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General Introduction

1.1. An Introduction to Solar Energy and its Prospects

Strictly speaking, all forms of energy on the earth are derived from the sun. However, the more conventional forms of energy, the fossil fuels received their solar energy input eons ago and possess the energy in a greatly concentrated form. These highly concentrated solar energy sources are being used as such at a rapid rate that they will be depleted in not-too distant future.

There are four primary sources of energy *viz.*, petroleum, natural gas and natural-gas-liquids, coal and wood. Excepting wood, all these common sources have finite supplies. The life-time is estimated to range from 15 years for a natural gas to nearly 300 years for coal. Therefore, as these non-renewable sources are consumed, the mankind must turn its attention to longer-term, permanent type of energy sources. The two most significant such sources are nuclear and solar energy. Nuclear energy requires advanced technology and costly means for its safe and reliable utilization and may have undesirable side effects. Solar energy, on the other hand, shows promise of becoming a dependable energy source without new requirement of a highly technical and specialized nature for its wide spread utilization. In addition, there appear to be no significant polluting effects from its use.

Modern scientific research in the utilization of solar energy commenced in 1855 when C. Guntur, an Austrian, invented a solar boiler using mirrors. In 1876 an American inventor, John Ericsson who invented several types of hot air engines prior to this date, visualised that at some time in the near future, a chain of solar power stations across North Africa, the Middle East India, Australia and Central America would be set up. In the latter half of the last century and during the first of this century, progress in the field of energy research was fairly slow. This was mainly due to availability of cheap fossil fuels. The waning solar energy research was revived in 1940 when Godfray Cabot left a large sum of money for research projects at the Massachussetts Institute of Technology. During the recent energy panic research in the utilization of solar energy has gathered considerable momentum, especially in industrialized countries such as U.S.A., U.S.S.R., France, Australia and Canada. The near future will certainly show some major break through in solar energy technology.

All countries in the world receive some solar energy. This amount varies from a few hundred hours per year as in the northern countries and the lower part of South America, to four thousands hours per year as in the case in most of the Arabian peninsula and the Sahara Desert. In estimating the amount of solar energy falling on the earth, let us consider first of all the natural deserts of the world. This area is about 20×10^6 km^2 with average solar insolation of 583.30 W/m^2/day (500 gm cal/cm^2/day). Another 30×10^6 km^2 receive about 291.65 W/m^2/day (250 gm cal/cm^2/day). Let us ignore all the areas of sea and the rest of the land. Therefore, the amount of solar energy received by this 50×10^6 km^2 is 162.2×10^{12} kWh/day, assuming eight hours of sunshine, or approximately 60×10^{15} kWh/year. Using 5%, this energy will result in 300×10^{13} kWh and comparing this with the estimated world energy demand in the year 2000 (50×10^{12} kWh/year), it can be seen that it is 60 times what the world will require then. Solar energy, which is the ultimate source of most forms of energy used now, is clean, safe and exists in viable quantities in many countries. The drawbacks in using solar radiation as energy, as have been pointed out, are that it cannot be stored and it is a dilute form of energy. This is however, an outdated argument since the energy can be stored by producing hydrogen, or by storing in other mechanical or electrical storage devices, the energy can be concentrated in solar furnaces, for example which can achieved temperatures in the region of 5000°C.

In addition to the thousands of ways in which the sun's energy has been used by both nature and man throughout the time to grow food, to see by, to get a suntan, to dry clothes, it has also been deliberately harnessed to perform a number of other 'chores'. Solar energy is used to heat and cool buildings, to heat water and swimming pools, to power refrigerators ; and to operate engines, pumps and sewage treatment plants. It powers cars, ovens, water stills, furnaces, distillation equipment, crop dryers, and sludge dryers powered by solar energy. Wind is used to generate electricity and mechanical power and solar-converted electricity is used both on earth and in space. Stoves and cars run on solar-made methane gas, power plants operate on organic trash and sewage plants produce methane gas. The sun powered evaporation/rain cycle, in combination with gravity, powers machines and electric turbines. Solar electrolizers convert water to clean hydrogen gas (a fuel).

None of these uses, however, can be comprehended without a knowledge of the basic principles of solar energy. Most of the energy we receive from the sun comes in the form of light, a short wave radiation, not all of which is visible to the human eye. When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy ; the material becomes warm and stores the heat ; conducts it to surroundings materials (air, water, other solids or liquids), or re-radiates it to other materials of lower temperature. The re-radiation is a large-wave radiation.

Glass easily transmits short-wave radiation, which means that it poses little interference to incoming solar energy, but it is a very poor transmitter of long wave radiation. Once the sun's energy has passed through the glass windows and has been absorbed by some material inside, the heat will not be re-radiated back outside. Glass, therefore, acts as a heat trap, a phenomenon which has been recognized for some time in the construction of green houses, which can get quite warm on sunny days, even in the middle of winter; this has come to be known, in fact, as the "green house effect". Solar collectors for home heating, usually called *flat-plate collectors*, almost always have one or more glass covers, although various plastic and other transparent materials are often used instead of glass.

Beneath the cover plate, collectors commonly have another plate which absorbs the sun's rays hitting it. This *absorber plate* is usually made of copper, aluminium, steel or another suitable material and is usually coated with a substance like black paint or one of the more sophisticated selective coatings available that will help it absorb the most heat, rather than reflect or re-radiate it. Once the heat is absorbed, it can be picked up and used. The glass cover plates help

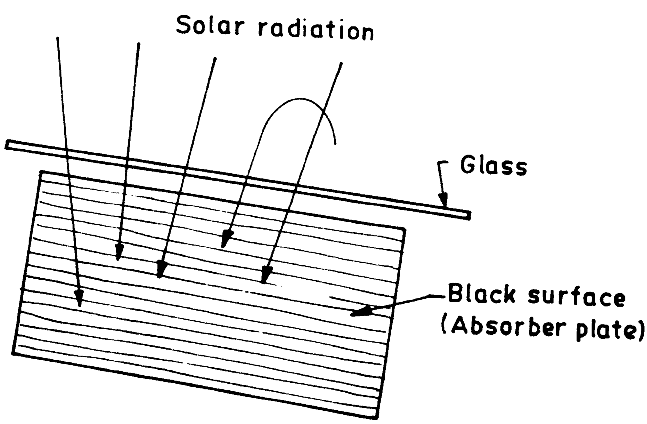

Fig. 1.1. Glass as a heat trap and a black surface as an absorber.

to reduce the loss of heat through the front while insulation reduces heat loss through the back.

From the absorber plate, heat is transferred by conduction to a transfer fluid, usually a liquid or air, which flows by the absorber plate, often with the help of a pump or blower. The liquids (water or a non-freezing fluid such as ethylene glycol) flows over the black surface or through tubes incorporated into the absorber plate. If air is used, it is blown across the surfaces of the absorber plate, which should have many small irregular surfaces with which the air can come in contact.

In some cases, it is possible to move the fluids (whether liquid or air) without mechanical aid, by natural convection or thermo siphoning. As the fluid is heated, it tends to rise, and cooler fluid flows in, to take its place. If the collector is tilted or vertical, this effect will move fluid across the collector plate and off without any external help. Some of the simplest systems work this way and in the right application, they are very effective pumping, however, usually gives greater collection efficiencies and allows more versatile use of the collected heat.

The applications of solar energy (other than on space craft enjoying most success today are :

1. Heating of buildings.
2. Cooling of buildings.
3. Solar water heating and solar air heating.
4. Salt production by evaporation of sea water or inland brines.
5. Solar distillation on a small community scale.
6. Solar drying or agricultural products.
7. Solar cookers.
8. Solar engines for water-pumping
9. Food refrigeration.
10. Photo-voltaic conversion.
11. Solar furnaces.
12. Solar thermal power generation.
13. Industrial process heat.
14. Indirect source of solar energy conversion, *i.e.* in the form of wind, through bio-conversion tides.

The heat from solar collectors is directly used for warming the living spaces of a building in conventional ways *e.g.*, through radiators and hot air registers. When the building does not require heat, the warmed air or liquid from the collector can be moved to a heat storage container. In the case of air, the storage is often a pile of rocks, or some other heat holding material ; in the case of liquid, it is usually a large, well-insulated tank of water, which has considerable heat capacity. Heat is also stored in containers of chemicals called eutectic or *phase changing salts*. The salts, which store large quantities of heat in a relatively small volume, melt when they are heated and release heat later as they cool and crystallize. When the building needs heat, the air or water from its heating system passes through the storage is warmed, and is then fed through the conventional heaters to warm the space. For sunless days or cloudy days, an auxiliary system as a back-up, is always required. The same is true for solar cooling systems.

The heat from solar energy can be used to cool buildings, using the absorption cooling principle operative in gas-fired refrigerators. Presently available equipment, however usually requires extremely high operating temperatures far above those for efficient solar collection. A great deal of current research is being devoted to developing systems requiring lower operating temperatures and collectors which are more efficient at higher temperatures, but it will probably be several years before solar collectors will be commercially viable.

Solar energy units for heating domestic water are commercially available and are used by millions of people in various parts of the world. The Australian government requires electrically supplemented solar water heaters for all new housing in the northern part of the country. In Israel, solar water heaters are widely used, and simple, plastic, non-supplemented water heaters have been widely used in Japan. There is a thriving, though small, solar water heater industry in Florida and California. Because of the low price of competitive fuels and difficulty of designing solar water heaters which can operate successfully during freezing weather, solar domestic water heating has not been widely used in northern climates. However, with rising fuel prices and the increased development of solar collectors, solar heating of domestic water in cold climates is being adopted.

A solar water heater commonly comprises a blackened flat plate metal collector with an associated metal tubing, facing the general direction of the sun. The collector is provided with a transparent glass cover and a layer of thermal insulation beneath the plate. The collector tubing is connected by a pipe to an insulated tank that stores hot water during non-sunny periods. The collector absorbs solar radiation and by transfer of resulting heat to the water circulating through the tubing by gravity or by a pump, hot water is supplied to the storage tank. The materials commonly used in flat plate collectors are copper, roll-bond aluminium, galvanised iron or mild steel. Various configurations of the plate and tubing using these materials have been experimented with, and the performance of a flat plate collector depends on the selective coating on the absorber plate. A solar collector area of one square meter can provide about 75 litres of hot water at about 60°C on an average sunny day. The present costs of various types of flat plate collectors range from Rs. 1000 to 1500 per square metre.

Solar water heating systems for domestic, industrial and commercial applications are at present available. Except in the hilly regions and in the northern latitudes, the potential for domestic water heaters is somewhat limited. In commercial establishments however, there is great potential especially in hotels, hospitals, guest houses, tourist bungalows, Canteen etc. For industrial applications, solar water heating system can meet the low and medium temperature process heat requirement hot water upto 90°C, hot air upto 110°C and low pressure steam upto 140°C. These are especially useful in engineering, textile, chemicals, pharmaceutical, food processing, sugar, dairy and other industries. Hot water systems have relevance for many agricultural and village industries also, such as for handloom fabrics, seri-culture, leather tanning and handmade paper. Pharmaceutical industry demands steam from coal and electricity. Not to depend entirely on such high grade energy some companies in Maharashtra state have gone in for solar flat plate collectors to supply water at 60°C. Availability of solar system for 250 days in a year have shown about a 5% saving in furnace oil in Hoechst pharmaceutical, with an annual saving of Rs. 20,000 in 1979. The company has planned to take advantage of the system and have gone for additional units and hope to ensure a payback period, of 6 to 7 years.

Hospitals on one hand, use the low temperature hot water as such or heat it further by electrical means. Cleaning, washing and sterilisation needs are thus partly met with. Jahangir Textile Mills, Ahmedabad have preferred to install solar hot air system for supplying 50 kg/min. of hot air at 80°C. Solar heated hot air is used in the cheese drying and as preheated air for printing float dryer. Hot water, steam and hot air could well be used in textile industry in the following areas at varying temperatures :

Spinning...	Dyeing and drying (80°–100°C)
Weaving...	Sizing and Kiers (100–85°C)
Bleaching...	Washing, Mercerising and drying (80–100°C)
Dyeing (cloth)...	Washing, Drying (100°C)
Printing ...	Drum drying (100°C)
	Aging (50°C)
Finishing ...	Sanforising (125°C)
	Stenters (150°C)
	Calendering (90°C)

Solar energy could be used for preheating water upto 50–60°C, with further heating of process steam to 90°C and above being done in boiler, resulting in 15 to 25% saving in the fuel cost, Madural coats, Madura and Jahangir Mills have paved the way for use of solar water heaters and air heaters. Jahangir Mill have installed collectors with 180 m^2 to provide 5500 litres of hot water at 80°C daily.

Hot air is predominently used for drying cloth and yarn. Normally team heating is resorted to and there is considerable loss of steam.

Here solar air heaters, are advantageously employed. Chest (yearn) dryer and printing float dryers are the machines best suited for the use of solar hot air. The total installed cost of the system in the mill is Rs. 250,000 (say). This system annually save 35 tonnes of coal or 15 kilo litres of oil and the pay back period for the heater ranges from 5 to 7 years. Solar hot air systems, if they prove to be practically adaptable in textile mills, have great potential for being retrofitted in a large number of textile mills. The mills also require hot water for humidifications, that could adopt a solar system. Of the total energy consumption in composite textile mills, more than 50% is accounted for thermal energy requirements. Steam, hot water and hot air requirements per kg of fabric, may be around 20, 40 and 30 kg respectively, in the temperature range of 80–110°C. Solar evaporation is historical and traditional method of obtaining salt from sea water or brine. Modern developments have been concerned mainly with improved pond construction.

The basic method of *solar distillation* is to admit solar radiation through a transparent cover in a shallow, covered brine basin ; water evaporates from the brine and the vapour condenses on the covers which are so arranged that the condensate flows therefrom into collection troughs and thence into a product-water storage tank. In arid, semi-arid, or coastal areas, there is abundant sun light that can be used for converting brackish or saline water into potable distilled water.

Solar stills can produce 3 to 5 litres of distilled water per square meter on an average sunny day. The solar distillation technology to convert brackish water into potable water is simple and small solar stills can be fabricated locally in rural areas.

A traditional and wide-spread use of solar energy is for drying particularly of agricultural products. This is a process of substantial economic significance in many areas. The process is of special interest in the case of soft fruits ; these are particularly vulnerable to attack by insects, as the sugar concentration increases during drying. Fruit dryer in which fruit is placed, in carefully designed racks to provide controlled exposure to solar radiation often improves product quality and saves considerable time.

A simple cabinet dryer consists of a box, insulated at the base, painted black on the inside and covered with an inclined transparent sheet of glass. Ventilation holes are provided at the base and at the top of the sides of the box to facilitate a flow of air over the drying material, which is placed on perforated trays in the interior of the cabinet base.

Large drying systems like grain, paddy, maize, cash crops like ginger, cashew, pepper etc., spray-drying of milk ; timber and veneer drying ; tobacco curing; fish and fruit drying, etc. have also been developed. A rise in 10–15°C of ambient air with a reduction in its relative humidity to 60%, is suitable for drying most of the cereal grains to the level of the safe moisture content for storage 500 kg of paddy could be dried from 30 to 14% moisture content in a period of 6 hours on bright sunny day by using air flow rate or 4 m^3/min., with temperature rise 8–10°C.

Solar cookers and ovens are developed for cooking all types of food in 40 to 60 minutes. Two types of solar cookers have been developed in our country, these are

(*a*) *A box type* closed cooker with glass, a cover and extra booster mirror which provides concentrated radiation in the oven and traps heat within the small space in which the food is placed.

(*b*) A cooker based on concentrating solar energy by a paraboloid mirror reflector which directly heats the cooking vessels. An inexpensive solar cooker made out of bamboo cane with aluminium sheet as the reflector surface has also been developed. On very clear days, temperatures of about 300°C in summer and about 200–250°C in winter can be achieved with the help of this cooker. The food even remains warm for a few hours after sunset. Roasting, baking and boiling of ingredients can be achieved within 30 to 90 minutes under clear sky conditions.

Factors such as problems of heat storage, regulation of heat for cooking, the socio-cultural habits of the people and inadequate promotional efforts have been the main reasons for the lack of interest shown in solar cookers inspite of their being functionally satisfactory and low priced.

Solar refrigeration is intended for food preservation (or storage of biological and medical materials) and deserves top-priority in our country. Solar air-conditioning can be utilised for space cooling. Solar assisted heat pumps would provide both cooling and heating.

Cold storages are very important for preservation and conservation of food articles. It estimated that in India, there is a loss of about 30 per cent of the produce, due to lack of proper cold storage facilities. There are two methods of solar refrigeration.

(*a*) *Vapour Absorption Refrigeration Systems* that utilize low grade thermal energy obtained from flat-plate collectors with a little modification.

(*b*) Concentrating (focusing) collectors to supply heat at a higher temperature to a heat engine which then drives the compressor of a conventional refrigerator.

Solar refrigeration, therefore, provides an effective solution particularly in sub-tropical and tropical areas of our country, where matching between the cooling load and the solar insolation is generally very good. Solar refrigeration with an absorption system is a better way of direct utilization of energy. For a country like India, the preservation of agricultural products before they are despatched to the urban areas from villages, could be considered essential. The vapour absorption system replacing the compressor by a generator absorber assembly can work with wide range of absorbents and refrigerants. In absorption system motion power required is very small, but still C.O.P. of the system is low.

The system efficiency could be improved, if it absorbs waste heat (flue-gas from boiler) or uses a low grade energy. Such absorption chillers are common in process industry. Solar energy based absorption system could very well be compared with vapour compression system using high grade energy. In such an analysis if the overall efficiency right from power generation is considered the vapour compression system may be no way better than solar absorption system. Still for the application of this low grade nonpolluting energy, the huge initial cost come as a hurdle for large scale adoption.

Solar absorption chilling system for food preservation has gained momentum, in northern part for preservation of potato and onions. With proper modifications of roof-cum collector type panels, the initial cost is brought down.

Using concentrating type collectors to heat fluids which can be used to operate heat engines which in turn drive generators to produce electricity. Low temperature flat-plate collectors are not adequate for heating building and water and with increased development will be adequate for powering solar absorption type cooling equipment. However, they are insufficient for the high efficiency production of electricity or for making artificial fuels by thermal processes. For this, high temperature collectors such as concentrating collectors are required. Solar energy is focused from a relatively large area into small, from which it is carried to storage. Such concentrator are usually parabolic or cylindrical in shape. Temperatures upto 500°C and more are attainable.

Seasonal efficiencies of most focussing collectors are often lower than that of flat plate collectors because of these higher operating temperatures ; in addition, because they rely only on direct rather than diffuse radiation, they need clear skies to operate. On the other hand, flat plate collectors are able to use solar radiation that is not nearly as bright as that necessary for concentrating collectors. Concentrating collectors are usually comparatively expensive.

Scientists have proposed schemes for using the sun's energy to generate electricity on a large scale by creating *farms* of many square km. of concentrating solar panels in areas where the skies are rarely cloudy.

The solar energy can be used for *power generation*. Research and development work is going on basically for two categories — one is the production of power specifically to run a solar thermal powered water pumps, in another category to generate solar thermal power in higher range of 10—100 kW (though still very big systems have been tried) for supplying the power to remote area far away for connection to a national electric grid due to high cost of transmission line and when no other sources of power such as mini hydro is available.

The solar furnaces constructed were found to give a high temperature of about 4000°C.

Solar energy is directly converted to electricity using *solar photovoltaic cells.* Silicon solar cells have been widely employed on space craft. Photovoltaic cells can be used to generate electricity on a large scale by covering square kilometers of land, but they can also be used on individual buildings, as is being done on what probably the most technologically-oriented solar powered house ever built. The house at the university of Delaware, converts solar radiation not only to heat but also to produce electricity through the use of photovoltaic cells.

Silicon solar cells employed on space craft, have typical efficiencies of about 10%. For terrestrial applications, such as isolated, off-shore oil derricks, slightly lower quality cells produce of 4 to 5%. The maximum theoretical efficiency for simple photo-voltaic conversion is about 35%, but efficiencies of 20% are believed to be achievable. Polycrystalline cells have a lower efficiency than single crystal cells now in use in space crafts, but they would be less expensive. Concentrators can be used to increase solar intensities on to a small area, greatly increasing the output of the solar cells. Peak kilowatt installations could be reduced considerably.

Solar photovoltaic system (PV system) has the applications in water pumping for drinking water supply and irrigation in rural areas. Power is supplied by PV systems to :

(*i*) radio bacons for ship navigation at ports,

(*ii*) community radio and TV sets,

(*iii*) railway signalling equipment,

(*iv*) weather monitoring, and

(*v*) battery charging etc.

As in the case of solar thermal systems, significant research is being made in solar cells also. The attempts include increasing the level of fabrication, development and indigenous production of basic raw materials, improvement in process technologies and efficiencies of solar cells, reduction in costs etc.

Using solar energy through *photosynthesis* to grow trees, plants and other organisms such as algae which can be used as a combustible fuel in place of coal after suitable processing, such as drying, chipping or grinding. Plants grown with sunshine could be used to fuel furnaces or boilers, for example. Photo-synthesis efficiencies are estimated to range from 0.3 to 3%, depending on the vegetation used. Because of the low conversion efficiencies, large land areas would be required to supply significant amount of energy.

Organic materials can also be converted into methane hydrogen and oil by destructive distillation (*pyrolysis*), by high pressure chemical processing, or by biochemical fermentation. *Pyrolysis* is a process in which organics are heated in the absence of air. In high pressure chemical processing, organics are heated under pressure in the presence of water and a cover gas of carbon-dioxide. Several biochemical fermentation processes which produce methane, re-used in the treatment processes as fuel, have been in use over the thirty years in U.S. for sanitary waste treatment. The purpose of most treatment plants, however is to process waste, not to produce fuel.

Hydrogen can also be produced through solar powered electrolysis processes (the separation of water into hydrogen and oxygen) and burned as a fuel or used in a fuel cell to produce electricity.

Waste from forestry operation and from municipal trash collection can be used directly as fuel for power or indirectly to produce other fuels such as methane or methanol. The gaseous fuel obtained is called *bio-gas*.

Wind energy which is an indirect source of solar energy conversion can be utilized to run wind mill, 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 mills 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. In these areas, there could be a possibility of using medium and large sized wind mills for generation of electricity and feeding the same into the grid.

Using solar heated layers and the cold lower depths of the ocean to operate a low temperature difference 16—22°C heat engine. This heat engine is then used to drive a generator, producing electricity or hydrogen fuel. These power plants are competitive in price with fossil fuel plants.

1.2. Conclusion

It is obvious that the known resources of fossil fuels in the world are depleting very fast and by the turn of the century, man will have to increasingly depend upon renewable resources of energy. Apart from these free availability in nature of such forms of energy, they are also pollution-free and can lend themselves to use in a decentralised manner, reducing the cost of transmission and distribution of power.

Sun is a primary source of energy, and all forms of energy on the earth are derived from it.

The solar energy can be harnessed either by deriving energy *directly* from sunlight or by *indirect* methods. Directly the solar energy can by obtained by :

(*i*) Solar thermal technology, *i.e.* harnessing of solar heat into useful energy using collectors.

(*ii*) Photovoltaic energy conversion technology. This is the most useful way of harnessing solar energy by directly converting it into electricity by means of solar photovoltaic cells. When sunshine is incident on solar cells, they generate D.C. electricity without the involvement of any mechanical generators. The electrical energy output from solar PV cells depends upon the intensity of sunlight incident on it, its conversion efficiency and temperature of operation. It is a highly versatile approach, since the generated electrical power can be used conveniently for various diverse purposes at the site of use. The *third source* is through :

(*iii*) Solar hydrogen gas production technology. It is still at an embryonic stage.

The *indirect* method is in the form of *wind, biomass* and *biogas* and *through tides.*

1.3. Solar Energy Utilisation in India

India has a total land area of 3.28×10^{11} square meters. On an average 5 kW/m^2 per day solar energy is falling on this land for over 300 days per annum ; in certain areas the bright sunny days may be more. Even if one per cent of this land is used to harness solar energy for electricity generation at an overall efficiency of ten percent, 492×10^9 kWh/year electricity can be generated. This is an enormous amount of energy and can be generated using thermal or photovoltaic routes of power generation.

Solar radiant energy is being utilised through thermal as well as photovoltaic (PV) routes in India. The thermal route has found many applications such as space heating and cooling using passive and/or active concepts, refrigeration and cold storages, cooking, water/air heating, drying of food grains/fish/fruits/vegetables, purification of brakish water, drying of timber, generation of power, etc. The PV solar cells are used for electric power generation.

Solar Thermal Applications. Being a large country, India has three main climatic zones namely cold, humid and hot, and arid. In certain areas the winters are extremely cold and summer months are very hot. The Indian architecture in olden days was based on passive concepts. Even after several hundred years, some such buildings can be seen in different parts of the country. In these buildings the conditions during summer months remain quite comfortable even when the outside temperature is 45°C or more. However, with the advancement of industrialisation the culture of multistoried buildings has been introduced in the country. In these buildings the passive concepts have been completely been neglected. Efforts are now being made to introduce these concepts in different types of buildings. Designs have been envolved for solarised buildings for different climatic zones and some buildings have been constructed. Three such buildings were constructed recently at Jodhpur, New Delhi and Srinagar. Apart from this, several buildings and huts have been designed and constructed in high altitude areas like Leh in Ladakh and hilly areas of Uttar Pradesh and Himachal Pradesh. These buildings have been constructed for schools, office use, residential use and for the use of Army Jawans in altitudes of 3,500 meters and above. Various building construction agencies, architects, contractors etc. are being involved in such activities. New buildings codes are being prepared so that the concepts of energy efficiency and passive architecture are introduced from the design stage.

Solar water heating systems are now quite common in the country. During last three years over, 45,000 square metres of collectors have been installed for this application. The water heating system of capacity 100 litres per day to over 60,000 litres per day have been installed in domestic, commercial and industrial sectors.

The objective of solar thermal programme of Department of Non-conventional. Energy sources (DNES) is to develop and popularise the solar thermal technologies to meet thermal applications and energy requirements for temperature range upto 100°C to 350°C and more than 350°C.

The solar energy centre was established as a division of DNES for inhouse R and D, certification and standardisation of renewable energy devices and man power development. It provides a link among government, industry and research institutes at National and International levels. Low grade solar thermal technologies have been successfully commercialized in our country. Low weight high efficiency flat plate collectors technology is being widely used for water heating systems.

Refrigeration systems are also under development. Refrigeration systems based on aqua-ammonia absorption principle have been developed and are being studied for large scale applications. Other combinations of materials are also being investigated.

Solar steam generating systems, solar cold storage and solar power generating systems have been installed under demonstration scheme of the Department. A 30 ton cold storage plant capable of storing 200 MT of potatoes is under study in a potato seeds farm. A 100 kg per hour steam generating plant (180°C) have been installed in a silk factory. A 22 kW power plant using dish concentrators and steam engine is under study in a village in Andhra Pradesh. Another power plant of capacity 50 kW using parabolic trough collectors and steam turbine is in operation at Solar Energy centre near Delhi. Feasibility report for the installation of 30 MW power plant has been completed and such power plants are likely to be installed in several states.

Solar photovoltaic lighting systems/solar power packs have become power units of magawatt size are technologically feasible. Within the next few years, with further development of technology, it is expected that even solar photovoltaic systems would be economically cost effective if not cheaper than conventional power in many areas of the country. With the development of amorphous silicon technology and thin film solar cells, it is expected that solar photovoltaic systems will be viable in the next few years.

BHEL is actively involved in the field of photovoltaic devices. A pilot plant for research and production of amorphous silicon photovoltaic modules is nearing completion at Gurgaon, Haryana. This will help to bring down the cost of solar cells substantially. A kW solar photovoltaic power plant has been made operational at Bitra Island, Lakshdeep.

Two public sector organisations namely Central Electronics Ltd. and Bharat Heavy Electronics Ltd. are manufacturing single crystal based solar cells on regular basis. The production capacity of these organisations is over 1 MW per annum. These solar cells are being used for water pumping, street lighting, operation of TV and Radio in remote areas, battery charging etc. Apart from this R and D programme on development of new materials, process technologies, etc. are also being supported by DNES. A pilot plant based on amorphous solar cell technology is being constructed at the solar energy centre. The facility will be capable of producing amorphous solar cells of capacity 50 kW per shift per annum. Electronic grade silicon is now being produced in India. A production facility of 25 tonnes per annum has been installed recently using indigenous know-how. The cost of power from such units is competitive with diesel based power plants. The much shorter gestation period for solar plants give great economic advantage.

Solar photovoltaic lighting systems are manufactured and supplied mainly by Bharat Heavy Electricals Ltd. (BHEL) Bangalore, Central Electronics Ltd (CEL) Sahibabad, Rajasthan Electronics and Instruments Ltd. (REIL), Jaipur, Renewable energy systems (RES)

Pvt. Ltd., Secundrabad, and SOPHOS Engineering Pvt. Ltd. New Delhi.

Solar cookers are now being sold all over the country by private manufacturers. These cookers have been found very useful in conserving commercial cooking fuels and wood etc. on an average one solar cooker capable of cooking four items at one time for 3.4 persons can save about six cylinders of LPG or 500-600 kg of wood per annum. Over Three lakhs box type solar cookers are in use today. Being a new technology it will take some time to popularise this item since the food habits of different categories of people do not suit to solar cooking. However, the sale of cookers is increasing day by day and even users from rural communities are now getting attracted and have started using solar cookers in certain areas of the country. The cookers are becoming more popular for community use in schools, hospitals, army etc.

Solar dryers, solar air heaters, solar desalination systems and wood seasoning kilns are also now being manufactured by several private manufacturers. Over 100 private and public sector organisations are manufacturing low grade solar thermal devices and systems including solar cookers.

Recent international development in the area of wind power has been very fast. Large scale wind farms have been installed in many countries. Over 1300 MW of power from wind is fed into the grid in California alone. It is estimated that over 2000 MW wind potential exists in our coastal areas. Hilly areas and desert areas of Western Rajasthan have great untapped wind potential. India in collaboration with many countries, notably Denmark and Holland, is progressing towards harnessing wind energy.

The demonstration wind farm projects of aggregate capacity 4.4 MW have been established in Gujarat, Tamil Nadu, Maharashtra and Orissa. The wind farms are based mainly on 55 kW wind electric generators. A wind farm of 1.35 MW based on fifteen 90 kW generators is under installation in Tamil Nadu. Higher capacity generators are under installation at Andhra and Karnataka.

By the turn of the century, about 5000 MW of power planned from large scale wind farms.

Biogas consisting mostly of methane gas is a clean smokeless fuel and is produced through an-aerobic digestion of organic materials, like cattle dung, agro-waste, water plants etc. The digested slurry is an excellent organic manure and hence the Biogas technology helps in generating economic benefits in terms of savings of firewood as well as chemical fertilizers, besides social benefits like removing drudgery of women and children in collection of fuel, elimination of eye and lung diseases caused due to smoke, saving in cooking time and improvement in sanitation and environment. The Biogas programme is gaining acceptance in rural areas.

The Biogas technology came to India at least half a century ago. However, the Govt. of India launched the National project on Biogas Development (NPBD) in 1981-82, to consolidate the gains made during the previous years in the propagation of Biogas technology and to accelerate the pace of its expansion.

Over 8.6 lakh biogas units were installed during the period of 1981-82 to 1987-88. A total sum of Rs. about 100 crores were released to state Governments and other implementing agencies under the NPBD.

Biogas is also being produced from night soil, water hyacinth and similar other aquatic biomass. Alternate feed stock like food processing wastes, pulps and sugar mill wastes, industrial effluents such as distillery spent waste, willow dust, leather industry waste, etc. are also being tried. By the year 2000/2001 about 12 million biogas plants are planned to be installed at a total estimated outlay of about Rs. 10,600 crores. These will save a minimum of 42 million tonnes of fuelwood annually.

Biomass for energy programme is one of most important programmes of DNES and Government of India. A total of about 1250 million tonnes of biomass is produced in the country annually. It is estimated that 1000 hectares of land having energy plantation can generate 3 MW of power. Energy plantation is therefore, being coupled with power generation based on gasifier technology. Energy plantation will also provide fuel wood for cooking and other day to day application. Apart from this energy plantation agricultural wastes like bagasse, rice straw and husk, and similar other materials can be used to generate power. Several power projects based on waste materials are under installation. A 3.75 MW power plant based on incineration of city garbage has recently been commissioned in New Delhi. A 10 MW power plant based on rice husk is under installation in the state of Punjab. Power generating systems from sewage plants are being planned in major cities and towns situated on the banks of major rivers of the country.