity. Wind can also be used to provide mechanical power such as for water pumping. In India generally wind speeds obtainable are in the lower ranges. Attempts are, therefore, on the development of low cost, low speed mills for
Irrigation of small and marginal farms for providing drinking water in rural areas. The developments are being mainly concentrated on water pumping wind mill suitable for operation in a wind speed range of 8 to 36 km per hour.

In India high wind speeds are obtainable in coastal areas of Saurashtra, western Rajasthan and some parts of central India [5]. Among the different renewable energy sources, wind energy is currently making a significant contribution to the installed capacity of power generation, and is emerging as a competitive option. India with an installed capacity of 3000 MW ranks fifth in the world after Germany, USA, Spain and Denmark in wind power generation. Energy of wind can be economically used for the generation of electrical energy. Wind energy equipment are modular in nature and the investment requirement for these equipments as compared to conventional energy equipments is not large and the industry is able to attract private investment thereby reducing the burden on the encourages such investment.

1.3.3 **Biomass and Biogas Energy**

The potential for application of biomass, as an alternative source of energy in India is large. Plenty of agricultural and forest resources is available for production of biomass. Biomass is produced in nature through photosynthesis achieved by solar energy conversion. As the word clearly signifies Biomass means organic matter. In simplest form, the process of photosynthesis is in the presence of solar radiation. Biomass energy co-generation programme is being implemented with the main objective of promoting technologies for optimum use of country’s biomass resources and for exploitation of the biomass power generation potential, estimated at 19500 MW. The technologies being
promoted include combustion, gasification and cogeneration, either for power in captive or grid connected modes or for heat applications.

1.3.4 Ocean Thermal Energy Conversion

This is also an indirect method of utilizing solar energy. A large amount of solar energy is collected and stored in tropical oceans. The surface of the water acts as the collector for solar heat, while the upper layer of the sea constitutes infinite heat storage reservoir. Thus the heat contained in the oceans, could be converted into electricity by utilizing the fact that the temperature difference between the warm surface waters of the tropical oceans and the colder waters in the depth is about 20 – 25K. Utilization of this energy, with its associated temperature difference and its conversion into work, forms the basis of Ocean Thermal Energy Conversion (OTEC) systems. The surface water, which is at higher temperature could be used to heat some low boiling organic fluid and the vapours of which would run a heat engine. The exit vapour would be conducted by pumping cold water from the deeper regions. The amount of energy available for ocean is replenished continuously.

1.3.5 Tidal Energy

The tides in the sea are the result of the universal gravitational effect of heavenly bodies like sun and moon on the earth. Due to fluidity of water mass, the effect of this force becomes apparent in the motion of water, which shows a periodic rise and fall in levels which is in synthesis with the daily cycle of rising and setting of sun and moon. This periodic rise and fall of the water level of sea is called tide. These tides can be used to produce electrical power
which is known as tidal power. When the water is above the mean sea level, it is called flood tide and when the level is below the mean sea level, it is called ebb tide. To harness the tides, a dam is to be built across the mouth of the bay. It will have large gates in it and also low head hydraulic reversible turbines are installed in it. A tidal basin is formed, which gets separated from the sea by dam. The difference in water level is obtained between the basin and sea. By using reversible water turbines, turbines can be run continuously, both during high tide and low tide. The turbine is coupled to generator, potential energy of the water stored in the basin as well as energy during high tides used to drive turbine, which is coupled to generator, generating electricity.

1.3.6 Geo Thermal Energy

This is the energy, which lies embedded within the earth. According to various theories the earth has a molten core. The steam and the hot water come naturally to the surface of the earth in some locations of the earth. Two ways of electric power production from geothermal energy has been suggested. In one of this heat energy is transferred to a working fluid which operates the power cycle. This may be particularly useful at places of fresh volcanic activity, where the molten interior mass of earth vents to the surface through fissures and substantially high temperatures, such as between 450 to 550°C can be found. By embedding coil of pipes and sending water through them can be raised. In the other, the hot geothermal water and or steam is used to operate the turbines directly.

At present only steam coming out of the ground is used to generate electricity, the hot water is discarded because it contains as much
as 30% dissolved salts and minerals and these cause serious rust
damage to the turbine.

1.3.7 Small Hydropower

Energy from small hydro is probably the oldest and yet, the most
reliable of all renewable energy sources. The term ‘small hydro’ has
a wide range in usage, covering schemes having installed
capacities from a few kW to 25 MW. In India small hydro schemes
are further classified as micro hydro up to 100 kW plant capacity,
mini hydro from 101 kW to 2000 kW and small hydro up to 25000
kW plant capacities. The advantage of this resource is that it can
be harnessed almost everywhere in India from any nearby stream
or canal in the most environmentally benign manner, and without
encountering any submergence, deforestation or resettlement
problems which are generally encountered in the development of
large hydro power development.

Small hydropower development can reduce the load on
conventional sources of energy. Small hydro technology is mature
and proven. Civil works and installation of equipment involve
simple processes, which offer sufficient employment opportunities
to local people and use locally available material. Gestation period
is also short. Simple and proven design concepts suit local
conditions. The development of small-scale hydropower in India
started almost in the pace with the world’s first hydroelectric
installation in 1882 at Appleton USA.

The 130 KW installations in Sidrapong (Darjeeling) in the year
1897 was the first installation in India. The other installations
were Shivasamundram at Mysore (2000 kW), and Bhoorisingh in
Chamba (40 kW) in 1902, Galogi at Mussoorie (3000 kW) in 1907,
Jubbal (50 kW) in 1911 and Chhaba (1750 kW) at Shimla in 1913. These plants were used primarily for lighting in important towns and are still working. The country has an estimated SHP potential of about 15000 MW. So far 514 SHP projects with an aggregated installed capacity of 1693 MW have been installed [6, 7].

1.3.8 Hydrogen Energy and Fuel Cells

In recent years hydrogen has been receiving worldwide attention as a clean and efficient energy carrier with a potential to replace liquid fossil fuels. Significant progress has been reported by several countries including India in the development of hydrogen energy as an energy carrier and an alternative to fossil fuels. Serious concern related to energy security. Depleting fossil fuel reserves, green house gas emissions and air quality are driving this global transformation effort towards a hydrogen-based economy. Hydrogen has high-energy content, when burnt, it produces only water as a by-product and is, therefore, environmentally benign. At present hydrogen is available as a by-product from several chemical processes, plants or industries.

1.4 Cost of RET Systems

The capital and generation cost of RET systems is given in Table 1.3 below [8].

1.5 Advantages of Renewable Energy Technologies

To augment the energy needs renewable energy options may be used to supply all substantial amount of energy as they do have the following advantages.
Renewable energy is an indigenous source available in considerable quantities to all developing nations and capable in principle of having a significant local, regional or national economic impact.

Several renewable options are financially and economically competitive for certain applications, such as in remote locations, where the costs of transmitting electrical power or transporting conventional fuels are high.

**Table 1.3: Capital and Generation Cost of RET Systems**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Sources</th>
<th>Capital Cost (Rs. Crores/MW)</th>
<th>Cost of Generation (Rs.Crores/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SHP</td>
<td>3.00-6.00</td>
<td>1.00 - 2.50</td>
</tr>
<tr>
<td>2</td>
<td>Wind</td>
<td>4 - 4.50</td>
<td>2.25 -2.75</td>
</tr>
<tr>
<td>3</td>
<td>Biomass/Cogeneration</td>
<td>0-2.50</td>
<td>1.75 - 2.00</td>
</tr>
<tr>
<td>4</td>
<td>Biomass/Gasification</td>
<td>2.50-3.00</td>
<td>1.75 - 2.00</td>
</tr>
<tr>
<td>5</td>
<td>S.P.V</td>
<td>20.00-25.00</td>
<td>9.00 - 12.00</td>
</tr>
</tbody>
</table>

Rapid scientific and technological advantages are expected to expand the economic range of renewable energy applications over the next 8-10 years making it imperative for international decision makers and planners to keep abreast of these developments.

Renewable are free for the taking. The power plants based on renewable do not have any fuel cost and hence negligible running cost.
Renewable have low energy density and more or less there is no pollution or ecological balance problem.

The use of renewable energy could help to conserve foreign exchange and generate local employment if conservation technologies are designed, manufactured, assembled and installed locally.

Provide energy in environmentally benign manner.

Short gestation period and low investment.

With the help of State/Union Govt. incentives, these schemes have become more attractive for private sector participation.

1.6 Photovoltaic: From the Beginning to Real Application

The photovoltaic effect discovered by the French scientist Edmond Becquerel in 1839 [9]. After observing electric potential between two electrodes attached to a solid or liquid system upon light irradiation has been the base for a variety of concept to convert solar radiation into electricity. This concept has opened a new road for alternative energy generation and is actually a hot topic in current research. One simple reason is that the Earth receives $1.2 \times 10^{17}$ W insolation or $3 \times 10^{24}$ Joule energy per year from the Sun and this means covering only 0.13% of the Earth’s surface with solar cells with an efficiency of 10% would satisfy our present needs [10]. Apart from the abundance of potentially exploitable solar energy, photovoltaic cells also have other competitive advantages such as little need for maintenance, off-grid operation and silence, which are ideal for usage in remote sites or mobile applications.
The life on the ground has been always governed by solar power. As early as in the 7th century B.C., magnifying glass was already used to concentrate sun’s rays to make fire. Later on, the Roman people built the famous bathhouses (in the first to fourth centuries A.D) with large south facing windows to employ the sun’s warmth. They named these sunspaces heliocamini (sun furnaces) [11]. However, it was until the 19th century that the photovoltaic effect was discovered. Since this discovery many effort have been made in this field. In 1883, an American inventor developed the first large area solar cells from selenium wafers [12]. However, since the selenium cells converted far less than 1% of all incident sunlight into electric power and deteriorated very rapidly when exposed to strong light, these pioneers in photo electricity failed to build the solar devices that they had hoped to. These preliminary results opened the road in this technology, which is nowadays amongst hot research topics.

The spectral distribution of the solar spectrum was described by Max Planck in 1901 through his Planck’s law [13]. Four years later, Albert Einstein published a simple description of “light quanta” (later called “photons” as suggested by Gilbert Lewis in 1926) and showed how they could be used to explain the photoelectric effect, which won him the Nobel Prize in 1921 [14]. This is the theoretical basis for all photovoltaic devices and in common semiconductors, photons excite electrons out of the valence band and into the higher-energy conduction band, where they are collected and transported to the outer circuit. In 1904, Wilhelm Hallwachs made a semiconductor-junction solar cell from copper and copper oxide, a prototype of thin-film Schottky barrier devices. This barrier layer at the semiconductor-metal interface was confirmed by Goldmann and Brodsky in 1914 and later studied in more details by Walter Schottky, Neville Mott and others.
in the 1930s [15-17]. In 1932, Audubert and Stora discovered the photovoltaic effect in Cadmium Sulfide (CdS), opening up a way to II-VI solar cells [18].

In the 1950s with the development of silicon electronic, Fuller, intuitively made near-surface $p$-$n$ junctions by boron trichloride treatment of $n$ type silicon wafer which greatly favoured charge separation of the device, and with these substrates, Chapin got near 6% conversion efficiency 50 times more efficient than the selenium cells in the 1930s [19, 20]. After this finding, many kinds of $p$-$n$ junction with CdS, GaAs, InP and CdTe were developed, however the cost of the photo electricity was so high and was exclusively used in space application. In the mid 1970s after the political crisis in the Middle East, the embargo and the realization of the limitations in fossil fuel resources, a great interest in the solar cell as an alternative energy source for terrestrial application.

It was during this period that second generation solar cells were developed, such as polycrystalline and amorphous silicon, thin-film deposits of silicon, CdTe, CuInSe$_2$, (CIS) and Cu(In,Ga)Se$_2$ (CIGS), as well as multi junction cell technology. This generation of device turned out to be advantageous in production cost with respect to silicon device.

In the 1990s new concepts were introduced and developed. The type called third generation includes dye-sensitized solar cells, polymers solar cells, and nanocrystalline solar cells. These are different to classical $p$-$n$ heterojunction since they consist of bulk junctions where charge separation takes place. This approach offers a new alternative for low-cost solar cells.
1.7 Types of Photovoltaic Cells

Current silicon based solar cells on the market, based on inorganic solid-state junction devices, are environmentally clean, but expensive, due to large amounts of materials required for production, and generally heavy or cumbersome [21-23]. Though silicon cells have relatively high reported power conversion efficiencies of between 15 and 20%, the efficiencies achieved in laboratory studies are often not conveyed in commercially available applications, due to problems with scale up and the requirement of highly controlled conditions [24].

![Chart of Photovoltaic Cell Developments from 1975 to 2010](image)

**Figure 1.1** Chart of Photovoltaic Cell Developments from 1975 to 2010 [27]
Silicon based cells have dominated the photovoltaic market for the last fifty years and much research is still made into enhancing existing systems [25]. However, silicon cells have a theoretical maximum power conversion capacity of less than 29% [26]. Alternate forms of cells are thus being heavily researched, particularly those using nanomaterials, due to the favourably small amount of material needed and the likely associated decrease in cost per watt. Currently, the silicon crystalline solar cells still dominate the industry due to the cell efficiency (Figure 1.1).

**Figure 1.2** Classification of Solar Cells
They could be roughly categorized into three categories: silicon based crystalline solar cells, thin film solar cells (silicon based and amorphous silicon), novel materials. A brief description of different types of solar cells and their classification was given (Figure 1.2.).

### 1.7.1 Mono-Crystalline and Poly-Crystalline Solar Cells

Silicon solar cells were invented by Russel Ohl in 1941 [28]. However, the first actual silicon solar cell module was built by Bell Lab researchers: Gerald Pearson, Calvin Fuller and Daryl Chapin [29]. The structure of the cells is simply a silicon p-n junction. Both mono and poly-crystalline cells require long fabrication processes and require massive amount of silicon material.

Mono crystalline solar cells, with continuous and unbroken crystal lattices, are generally grown from cylindrical ingots that are grown by Czochralski process. Poly-crystalline cells, on the other hand, are generated simply by casting the silicon ingots that are made from cooling and solidifying the molten silicon. The performance of the cells can achieve efficiency as high as 25% for mono crystalline and 18% for polycrystalline in laboratory researches, which is close to the theoretical optimal efficiency. Commercialized cells have also achieved 12% efficiencies.

### 1.7.2 Silicon Thin Film Solar Cell

Silicon thin film solar cells are another type of polysilicon cells. Instead of cutting slices from silicon ingots, the materials are deposited onto low cost substrates, such as glass and ceramic, using technologies like Plasma Enhanced Chemical Vapor Deposition (PECVD), with a certain thickness. There are three
types of silicon thin film cell structures: single junction, twin junction and multiple junctions. The major difference between these structures is the number of p-i-n junction layers in the cell. These types of solar cells require less material and simpler fabrication than crystalline cells but still maintain the characteristics of crystalline cells such as high absorption in visible light range and good light stability, preventing light induced degradation to occur. The only downside of this type of cell is that its efficiency is still very low in comparison with crystalline solar cells [30].

1.7.3 Amorphous Silicon Solar Cell

In 1976, Pankove and Carlson reported the first amorphous silicon solar cell with 2.4 % and the efficiency was soon improved to 4 % [31]. Amorphous silicon differs from crystalline silicon by the lack of long range well ordered lattice that exists in crystalline silicon. The cells can be produced on cheap substrates such as glass or plastics. The thickness of the cell is very thin, even less than 1/100th of crystalline silicon cell thickness, reducing the cost of silicon material. Moreover, the cells can be fabricated under low temperature, reducing the energy consumption.

During the fabrication process and hence lower the fabrication cost. Because of the low in efficiency—approximately 10% in large scale fabrication and 13% in laboratory researches, there are researches focusing on improving the cell design, either by improving the fabrication technology and by develop new amorphous alloys [32-34].
1.7.4 CIS and CIGS Solar Cell

Researches on Chalcopyrite based solar cells began in early 1970s and the research group lead by Dr Goryunova was the pioneer of this area. The cells can be separated into two main categories: CuInSe\(_2\), short for CIS, and Cu (In\(_{1-X}\)Ga\(_X\)) (Se\(_{1-Y}\)S\(_Y\))\(_2\), short for CIGS. Although the efficiency of the cells are lower than the silicon crystalline (20% in comparison with 25%), its advantages such as low material costs, wide light absorption range and good stability draw the public attentions, resulting in massive research [35]. For these types of cells, the ratio between Ga/(Ga+In) and Se/(Se+S) for CIGS and the ratio between Se(Cu+Se) and In/(Se+In) for CIS are important aspects in controlling the band gap width and the phase type that are directly related to the conversion efficiencies.

The cell structures are in sandwich form (Figure 1.3). There are several ways in fabricating the CIS or CIGS compound layer, such as Metallic Organic Chemical Vapour Deposition (MOCVD), Vacuum Evaporation, Chemical Bath Deposition (CBD) and more [36]. There are seven methods in fabricating CdTe thin film: Electro-Deposition (ED), Closed-Space Sublimation (CSS), Screen Printing (SP), Spray Deposition (SD), Vapour Transport Deposition (VTD), MOCVD and Sputtering [37-40].

However, method such as CSS, because of its capability in determining precise amount needed in forming CdTe, (Figure 1.4) requires higher fabrication cost and thus is normally not used in large production. SD, on the other hand, is simple and does not need to be done in vacuum environment, so companies like Golden Photo have managed to industrialize this method. The efficiency of the cell produced by Golden Photo has reached around 8%.
1.7.5 Photo Electrochemical Solar Cell

Photoelectrochemical cells, including dye sensitized solar cell and organic solar cells, utilize photochemical reaction to generate electricity. This type of cell has a number of advantages such as low mass production cost, good alterability in material structure, and wide range in visible light absorption. Some materials used for
this type of cells are said to be reproducible. Furthermore, the cells are much less sensitive to the semiconductor defects than the conventional crystalline cells. The structure of the cell is normally in sandwich structure, with transparent substrates as the top and bottom layer and Transparent Conductive Oxide (TCO) layers as conductor. This type of solar cell will be investigated in this thesis work [41, 42].

1.8 The Solar Source and Air Mass

The solar spectrum is a mixture of light with different wavelengths, ranging from ultraviolet, visible and infrared region of the electromagnetic spectrum[43]. According to the black-body radiation, the energy density per wavelength \( \frac{de_r}{\lambda} \) can be expressed as a function of \( \lambda \) by eq.1.1

\[
\frac{de_r(\lambda)}{d\lambda} = \frac{2hc_0d\Omega}{\lambda^5} \frac{1}{\exp\left(\frac{hc_0}{\lambda k_BT}\right)-1}
\]  

(1.1)

where \( d\Omega \) is solid angle element, \( c_0 \) is the velocity of the light in the medium, \( k_B \) and \( h \) are the Boltzmann constant and Planck constant, respectively. By taking \( \frac{d^2e_r(\lambda)}{d\lambda^2} = 0 \), the maximum value of \( \frac{de_r(\lambda)}{d\lambda} \) is at the wavelength

\[
\lambda_{max} = \frac{hc_0}{4.965k_BT} = 0.2497 \frac{\mu\text{meV}}{k_BT}
\]

(1.2)

The power density at the sun's surface is 62 MWm\(^{-2}\) and it reduces to 1353 Wm\(^{-2}\) at the point just outside the Earth’s atmosphere since the solid angle subtended by the sun, \( \Omega_s \), is as small as 6.8 x 10\(^{-5}\) sr. On passing through the atmosphere, the spectrum is
partially attenuated by the absorption of oxygen, ozone in the ultraviolet region and water vapour, carbon dioxide, methane in the infrared. This attenuation is described by the ‘Air Mass’ (Figure 1.5) factor since the absorption increases with the mass of air through which the radiation passes[44(a,b)]. For a thickness of ZO of the atmosphere, the path length SO through the atmosphere for radiation at an incident angle \( \theta \) relative to the normal to the earth’s surface is given by

\[
SO = \frac{ZO}{\cos \theta}
\]  

(1.3)

The ratio SO/ZO is called the Air Mass factor. The spectrum outside the atmosphere is denoted as AM0 and that on the surface of the earth for perpendicular incidence as AM1.

![Figure 1.5 Illustration Scheme of the “Air Mass” Concept.](image)
The standard spectrum for moderate weather is AM 1.5, which corresponds to a solar incident angle of 48° relative to the surface normal and gives a mean irradiance of 1000 Wm\(^{-2}\). The comparison between the spectrum of AM0 and AM1.5 (Figure 1.6) was also shown. The standard test conditions have been defined by American Society for Testing and Materials (ASTM) for comparing the solar cell characteristics in different laboratories all over the world. These specify that the temperature of the cell should be 25°C and that the solar radiation incident on the cell should have a total power density of 100 mW/cm\(^2\), with a spectral power distribution characterized as AM1.5.

**Figure 1.6** Solar Irradiance Spectra of: a) AM0 and b) AM1.5
1.9 Advantages and Limitations of Solar Cells

Advantages of Solar cell technology can be mostly viewed by their comparison with the limitations of the present day primary energy sources, fossil fuels [45].

(a) Advantages:

- **Abundant source of energy**: Unlike fossil fuels, like natural gas, petroleum, coal, oil etc which are associated with expensive and hazardous processes like drilling and mining for their extraction, solar energy is abundant, free and readily available source of energy.

- **No harmful emissions**: solar cells are clean sources of energy with any harmful emissions of greenhouse gases.

- **Reliable and low maintainance**: Solar cells do not have any moving parts and are free from vibrations. Therefore, require minimal maintainance over their life time and last longer.

- **Sustainable energy source**: Solar is renewable and sustainable source of energy.

- **Allows Distributed Power Generation**: Photovoltaic power generation do not require a large scale installation to operate unlike conventional power generation stations. Solar power generators can be installed in a distributed fashion, on the user end utilizing area that is already present, and allowing individual users to generate their own power.
(b) Limitations:

- Initial installation cost of a solar system is expensive and less efficient.

- Energy from the sun is not constant. Solar energy cannot be harnessed during cloudy days, rains and at night. This limits the energy production from the solar cells and thus to a certain extent making it necessary to rely on fossil fuels for power demands.

- Since the solar energy availability is limited and varying, they need storage through batteries, for use during night time and cloudy days.
References


