UNIT I

INTRODUCTION ABOUT ENERGY RESOURCES

General primary and commercial energy resources

Energy Resources: Primary and Secondary | Environment

It is equivalent to 600 billion units of energy per year. But at present, only 16% or 6500 mega watt of hydroelectricity is being generated.

For generation of electricity from hydel projects, it is necessary to utilise energy produced from the descent of water from higher to lower level. In practice, a water reservoir is constructed by means of dams in a river for storage of water. High dams are built to obtain a substantial amount of hydrostatic pressure. When stored water under high pressure is released from the upper level into a water driven turbine placed at a lower level, electricity is generated (Fig. 1). The hydel projects of Jaldhaka, Panchyet and Maithon constitute typical examples.

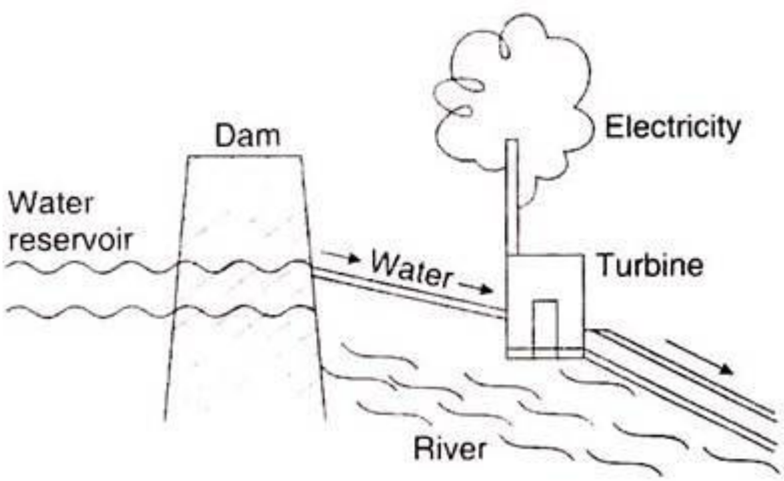


Fig. 1. Hydroelectricity from hydel project.

In US, about 300 large dams generate 9.5% of its total electrical power production. In Venezuela, (South America), 10,000 mega-watt of hydroelectricity is produced which is equivalent to the production of electricity from 10 thermal power plants.

Advantages of Hydroelectricity:

1. Hydroelectricity is basically non-polluting renewable clean source of energy.

2. There is no emission of green-house gases.

3. No consumption of fuel

4. No need of high technology.

Problems in the Development of Hydroelectric Energy:

1. Land acquisition,

2. Environmental aspects,

Hydroelectricity is still associated with serious problems:

1. Dams have drowned out beautiful stretch of rivers, forests, productive farm land and wild life habitat.

2. Local people become refugees as they are uprooted from their houses.

3. Capacity of the reservoir gets reduced due to siltation.

4. Since water flow from the dam is regulated as per the requirement of power, dams play havoc downstream because water level may change from extremes of near flood levels to virtual dryness and back to flood even overnight.

Many developing countries have great potential for large hydel power projects but due to certain limitations, there is a lot of opposition from Environmental Protection Organisations and people.

Nuclear Energy:

Nuclear Energy from Nuclear Fission and Nuclear Fusion:

Nuclear energy can be generated by nuclear power (fission) reactors which are based on the fission of uranium-235 nuclei by thermal neutrons.

$$_{92}U^{235} + {}_0n^1 \longrightarrow {}_{51}Sb^{133} + {}_{41}Nb^{99} + 2.5\ {}_0n^1 + 200\ \text{MeV}$$

The energy from these nuclear reactions is used to heat water in the reactor and produce steam to drive a steam turbine. Thus energy is converted into electricity.

1. Fission of 1 kg of U-235 releases energy equal to 1.7×10^{13} cals.

2. 1 lb of U-235 = 5 million lb of coal = 20 million lb of TNT.

3. 1 g of U-235 produces heat energy equivalent to energy produced by 3 tonne of coal or 14 barrels of crude oil.

Light water reactor (LWR), high temperature gas cooled reactor (HTGR) and fast breeder reactor (FBR) are viable for power generation. LWR consumes only U-238 and Th-232 to fissionable Pu-23.9 and Np-244.

Nuclear power contributes only 5% of total electricity generation.

Advantages of nuclear energy:

Nuclear power plants do not emit polluting gases such as CO_2 and SO_2as thermal power plants do.

Limitations:

1. The major constraint in the use of nuclear fission power is the yield of large quantities of radioactive fission waste products which remain lethal for thousands of years.

2. Safe disposal methods have not been devised.

Nuclear fusion reactions are based on deuterium-deuterium and deuterium-tritium reactions. The latter is energetically more viable.

$_1H^2 + _1H^3$ ——-> $_2He^4$ + o^{n1}+17.6MeV

The deuterium-deuterium reaction promises an endless source of energy without any radioactive wastes, but the technological problems for harnessing fusion energy will take several years to solve.

Thermal Power:

Electricity is generated by combustion of coal in a furnace. This heat is utilised to produce steam at high temperature and pressure. Steam is then used to run a turbine which is linked with the generator producing electricity.

Coal-fired thermal power plants are operated on the above principle by mechanical rotation of the steam turbine. In India, thermal power contributes about 65000 MW of electricity, that is, 70% of the total power supply. Some of the major thermal power stations of National Thermal Power Corporation (NTPC) of India are at Singrauli and Rihand in Up Farakka in West Bengal and Talchar in Orissa. They are the major source of thermal pollutants, flyash and decreased content of dissolved oxygen.

(ii) Non-Conventional Sources of Energy:

Solar Energy (Electromagnetic Radiation from the Sun):

Sun is the source of all energy on the planet earth. It is a large nuclear reactor where hydrogen gas is continuously burning at high temperature and pressure. Solar energy originates from the thermonuclear fusion reactions occurring in sun. The energy generated by sun into the space is received on the earth as electromagnetic radiant energy. Out of the solar radiations reaching the earth, 92% consist of radiations in the range 315 nm to 1400 nm, 45% of this radiation is in the visible region, 400 nm to 700 nm. The earth absorbs radiation mainly in the visible region and emits radiation in the infra red region (2 p to 40 p with maximum at 10 p).

Energy Output:

The value of solar flux reaching the earth's upper atmosphere is estimated to be about 1400 watt m^{-2} min^{-1}. The heat equivalent of the solar radiation reaching the earth is 2.68×10^{24} Joule per year. The total energy output of the sun is estimated at 3.45×10^{23} KWH. The average intensity of solar radiation is 2.1 to 2.5 kJ per cm^2 per day in India.

Location:

India is situated between 7° N and 37° N latitudes and the prospects of using solar energy are very bright indeed. If India can trap 1% of the incident radiation, it can generate many times the energy of its actual requirement at present. But it utilises only 25×10^{-7}% (13×10^{7} KWH per year) of the incident solar radiation (5×10^{15} KWH per year). Only 0.5% of solar energy reaching the earth is trapped by photosynthesis which is the energy source for the ecosystem.

Production of Electricity using Solar Energy:

Solar energy can be used either by absorbing radiations to produce heat or by converting it directly into electricity by the following methods:

1. Photovoltaic Cells (Solar Cells):

Solar panels or a large number of solar cells are connected in series parallel combination to obtain the required amount of power. These cells when exposed to solar radiation give direct current (DC) which can be converted into alternating current (AC) using inverters. The silicon solar cell, developed for the space programme consists of a sandwich of n-type and p-type silicon semiconductors, the charge separation is developed across the junction between them and electricity is produced.

N-type Silicon cell (semiconductor):

When Si lattice contains an impurity of As, which contains 5 electrons in the outer shell, 4 of these electrons form bonds with Si while the fifth electron is available for conducting current. Such solids are called n-type semiconductors.

P-type Silicon cell (semiconductor):
When Si lattice contains some atoms of indium (In), with three electrons in the outer shells the covalent bonding is incomplete, some sites being vacant, which constitute positive (+ve) holes. If these holes are filled by adjacent electrons, they form other holes and by migration, they carry current. Such solids are called p-type Si cells.

If a crystal of Si is prepared such that one part is p-type (which conducts positive charge) and the other n-type (which conducts negative charge), the p-n junction will permit current from an external source of flow through it in one direction. The silicon cell produces only 15% electricity and is quite expensive since very high grade crystalline Si is required (Fig. 2).

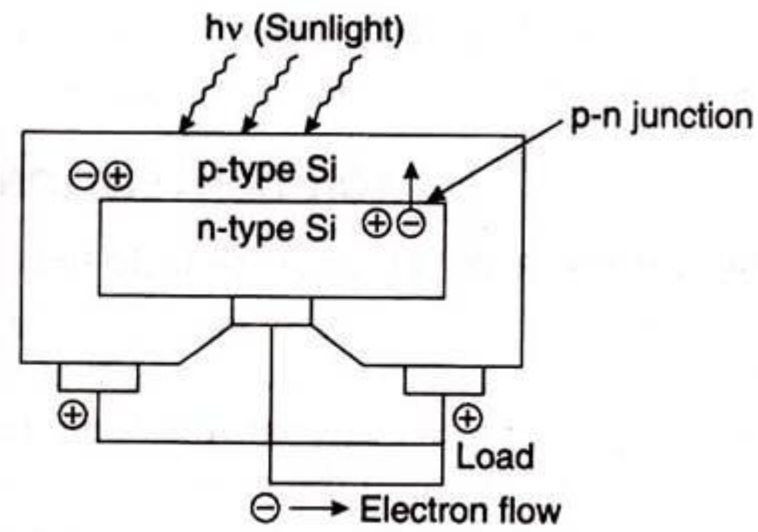


Fig. 2. Solar cells for generation of electricity.

With innovation in manufacturing process and more advanced technology, the photovoltaic power plants may produce power nearly at the same cost as traditional power plants. Experiments with vehicles run on PV cells are under way using ultra-efficient designs. Solar photovoltaic cells deteriorate due to exposure to weather. Other solar cells developed are CdS (n-type), CU_2S (p-type), gallium arsenide and indium phosphide.

2. Solar Trough Collectors (Invented by Charles Abbott):

Sunlight hitting the solar trough collector is reflected onto a pipe and heat the fluid circulating through it. The heated fluid is used to boil water, thereby generating steam to run turbo generator.

3. Power Tower:

In this method, an array of sun tracking mirrors is used to focus sunlight on a large area of land onto a boiler mounted on a tower. The intense heat produces steam in the boiler which drives a turbo generator to generate electricity.

4. Solar Furnace:

Here thousands of small plane mirrors are arranged in concave reflectors which collect the solar heat and produces high temperature up to ‘3000°C.

Applications of Solar Energy:

The best application of solar energy is in heating buildings and providing hot water which in developed countries like USA, consumes about 25% of the fuel supply. Figure 3 illustrates the detailed heating system in a solar heated house. Sunlight is collected on plates on the roof and heat transferred to a circulating water system. It has been calculated, that in US, an average house with a collection area of 1300 ft^2 can get its energy supply for heating and hot water in December by this method.

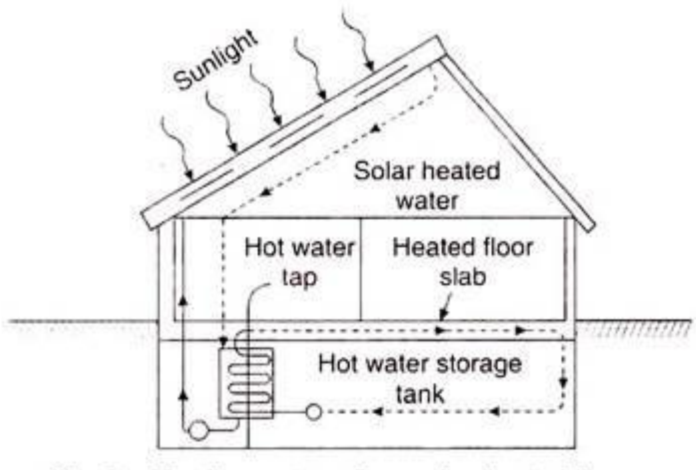


Fig. 3. Heating system in a solar heated house.

1. The use of solar energy is a completely benign operation. Solar energy can be used as solar heat by several gadgets such as solar cooker, solar dryer, solar water heater, solar distillation, space conditioning, green house technology, solar air crafts.

2. Solar energy can also be used as solar electricity by PVC or solar cells. Solar photovoltaic cells could be installed in remote areas in forests and deserts where installation of electric cables is cost-prohibitive.

3. Solar energy being non-polluting and non-depletable is considered as renewable energy and fits into the principle of sustainability.

4. Solar cells are widely used in electronic watches, calculators, traffic signals and artificial satellites. Because of their nonpolluting nature, solar cells are known as clean and green cells.

Limitations of Solar Energy:

1. The major constraint is that sunlight is diffuse and intermittent.

2. Density of solar energy is low as compared to oil, gas or coal etc.

3. CO_2 produced while forming silicon from silica increases atmospheric temperature. Silicon dust is also an occupational hazard.

4. Cadmium is used in fabricating thin film solar cells which is carcinogenic. However, only traces of Cd are released from discarded PV panels.

Wind Energy:

Principle:

In India, wind power can be usefully exploited for the generation of electricity as there are large coastal, hill and desert areas. The concept of air plane type propeller blades turning a generator geared to shaft is applied. Wind turbines, comprising of two blades, convert kinetic energy of the wind into electrical energy.

Operation:

The flow of air against the windward side of the blades creates suction on the reverse side, which turns the rotor shaft on which the blades are mounted. This rotor turns the generator which is linked directly to the electricity grid. When the wind speed is greater than 25 m/s, a disc brake stops the turbine from operation.

The operation of the wind turbine is monitored and controlled by a computer in the bottom of the tower. The computer receives information regarding wind speed and wind direction via an anemometer and a wind wave mounted on the top of turbine housing. Currently, wind turbines have horizontal axis with high hub height (328 ft) and large rotors (180 ft). A prototype electrical generator develops 20 kW power at Rensselaur polytechnic Institute in Troy, New York.

Energy Consumption in India : an indicator analysis

India is the second largest commercial energy consumer in Non-OECD East Asia, comprising 19 percent of the region's total primary energy consumption. Economic growth in India has largely been associated with increased energy consumption. While 60% of total energy needs in India are met by commercial energy sources, remaining 40% are comprised of non-conventional fuels. Over past few years, climate change has become one of the main concerns driving energy policy. More than 150 countries, including India, have committed themselves under the United Nations Framework Convention on Climate Change to formulate and implement mitigation and adaptation measures to climate change. India accounts for over 3.5% of world carbon emissions. Since energy use is a major source of emissions, it is necessary to focus on the management of energy demand and supply as a means to abatement. While energy demand grows significantly with economic growth, this coupling varies over time, depending on various other things. Technological progress, energy efficiency programmes and structural changes contribute towards the variation in energy demand. Understanding the various components of energy demand is therefore important and necessary in order to deal with future emissions.

Energy use profile of the Indian economy

Sectoral demand for energy arises mainly from lighting and cooking in the household sector; irrigation and other operations in the agricultural sector; transport of passengers and freight and fuel input requirements in the industrial sector. Table 1 shows sector-wise activity level and energy consumption pattern in India. India's commercial energy consumption has increased from 130.7 million tonnes of oil equivalent (mtoe) in 1991/92 to 176.08 mtoe in 1997/98. Per capita commercial energy consumption increased from 152.7 kilo grams of oil equivalent (kgoe) to 184.7 kgoe over the same period. Average annual growth rate for the agricultural GDP is 2.6 percent, the same figures for the industrial, transport and the service sectors are 6.8 percent, 7.6 percent and 6.4 percent respectively. Industrial sector has consistently remained the largest consumer of commercial energy, followed by the transport sector despite declining share of industrial sector from 50.4 percent in 1991-92 to 47.8 percent in 1997-98.

Indicator analysis

Energy use can be viewed as a function of total GDP, structure of the economy and technology. Aggregate energy intensity is taken as an energy performance indicator in energy demand analysis. Literature on indicator analysis adopts either of the two approaches: energy consumption approach or energy intensity approach. We follow the intensity approach and decompose total energy-GDP ratio into structural effect (S.E) and intensity effect (I.E). Structural effect shows that part of change in energy use which is attributable to change in activity composition of an economy. Intensity effect tells us that keeping GDP effect and structural effect unchanged, what has been the change in energy use solely due to conservation measures. Figure 1 and accompanying table show the respective values for the structural effect (Dstr), intensity effect (Dint) and the total effect (Dtot) comprising of these two effects. In last decade, India experienced a structural change that has worsened the overall energy intensity index as it is greater than one except in two intermediate years of 1992-'94. Beyond 1993-94 the structural effect shows a rising trend in energy intensity. Intensity effect showing the conservation effort had a fluctuating trend, though this effect alone could outweigh the structural effect and overall energy intensity index shows falling trend after 1995-96.

Table 1: GDP at constant prices (Rs Th crores) and energy consumption (mtoe) in India

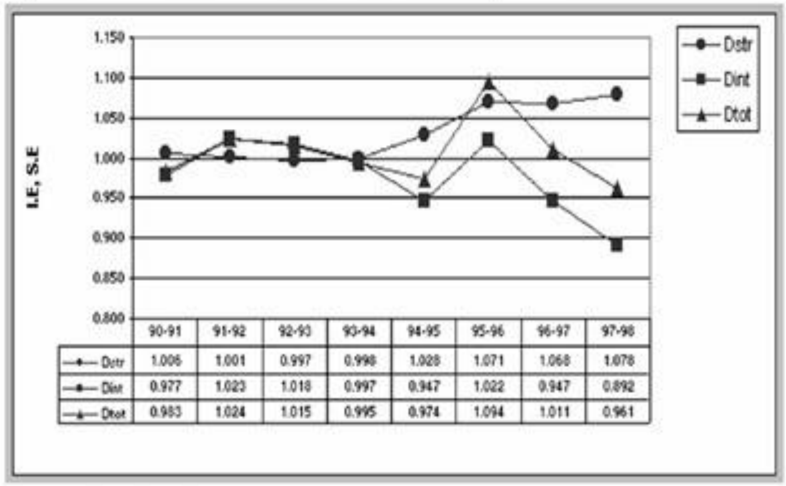
Years	Agriculture GDP	Energy consumed in agriculture	Industry GDP	Energy consumed in industry	Transport and trade GDP	Energy consumed in transport	Services GDP	Energy consumed in services
1989-90	63.3	4.3	50.6	60.5	35.9	27.8	51.7	15.8
1990-91	65.7	4.9	53.9	62.9	37.7	28.0	55.0	16.5
1991-92	64.1	5.6	52.8	65.9	38.6	29.3	58.4	17.1
1992-93	68.0	6.1	55.1	68.5	41.0	30.6	61.1	17.8
1993-94	70.5	6.8	59.3	71.0	44.0	31.6	65.3	18.7
1994-95	74.1	7.7	66.0	73.9	48.7	33.4	68.9	20.0
1995-96	71.9	8.44	74.5	87.0	55.2	45.3	74.5	21.8
1996-97	77.6	8.34	79.4	92.3	60.0	42.1	79.9	18.8
1997-98	76.4	8.71	84.0	77.5	63.1	47.6	88.4	27.6

Source: Reserve Bank of India, 1999 and Tata Energy Research Institute (various issues).

Sectoral Energy Intensities

Structural effect is dominated by sharp increase in the industrial and transport sector GDP. Figure 2 shows that energy intensity is higher in the industrial sector, followed by the transport sector. But, the industrial sector records a downward trend in energy intensity. The average annual decline in energy intensity during 1989-90 to 1997-98 is 2.14 per cent as compared to 0.33 per cent in the transport sector and 1.08 per cent in the service sector. On the other hand, agriculture sector records an increase in the energy intensity over the same period (6.5 per cent). But, there seems to be significant energy efficiency improvements to curb the rising structural effect, and as a result of which the aggregate energy intensity index of the economy has improved after 1995-96. This can be traced to demographic changes, including relatively faster growth in urban areas, high per capita GDP, penetration of more end use devices, technological improvements in conversion equipment and inter-fuel substitution with more efficient alternatives in the energy intensive industries.

Figure 1. Results of Refined Divisia Index Decomposition.

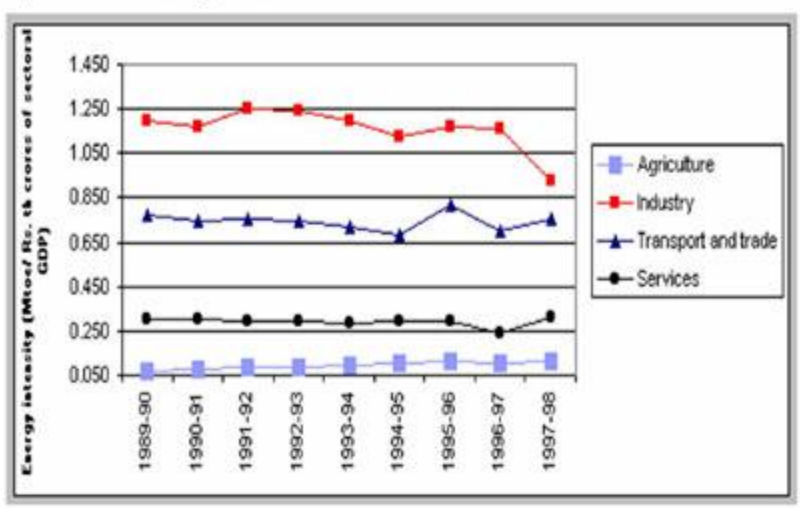


	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98
Dstr	1.006	1.001	0.997	0.998	1.028	1.071	1.068	1.078
Dint	0.977	1.023	1.018	0.997	0.947	1.022	0.947	0.892
Dtot	0.983	1.024	1.015	0.995	0.974	1.094	1.011	0.961

Source: authors' calculations.

Since sectoral output growth is the main contributing factor to rising energy intensity, one might think that policies should be designed to curb this growth. However, this would mean imposition of real cost on the economy. Hence, policy alternatives should see how to offset this increasing output effect by negative intensity and structural effects. Declining structural effect can be achieved by a greater shift towards non-energy intensive industries, expansion of service sector etc. Negative trend in intensity effects can be intensified by inter-fuel substitution, introducing efficient technology to improve energy productivity. Other country studies reveal one thing in common that in most of the OECD countries energy intensity declined and improved energy efficiency played a substantial role in it. Intensity effect is smaller for India than for other countries. Energy demand can be restricted directly through economic instruments like prices, taxes or rationing etc. But they have their adverse welfare impact also unless supplemented by indirect policies in the form of introduction of more efficient technologies. Conservation in industry sector has been successful in putting a break to rising overall intensity

Figure 2. Sectoral energy intensities.



Source: authors' calculations

trend. Energy efficiency improvement through R&D, labels and standards, technology transfer may be a better policy tool to strengthen conservation effect to offset rising energy intensity due to structural change and activity growth.

Economic growth and structural change are the big drivers in positive growth in energy intensity in India. The structural component is driven mainly by incomes and by forces not directly related to energy or energy policies. Since it is difficult to restrict energy demand rising from increased output or activity directly, stress needs to be on conservation measures at the early stage of development. Sectoral policies on housing, commercial buildings, industry and transport must integrate energy efficiency at local, regional and

The **energy policy of India** is largely defined by the country's expanding energy deficit and increased focus on developing alternative sources of energy, particularly nuclear, solar and wind energy. India ranks 81 position in overall energy self-sufficiency at 66% in 2014.[3][4]

The primary energy consumption in India is the third biggest after China and USA with 5.5% global share in 2016.[5][6] The total primary energy consumption from crude oil (212.7 Mtoe; 29.38%), natural gas (45.1 Mtoe; 6.23%), coal (411.9 Mtoe; 56.90%), nuclear energy (8.6 Mtoe; 1.19%), hydro electricity (29.1 Mtoe; 4.01%) and renewable power (16.5 Mtoe; 2.28%) is 723.9 Mtoe (excluding traditional biomass use) in the calender year 2016.[5] In 2013, India's net imports are nearly 144.3 million tons of crude oil, 16 Mtoe of LNG and 95 Mtoe coal totalling to 255.3 Mtoe of primary energy which is equal to 42.9% of total primary energy consumption. About 70% of India's electricity generation capacity is from fossil fuels. India is largely dependent on fossil fuel imports to meet its energy demands – by 2030, India's dependence on energy imports is expected to exceed 53% of the country's total energy consumption.[1] In 2009-10, the country imported 159.26 million tonnes of crude oil which amounts to 80% of its domestic crude oil consumption and 31% of the country's total imports are oil imports.[1][7] By the end of calendar year 2015, India has become a power surplus country with huge power generation capacity idling for want of electricity demand.[8]India ranks second after China in renewables production with 208.7 Mtoe in 2014.[3]

In 2015-16, the per-capita energy consumption is 22.042 Giga Joules (0.527 Mtoe) excluding traditional biomass use and the energy intensity of the Indian economy is 0.271 Mega Joules per INR (65 kcal/INR).[9] Due to rapid economic expansion, India has one of the world's fastest growing energy markets and is expected to be the second-largest contributor to the increase in global energy demand by 2035, accounting for 18% of the rise in global energy consumption.[10] Given India's growing energy demands and limited domestic fossil fuel reserves, the country has ambitious plans to expand its renewable and most worked out nuclear power programme.[11] India has the world's fifth largest wind power market and also plans to add about 100,000 MW of solar power capacity by 2020.[12][13] India also envisages to increase the contribution of nuclear power to overall electricity generation capacity from 4.2% to 9% within 25 years.[14] The country has five nuclear reactors under construction (third highest in the world) and plans to construct 18 additional nuclear reactors (second highest in the world) by 2025.[15]

Indian solar power tariff has fallen to ₹2.44 (3.8¢ US) per kWh in May 2017 which is lower than any other type of power generation in India.[16] In the year 2016, the levelized tariff in US$ for solar electricity has fallen below 2.42 cents/kWh.[17][18] Solar electricity price is going to become the benchmark price for deciding the other fuel prices (Petroleum products, LNG, CNG, LPG, coal, lignite, biomass, etc.) based on their ultimate use and advantages.

India: Total primary energy use of 775 Mtoe in 2013[20][21]

Coal (44%)

Biomass and waste (23%)

Petroleum & oth liquids (23%)

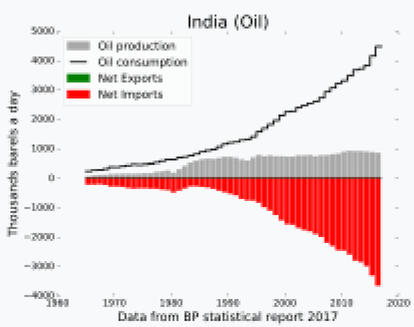
Natural gas (6%)

Nuclear (1%)

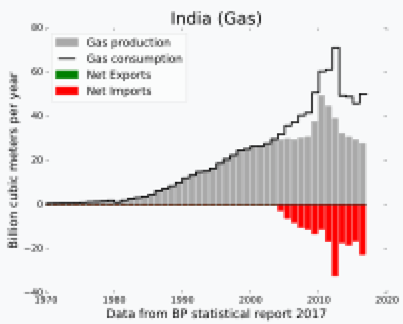
Hydroelectric (2%)

Other renewables (1%)

Oil and gas



India's oil deficit



Gas Balance of India

India ranks third in oil consumption with 212.7 million tons in 2016 after USA and China. During the calendar year 2015, India imported 195.1 million tons crude oil and 23.3 million tons refined petroleum products and exported 55 million tons refined petroleum products. India has built surplus world class refining capacity using imported crude oil for exporting refined petroleum products. The net imports of crude oil is lesser by one fourth after accounting exports and imports of refined petroleum products.[23] Natural gas production was 29.2 billion cubic meters and consumption 50.6 billion cubic meters during the calendar year 2015.

During the financial year 2012–13, the production of crude oil is 37.86 million tons and 40,679 million standard cubic meters (nearly 26.85 million tons) natural gas. The net import of crude oil & petroleum products is 146.70 million tons worth of Rs 5611.40 billions. This includes 9.534 million tons of LNG imports worth of Rs. 282.15 billions.[24] Internationally, LNG price (One mmBtu of LNG = 0.1724 barrels of crude oil (boe) = 24.36 cubic meters of natural gas = 29.2 litres diesel) is fixed below crude oil price in terms of heating value.[25][26] LNG is slowly gaining its role as direct use fuel in road and marine transport without regasification.[27][28][29] By the end of June 2016, LNG price has fallen by nearly 50% below its oil parity price making it more economical fuel than diesel/gas oil in transport sector.[30][31] In 2012-13, India consumed 15.744 million tons petrol and 69.179 million tons diesel which are mainly produced from imported crude oil at huge foreign exchange out go. Use of natural gas for heating, cooking and electricity generation is not economical as more and more locally produced natural gas will be converted into LNG for use in transport sector to reduce crude oil imports.[32][33] In addition to the conventional natural gas production, coal gasification, coal bed methane, coal mine methane and Biogas digesters / Renewable natural gas will also become source of LNG forming decentralised base for production of LNG to cater to the widely distributed demand.[34][35] There is possibility to convert most of the heavy duty vehicles (including diesel driven rail engines) into LNG fuelled vehicles to reduce diesel consumption drastically with operational cost and least pollution benefits.[36][37][38] Also, the break even price at user end for switching from imported coal to LNG in electricity generation is estimated near 6 US$/mmBtu.[39] The advent of cheaper marine CNG transport will restrict LNG use in high end transport sector to replace costly liquid fuels leaving imported CNG use for other needs.[40][41]

The state-owned Oil and Natural Gas Corporation (ONGC) acquired shares in oil fields in countries like Sudan, Syria, Iran, and Nigeria – investments that have led to diplomatic tensions with the United States.[42] Because of political instability in the Middle East and increasing domestic demand for energy, India is keen on decreasing its dependency on OPEC to meet its oil demand, and increasing its energy security. Several Indian oil companies, primarily led by ONGC and Reliance Industries, have started a massive hunt for oil in several regions in India, including Rajasthan, Krishna Godavari Basin and north-eastern Himalayas.[43] India is developing an offshore gas field in Mozambique.[44] The proposed Iran-Pakistan-India pipeline is a part of India's plan to meet its increasing energy demand.

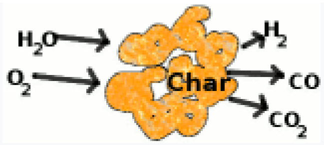
Coal[edit]

A coal mine in Jharkhand state

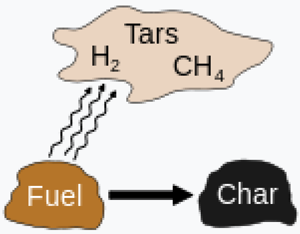
India has the world's 4th largest coal reserves. In India, coal is the bulk of primary energy contributor with 56.90% share equivalent to 411.9 Mtoe in 2016.[5] India is the third top coal producer in 2013 with 7.6% production share of coal (including lignite) in the world. Top five hard and brown coal producing countries in 2013 (2012) are (million tons): China 3,680 (3,645), United States 893 (922), India 605 (607), Australia478 (453) and Indonesia 421 (386). However, India ranks fifth in global coal production at 228 mtoe (5.9%) in 2013 when its inferior quality coal tonnage is converted into tons of oil equivalent. Coal-fired power plants account for 59% of India's installed electricity capacity. After electricity production, coal is also used for cement production in substantial quantity. In 2013, India imported nearly 95 Mtoe of steam coal and coking coal which is 29% of total consumption to meet the demand in electricity, cement and steel production. Pet cokeavailability, at cheaper price to local coal, is replacing coal in cement plants.

Gasification of coal or lignite or pet coke produces syngas or coal gas or coke oven gas which is a mixture of hydrogen, carbon monoxide and carbon dioxide gases Coal gas can be converted into synthetic natural gas (SNG) by using Fischer–Tropsch process at low pressure and high temperature. Coal gas can also be produced by underground coal gasification where the coal deposits are located deep in the ground or uneconomical to mine the coal. CNG and LNG are emerging as economical alternatives to diesel oil with the escalation in international crude oil prices. Synthetic natural gas production technologies have tremendous scope to meet the transport sector requirements fully using the locally available coal in India. Dankuni coal complex is producing syngas which is piped to the industrial users in Calcutta. Many coal based fertiliser plants which are shut down can also be retrofitted economically to produce SNG as LNG and CNG fetch good price by substituting imports. Recently, Indian government fixed the natural gas price at producer end as 5.61 US$ per mmbtu on net calorific value (NCV) basis which is at par with the estimated SNG price from coal.

Bio-fuels[edit]



Gasification of Char / Coal



Pyrolysis of carbonaceousfuels

Gasification of bio mass yields wood gas or syngas which can be converted into substitute natural gas by Methanation. Nearly 750 million tons of non edible (by cattle) biomass is available annually in India which can be put to higher value addition use and substitute imported crude oil, coal, LNG, urea fertiliser, nuclear fuels, etc. It is estimated that renewable and carbon neutral biomass resources of India can replace present consumption of all fossil fuels when used productively.[2][59]

Huge quantity of imported coal is being used in pulverised coal-fired power stations. Raw biomass can not be used in the pulverised coal mills as they are difficult to grind into fine powder due to caking property of raw biomass. However biomass can be used after Torrefaction in the pulverised coal mills for replacing imported coal.[60] North west and southern regions can replace imported coal use with torrefied biomass where surplus agriculture/crop residual biomass is available. Biomass power plants can also get extra income by selling the Renewable Purchase Certificates (RPC).[61]

India's three Oil Marketing Companies (OMCs) are currently setting up 12 second-generation ethanol plants across the country which will collect agriculture waste from farmers and convert it into bio-ethanol.[62] Cheaper production cost of algae oil from algae particularly in tropical countries like India would displace the prime position of crude oil in near future.[63][64]

The former President of India, Dr. A. P. J. Abdul Kalam, was a strong advocaters of Jatropha cultivation for production of bio-diesel.[65] He said that out of the 6,00,000 km² of waste land that is available in India over 3,00,000 km² is suitable for Jatropha cultivation. Once the plant is grown, it has a useful lifespan of several decades. During its life Jatropha requires very little water when compared to other cash crops. A plan for supplying incentives to encourage the use of Jatropha has been coloured with green stripes.

Nuclear power

The Koodankulam Nuclear power plant (2x1000 MW) in Tamil Nadu while under construction

India boasts a quickly advancing and active nuclear power programme. It is expected to have 20 GW of nuclear capacity by 2020, though they currently stand as the 9th in the world in terms of nuclear capacity.

An achilles heel of the Indian nuclear power programme, however, is the fact that they are not signatories of the Nuclear Non-Proliferation Treaty. This has many times in their history prevented them from obtaining nuclear technology vital to expanding their use of nuclear industry. Another consequence of this is that much of their programme has been domestically developed, much like their nuclear weapons programme. United States-India Peaceful Atomic Energy Cooperation Act seems to be a way to get access to advanced nuclear technologies for India.

Further information: India's three stage nuclear power programme

India has been using imported enriched uranium and are under International Atomic Energy Agency (IAEA) safeguards, but it has developed various aspects of the nuclear fuel cycle to support its reactors. Development of select technologies has been strongly affected by limited imports. Use of heavy water reactors has been particularly attractive for the nation because it allows Uranium to be burnt with little to no enrichment capabilities. India has also done a great amount of work in the development of a Thorium centred fuel cycle. While Uranium deposits in the nation are extremely limited, there are much greater reserves of Thorium and it could provide hundreds of times the energy with the same mass of fuel. The fact that Thorium can theoretically be utilised in heavy water reactors has tied the development of the two. A prototype reactor that would burn Uranium-Plutonium fuel while irradiating a Thorium blanket is under construction at the Madras/Kalpakkam Atomic Power Station.

Uranium used for the weapons programme has been separate from the power programme, using Uranium from scant indigenous reserves.

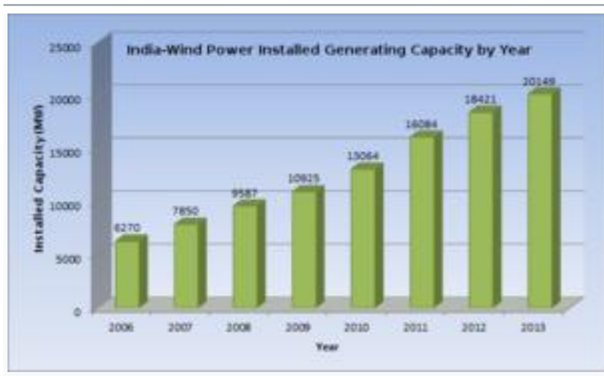
Hydro electricity

India is endowed with economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% capacity factor.[66] In addition, 6,780 MW in terms of installed capacity from Small, Mini, and Micro Hydel schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified for catering to peak electricity demand and water pumping for irrigation needs. It is the most widely used form of renewable energy. The hydro-electric potential of India ranks 5th in terms of exploitable hydro-potential on global scenario.

The installed capacity of hydro power is 44,594.42 MW as of 30 April 2017.[67] India ranks sixth in hydro electricity generation globally after China, Canada, Brazil, USA and Russia. During the year 2015-16, the total hydro electricity generation in India is 121.377 billion kWh which works out to 23,093 MW at 60% capacity factor. Till now, hydroelectricity sector is dominated by the state and central government owned companies but this sector is going to grow faster with the participation of private sector for developing the hydro potential located in the Himalaya mountain ranges including north east of India.[68] However the hydro power potential in central India forming part of Godavari, Mahanadi and Narmada river basins has not yet been developed on major scale due to potential opposition from the tribal population.

Pumped storage schemes are perfect centralised peaking power stations for the load management in the electricity grid. Pumped storage schemes would be in high demand for meeting peak load demand and storing the surplus electricity as India graduates from electricity deficit to electricity surplus. They also produce secondary /seasonal power at no additional cost when rivers are flooding with excess water. Storing electricity by other alternative systems such as batteries, compressed air storage systems, etc. is more costlier than electricity production by standby generator. India has already established nearly 6800 MW pumped storage capacity which is part of its installed hydro power plants.[69]

Wind power



Progress in India's installed wind power generating capacity since 2006

India has the fifth largest installed wind power capacity in the world.[70] As of 31 March 2015, the installed capacity of wind power was 23,444 MW an increase of 2312 MW over the previous year[71][72] Wind power accounts nearly 8.5% of India's total installed power generation capacity and generated 28.314 billion kWh in the fiscal year 2014-15 which is nearly 2.6% of total electricity generation.[73] The capacity utilisation factor is nearly 15% in the fiscal year 2014-15. The Ministry of New and Renewable Energy (MNRE) of India has announced a revised estimation of the potential wind power resource (excluding offshore wind power potential) from 49,130 MW assessed at 50m Hub heights to 102,788 MW assessed at 80m Hub height at 15% capacity factor.

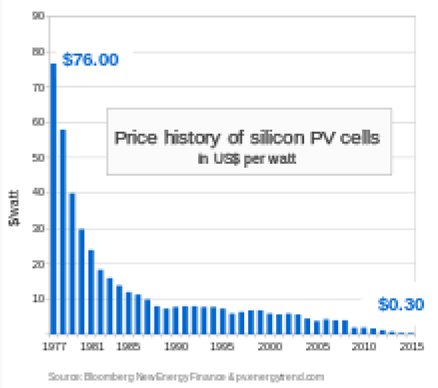
Solar energy

Solar Resource Map of India

India's solar energy insolation is about 5,000 T kWh per year (i.e. ~ 600 TW), far more than its current total primary energy consumption.[74][75] India's long-term solar potential could be unparalleled in the world because it has the ideal combination of both high solar insolation and a big potential consumer base density.[76][77] With a major section of its citizens still surviving off-grid, India's grid system is considerably under-developed. Availability of cheap solar can bring electricity to people, and bypass the need of installation of expensive grid lines. Also a major factor influencing a region's energy intensity is the cost of energy consumed for temperature control. Since cooling load requirements are roughly in phase with the sun's intensity, cooling from intense solar radiation could make perfect energy-economic sense in the subcontinent, whenever the required technology becomes competitively cheaper.

Installation of solar power plants require nearly 2.4 hectares (6 acres) land per MW capacity which is similar to coal-fired power plants when life cycle coal mining, consumptive water storage & ash disposal areas are also accounted and hydro power plants when submergence area of water reservoir is also accounted. 1.33 million MW capacity solar plants can be installed in India on its 1% land (32,000 square km). There are vast tracts of land suitable for solar power in all parts of India exceeding 8% of its total area which are unproductive barren and devoid of vegetation.[78][79] Part of waste lands (32,000 square km) when installed with solar power plants can produce 2000 billion kWh of electricity (two times the total generation in 2013-14) with land productivity/yield of 1.25 million Rs per acre (5 Rs/kWh price) which is at par with many industrial areas and many times more than the best productive irrigated agriculture lands.[80] Moreover, these solar power units are not dependent on supply of any raw material and are self productive. There is unlimited scope for solar electricity to replace all fossil fuel energy requirements (natural gas, coal, lignite and crude oil) if all the marginally productive lands are occupied by solar power plants in future. The solar power potential of India can meet perennially to cater per capita energy consumption at par with USA/Japan for the peak population in its demographic transition.[81]

Synergy with irrigation water pumping and hydro power stations



Price history of silicon PV cells since 1977. The great thing about solar power is that it is a technology and not a fuel. It is unlimited and the more it is deployed the cheaper it would be.[16]While the more limited fossil fuels are used, the more expensive they become.

The major disadvantage of solar power (PV type) is that it can not produce electricity during the night time and cloudy day time also. In India, this disadvantage can be overcome by installing pumped-storage hydroelectricity stations. Ultimate electricity requirement for river water pumping (excluding ground water pumping) is 570 billion kWh to pump one cubic meter of water for each square meter area by 125 m height on average for irrigating 140 million hectares of net sown area (42% of total land) for three crops in a year.[82] This is achieved by utilising all the usable river waters by interlinking Indian rivers.[83] These river water pumping stations would also be envisaged with pumped-storage hydroelectricity features to generate electricity during the night time. These pumped-storage stations would work at 300% water pumping requirement during the day time and generate electricity at 33% of its total capacity during the night time. Also, all existing and future hydro power stations can be expanded with additional pumped-storage hydroelectricity units to cater night time electricity consumption. Most of the ground water pumping power can be met directly by solar power during daytime. To achieve food security, India needs to achieve water security which is possible only by energy security for harnessing its water resources.

Electricity driven vehicles

The retail prices of petrol and diesel are high in India to make electricity driven vehicles more economical as more and more electricity is generated from solar energy in near future without appreciable environmental effects. During the year 2013, many IPPs offered to sell solar power below 6.50 Rs/kWh to feed into the low voltage (< 33 KV) grid.[85] This price is below the affordable electricity retail tariff for the solar power to replace petrol and diesel use in transport sector.

The retail price of diesel is 53.00 Rs/litre in 2012-13. The affordable electricity retail price (860 kcal/kWh at 75% input electricity to shaft power efficiency) to replace diesel (lower heating value 8572 kcal/litre at 40% fuel energy to crank shaft efficiency) is 9.97 Rs/kWh. The retail price of petrol is 75.00 Rs/litre in 2012-13. The affordable electricity retail price (860 kcal/kWh at 75% input electricity to shaft power efficiency) to replace petrol (lower heating value 7693 kcal/litre at 33% fuel energy to crank shaft efficiency) is 19.06 Rs/kWh. In 2012-13, India consumed 15.744 million tons petrol and 69.179 million tons diesel which are mainly produced from imported crude oil at huge foreign exchange out go.[24]

V2G is also feasible with electricity driven vehicles to contribute for catering to the peak load in the electricity grid. The electricity driven vehicles would become popular in future when its energy storage / battery technology becomes more compact, lesser density, longer lasting and maintenance free

Commercial and Non-Commercial Sources of Energy in India

a) Commercial energy sources:

A brief description of commercial energy sources is given below:

(i) Coal and Lignite:

It has been considered as the major source of energy in India. It can be easily converted into other forms of energy such as electricity, gas and oil. The total estimate resources of coal are now placed at 1, 48, 79 million tonnes, but the mineable reserves are estimated to be 60,000 million tonnes i.e. on 40% of the total coal reserves. Lignite is brown coal with lesser amount of energy than black coal. In 1950-51, production of coal and lignite in India was 32.3 million tonnes which increased to 413 million tonnes in 2004-05.

(ii) Oil and Gas:

Demand for fossil fuels grew rapidly with the growth of the industrial sector and transport services. Crude oil production has constantly, been increasing since the beginning of economic plans in India. After Independence, the Government of India felt the need for oil exploration on an extensive scale, and therefore, the Oil and Natural Gas Commission (ONGC) was set up in 1956, an(in 1959, Oil India Limited (OIL) was established.

Total recoverable reserves of oil are estimated at 550 million tonnes and those of gas are estimated at 500 billion cubic tonnes, Production of crude oil is estimated in 200 05 at about 34 million tonnes. Coal and other fossil fuels play the most important role in the generation of the thermal power.

(iii) Hydroelectric power:

It plays an important role in the filed of power development in country, our country has made considerable progress in the field of hydroelectricity power generation.

c) There is no waste disposal problem

(d) Generation o hydel-power depends on renewable water resources, whereas the generation of thermal power depends on the use of non-renewal resources like coal and petroleum oil.

The annual hydroelectric potential is estimated to be around 90,000 MW (Mega-watt). Out of this, so far about 18,000 mw has been developed. This mean that only 20% of the total potential has been utilized. So, there is a vast scope for harnessing hydro-potential in India.

(iv) Atomic or Nuclear Power:
India has also developed nuclear power. Uranium and thorium are both sources of nuclear power generation. India's uranium reserves have been estimated to be of the order of about 70,000 tonnes, which is equal to 120 billion tonnes of coal. Similarly, our thorium reserves of 3, 60,000 tonnes would be equivalent to 600 billion tonnes of coal

b) Non-commercial Energy Sources:
(i) Fuelwood:
It is required for cooking purpose. The total fuel wood consumption has been estimated at about 223 million tonnes in 2001- 02.

(ii) Agricultural wastes:
It is also used how for cooing purpose. Agriculture waste are also used as feed and fodder for animals, roofing materials in Katcha houses. It has been estimated that for fuel alone, the consumption of agricultural wastes was around 65 million tonnes in 2001.

(iii) Animal dung:
Dried dung of animals is commonly used as fuel in our rural India, out of the total estimated production of 324 million tonnes of animal dung, nearly 73 million tonnes (22.5%) is burnt as fuel every year.

Economic Efficiency

Definition of efficiency

Efficiency is concerned with the optimal production and distribution or these scarce resources.

There are different types of efficiency

1. Productive efficiency

This occurs when the maximum number of goods and services are produced with a given amount of inputs. This will occur on the production possibility frontier. On the curve it is impossible to produce more goods without producing less services.Productive efficiency will also occur at the lowest point on the firms average costs curve

2. Allocative efficiency

This occurs when goods and services are distributed according to consumer preferences. An economy could be productively efficient but produce goods people don't need this would be allocative inefficient.

A2: Allocative efficiency occurs when the price of the good = the MC of production

3. X inefficiency:

This occurs when firms do not have incentives to cut costs, for example a monopoly which makes supernormal profits may have little incentive to get rid of surplus labour. Therefore a firms average cost may be higher than necessary.

4. Efficiency of scale

This occurs when the firms produces on the lowest point of its Long run average cost and therefore benefits fully from economies of scale

5. Dynamic efficiency This refers to efficiency over time for example a Ford factory in 1920 would be very efficient for the time period, but by comparison would now be inefficient.. Dynamic efficiency involves the introduction of new technology and working practises to reduce costs over time.

- Dynamic efficiency
- Static efficiency – efficiency at a particular point in time.

6. Social efficiency

This occurs when externalities are taken into consideration and occurs at an output where the social cost of production (SMC) = the social benefit (SMB)

7. Technical efficiency

Optimum combination of factor inputs to produce a good: related to productive efficiency.

8. Pareto efficiency

A situation where resources are distributed in the most efficient way. It is defined as a situation where it is not possible to make one party better off without making another party worse off.

9. Distributive efficiency

Concerned with allocating goods and services according to who needs them most. Therefore, requires an equitable distribution.

UNIT II

SOLAR ENERGY AND APPLICATIONS OF SOLAR ENERGY

Solar thermal energy

Solar thermal energy (**STE**) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors.

Overview

Solar thermal collectors are classified by the United States Energy Information Administration as low-, medium-, or high-temperature collectors. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for fulfilling heat requirements up to 300 deg C / 20 bar pressure in industries, and for electric power production. Two categories include Concentrated Solar Thermal (CST) for fulfilling heat requirements in industries, and Concentrated Solar Power (CSP) when the heat collected is used for power generation. CST and CSP are not replaceable in terms of application. The largest facilities are located in the American Mojave Desert of California and Nevada. These plants employ a variety of different technologies. The largest examples include, Ivanpah Solar Power Facility (377 MW), Solar Energy Generating Systemsinstallation (354 MW), and Crescent Dunes (110 MW). Spain is the other major developer of solar thermal power plant. The largest examples include, Solnova Solar Power Station(150 MW), the Andasol solar power station (150 MW), and Extresol Solar Power Station (100 MW).

History

Augustin Mouchot demonstrated a solar collector with a cooling engine making ice cream at the 1878 Universal Exhibition in Paris. The first installation of solar thermal energy equipment occurred in the Sahara approximately in 1910 by Frank Shuman when a steam engine was run on steam produced by sunlight. Because liquid fuel engines were developed and found more convenient, the Sahara project was abandoned, only to be revisited several decades later.[1]

Low-temperature solar heating and cooling systems

MIT's Solar House #1 built in 1939 used seasonal thermal energy storage(STES) for year-round heating.

Systems for utilizing low-temperature solar thermal energy include means for heat collection; usually heat storage, either short-term or interseasonal; and distribution within a structure or a district heating network. In some cases more than one of these functions is inherent to a single feature of the system (e.g. some kinds of solar collectors also store heat). Some systems are passive, others are active (requiring other external energy to function).

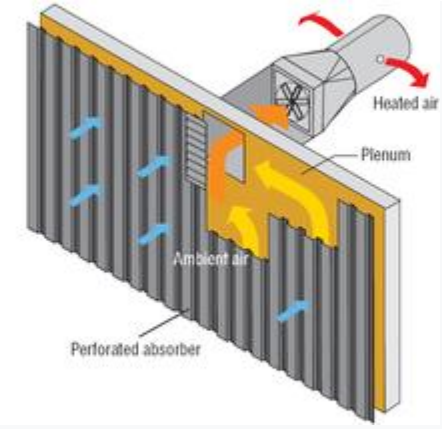
Heating is the most obvious application, but solar cooling can be achieved for a building or district cooling network by using a heat-driven absorption or adsorption chiller (heat pump). There is a productive coincidence that the greater the driving heat from insulation, the greater the cooling output. In 1878, Auguste Mouchout pioneered solar cooling by making ice using a solar steam engine attached to a refrigeration device.

In the United States, heating, ventilation, and air conditioning (HVAC) systems account for over 25% (4.75 EJ) of the energy used in commercial buildings and nearly half (10.1 EJ) of the energy used in residential buildings. Solar heating, cooling, and ventilation technologies can be used to offset a portion of this energy.

In Europe, since the mid-1990s about 125 large solar-thermal district heating plants have been constructed, each with over 500 m^2 (5400 ft^2) of solar collectors. The largest are about 10,000 m^2, with capacities of 7 MW-thermal and solar heat costs around 4 Eurocents/kWh without subsidies. 40 of them have nominal capacities of 1 MW-thermal or more. The Solar District Heating program (SDH) has participation from 14 European Nations and the European Commission, and is working toward technical and market development, and holds annual conferences.

Low-temperature collectors

Glazed solar collectors are designed primarily for space heating. They recirculate building air through a solar air panel where the air is heated and then directed back into the building. These solar space heating systems require at least two penetrations into the building and only perform when the air in the solar collector is warmer than the building room temperature. Most glazed collectors are used in the residential sector.



Unglazed, "transpired" air collector

Unglazed solar collectors are primarily used to pre-heat make-up ventilation air in commercial, industrial and institutional buildings with a high ventilation load. They turn building walls or sections of walls into low cost, high performance, unglazed solar collectors. Also called, "transpired solar panels" or "solar wall", they employ a painted perforated metal solar heat absorber that also serves as the exterior wall surface of the building. Heat conducts from the absorber surface to the thermal boundary layer of air 1 mm thick on the outside of the absorber and to air that passes behind the absorber. The boundary layer of air is drawn into a nearby perforation before the heat can escape by convection to the outside air. The heated air is then drawn from behind the absorber plate into the building's ventilation system.

A Trombe wall is a passive solar heating and ventilation system consisting of an air channel sandwiched between a window and a sun-facing thermal mass. During the ventilation cycle, sunlight stores heat in the thermal mass and warms the air channel causing circulation through vents at the top and bottom of the wall. During the heating cycle the Trombe wall radiates stored heat.[8]

Solar roof ponds are unique solar heating and cooling systems developed by Harold Hay in the 1960s. A basic system consists of a roof-mounted water bladder with a movable insulating cover. This system can control heat exchange between interior and exterior environments by covering and uncovering the bladder between night and day. When heating is a concern the bladder is uncovered during the day allowing sunlight to warm the water bladder and store heat for evening use. When cooling is a concern the covered bladder draws heat from the building's interior during the day and is uncovered at night to radiate heat to the cooler atmosphere. The Skytherm house in Atascadero, California uses a prototype roof pond for heating and cooling.[9]

Solar space heating with solar air heat collectors is more popular in the USA and Canada than heating with solar liquid collectors since most buildings already have a ventilation system for heating and cooling. The two main types of solar air panels are glazed and unglazed.

Of the 21,000,000 square feet (2,000,000 m^2) of solar thermal collectors produced in the United States in 2007, 16,000,000 square feet (1,500,000 m^2) were of the low-temperature variety.[10] Low-temperature collectors are generally installed to heat swimming pools, although they can also be used for space heating. Collectors can use air or water as the medium to transfer the heat to their destination.

Heat storage in low-temperature solar thermal systems

Interseasonal storage. Solar heat (or heat from other sources) can be effectively stored between opposing seasons in aquifers, underground geological strata, large specially constructed pits, and large tanks that are insulated and covered with earth.

Short-term storage. Thermal mass materials store solar energy during the day and release this energy during cooler periods. Common thermal mass materials include stone, concrete, and water. The proportion and placement of thermal mass should consider several factors such as climate, daylighting, and shading conditions. When properly incorporated, thermal mass can passively maintain comfortable temperatures while reducing energy consumption.

Solar-driven cooling

Worldwide, by 2011 there were about 750 cooling systems with solar-driven heat pumps, and annual market growth was 40 to 70% over the prior seven years. It is a niche market because the economics are challenging, with the annual number of cooling hours a limiting factor.

Respectively, the annual cooling hours are roughly 1000 in the Mediterranean, 2500 in Southeast Asia, and only 50 to 200 in Central Europe. However, system construction costs dropped about 50% between 2007 and 2011. The International Energy Agency (IEA) Solar Heating and Cooling program (IEA-SHC) task groups working on further development of the technologies involved.[11]

Solar heat-driven ventilation

A solar chimney (or thermal chimney) is a passive solar ventilation system composed of a hollow thermal mass connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. These systems have been in use since Roman times and remain common in the Middle East.

Process heat

Solar Evaporation Ponds in the Atacama Desert.

Solar process heating systems are designed to provide large quantities of hot water or space heating for nonresidential buildings.

Evaporation ponds are shallow ponds that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from sea water is one of the oldest applications of solar energy. Modern uses include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams. Altogether, evaporation ponds represent one of the largest commercial applications of solar energy in use today.

Unglazed transpired collectors are perforated sun-facing walls used for preheating ventilation air. Transpired collectors can also be roof mounted for year-round use and can raise the incoming air temperature up to 22 °C and deliver outlet temperatures of 45-60 °C. The short payback period of transpired collectors (3 to 12 years) make them a more cost-effective alternative to glazed collection systems. As of 2015, over 4000 systems with a combined collector area of 500,000 m^2 had been installed worldwide. Representatives include an 860 m^2 collector in Costa Rica used for drying coffee beans and a 1300 m^2 collector in Coimbatore, India used for drying marigolds.

A food processing facility in Modesto, California uses parabolic troughs to produce steam used in the manufacturing process. The 5,000 m^2 collector area is expected to provide 15 TJ per year.

Medium-temperature collectors

These collectors could be used to produce approximately 50% and more of the hot water needed for residential and commercial use in the United States. In the United States, a typical system costs $4000–$6000 retail ($1400 to $2200 wholesale for the materials) and 30% of the system qualifies for a federal tax credit + additional state credit exists in about half of the states. Labor for a simple open loop system in southern climates can take 3–5 hours for the installation and 4–6 hours in Northern areas. Northern system require more collector area and more complex plumbing to protect the collector from freezing. With this incentive, the payback time for a typical household is four to nine years, depending on the state. Similar subsidies exist in parts of Europe. A crew of one solar plumber and two assistants with minimal training can install a system per day. Thermosiphon installation have negligible maintenance costs (costs rise if antifreeze and mains power are used for circulation) and in the US reduces a households' operating costs by $6 per person per month. Solar water heating can reduce CO_2 emissions of a family of four by 1 ton/year (if replacing natural gas) or 3 ton/year (if replacing electricity).[18] Medium-temperature installations can use any of several designs: common designs are pressurized glycol, drain back, batch systems and newer low pressure freeze tolerant systems using polymer pipes containing water with photovoltaic pumping. European and International standards are being reviewed to accommodate innovations in design and operation of medium temperature collectors. Operational innovations include "permanently wetted collector" operation. This innovation reduces or even eliminates the occurrence of no-flow high temperature stresses called stagnation which would otherwise reduce the life expectancy of collectors.

Solar drying

Industrial indirect solar fruit and vegetable dryer

Solar thermal energy can be useful for drying wood for construction and wood fuels such as wood chips for combustion. Solar is also used for food products such as fruits, grains, and fish. Crop drying by solar means is environmentally friendly as well as cost effective while improving the quality. The less money it takes to make a product, the less it can be sold for, pleasing both the buyers and the sellers. Technologies in solar drying include ultra low cost pumped transpired plate air collectors based on black fabrics. Solar thermal energy is helpful in the process of drying products such as wood chips and other forms of biomass by raising the temperature while allowing air to pass through and get rid of the moisture.

Cooking

The Solar Bowl above the Solar Kitchen in Auroville, India concentrates sunlight on a movable receiver to produce steam for cooking.

Solar cookers use sunlight for cooking, drying and pasteurization. Solar cooking offsets fuel costs, reduces demand for fuel or firewood, and improves air quality by reducing or removing a source of smoke.

The simplest type of solar cooker is the box cooker first built by Horace de Saussure in 1767. A basic box cooker consists of an insulated container with a transparent lid. These cookers can be used effectively with partially overcast skies and will typically reach temperatures of 50–100 °C.

Concentrating solar cookers use reflectors to concentrate solar energy onto a cooking container. The most common reflector geometries are flat plate, disc and parabolic trough type. These designs cook faster and at higher temperatures (up to 350 °C) but require direct light to function properly.

The Solar Kitchen in Auroville, India uses a unique concentrating technology known as the solar bowl. Contrary to conventional tracking reflector/fixed receiver systems, the solar bowl uses a fixed spherical reflector with a receiver which tracks the focus of light as the Sun moves across the sky. The solar bowl's receiver reaches temperature of 150 °C that is used to produce steam that helps cook 2,000 daily meals.[22]

Many other solar kitchens in India use another unique concentrating technology known as the Scheffler reflector. This technology was first developed by Wolfgang Scheffler in 1986. A Scheffler reflector is a parabolic dish that uses single axis tracking to follow the Sun's daily course. These reflectors have a flexible reflective surface that is able to change its curvature to adjust to seasonal variations in the incident angle of sunlight. Scheffler reflectors have the advantage of having a fixed focal point which improves the ease of cooking and are able to reach temperatures of 450-650 °C.[23] Built in 1999 by the Brahma Kumaris, the world's largest Scheffler reflector system in Abu Road, Rajasthan India is capable of cooking up to 35,000 meals a day.[24] By early 2008, over 2000 large cookers of the Scheffler design had been built worldwide.

Distillation

Solar stills can be used to make drinking water in areas where clean water is not common. Solar distillation is necessary in these situations to provide people with purified water. Solar energy heats up the water in the still. The water then evaporates and condenses on the bottom of the covering glass.[19]

High-temperature collectors

Part of the 354 MW SEGS solar complex in northern San Bernardino County, California.

The solar furnace at Odeillo in the French Pyrenees-Orientales can reach temperatures up to 3,500°C .

Where temperatures below about 95 °C are sufficient, as for space heating, flat-plate collectors of the nonconcentrating type are generally used. Because of the relatively high heat losses through the glazing, flat plate collectors will not reach temperatures much above 200 °C even when the heat transfer fluid is stagnant. Such temperatures are too low for efficient conversion to electricity.

The efficiency of heat engines increases with the temperature of the heat source. To achieve this in solar thermal energy plants, solar radiation is concentrated by mirrors or lenses to obtain higher temperatures – a technique called Concentrated Solar Power (CSP). The practical effect of high efficiencies is to reduce the plant's collector size and total land use per unit power generated, reducing the environmental impacts of a power plant as well as its expense.

As the temperature increases, different forms of conversion become practical. Up to 600 °C, steam turbines, standard technology, have an efficiency up to 41%. Above 600 °C, gas turbines can be more efficient. Higher temperatures are problematic because different materials and techniques are needed. One proposal for very high temperatures is to use liquid fluoride salts operating between 700 °C to 800 °C, using multi-stage turbine systems to achieve 50% or more thermal efficiencies.[25] The higher operating temperatures permit the plant to use higher-temperature dry heat exchangers for its thermal exhaust, reducing the plant's water use – critical in the deserts where large solar plants are practical. High temperatures also make heat storage more efficient, because more watt-hours are stored per unit of fluid.

Commercial concentrating solar thermal power (CSP) plants were first developed in the 1980s. The world's largest solar thermal power plants are now the 370 MW Ivanpah Solar Power Facility, commissioned in 2014, and the 354 MW SEGS CSP installation, both located in the Mojave Desert of California, where several other solar projects have been realized as well. With the exception of the Shams solar power station, built in 2013 near Abu Dhabi, the United Arab Emirates, all other 100 MW or larger CSP plants are either located in the United States or in Spain.

The principal advantage of CSP is the ability to efficiently add thermal storage, allowing the dispatching of electricity over up to a 24-hour period. Since peak electricity demand typically occurs at about 5 pm, many CSP power plants use 3 to 5 hours of thermal storage.[26] With current technology, storage of heat is much cheaper and more efficient than storage of electricity. In this way, the CSP plant can produce electricity day and night. If the CSP site has predictable solar radiation, then the CSP plant becomes a reliable power plant. Reliability can further be improved by installing a back-up combustion system. The back-up system can use most of the CSP plant, which decreases the cost of the back-up system.

CSP facilities utilize high electrical conductivity materials, such as copper, in field power cables, grounding networks, and motors for tracking and pumping fluids, as well as in the main generator and high voltage transformers. *(See: Copper in concentrating solar thermal power facilities.)*

With reliability, unused desert, no pollution, and no fuel costs, the obstacles for large deployment for CSP are cost, aesthetics, land use and similar factors for the necessary connecting high tension lines. Although only a small percentage of the desert is necessary to meet global electricity demand, still a large area must be covered with mirrors or lenses to obtain a significant amount of energy. An important way to decrease cost is the use of a simple design.

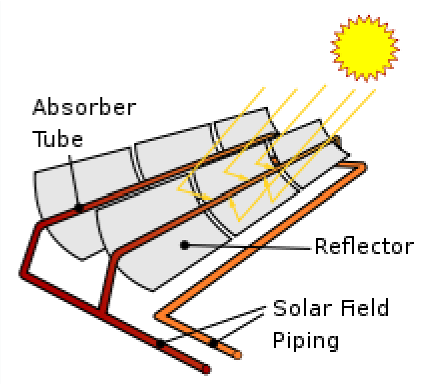
When considering land use impacts associated with the exploration and extraction through to transportation and conversion of fossil fuels, which are used for most of our electrical power, utility-scale solar power compares as one of the most land-efficient energy resources available:[27]

The federal government has dedicated nearly 2,000 times more acreage to oil and gas leases than to solar development. In 2010 the Bureau of Land Managementapproved nine large-scale solar projects, with a total generating capacity of 3,682 megawatts, representing approximately 40,000 acres. In contrast, in 2010, the Bureau of Land Management processed more than 5,200 applications gas and oil leases, and issued 1,308 leases, for a total of 3.2 million acres. Currently, 38.2 million acres of onshore public lands and an additional 36.9 million acres of offshore exploration in the Gulf of Mexico are under lease for oil and gas development, exploration and production.[27]

System designs[edit]

During the day the sun has different positions. For low concentration systems (and low temperatures) tracking can be avoided (or limited to a few positions per year) if nonimaging optics are used.[28][29] For higher concentrations, however, if the mirrors or lenses do not move, then the focus of the mirrors or lenses changes (but also in these cases nonimaging optics provides the widest acceptance angles for a given concentration). Therefore, it seems unavoidable that there needs to be a tracking system that follows the position of the sun (for solar photovoltaic a solar tracker is only optional). The tracking system increases the cost and complexity. With this in mind, different designs can be distinguished in how they concentrate the light and track the position of the sun.

Parabolic trough design



Sketch of a parabolic trough design. A change of position of the sun parallel to the receiver does not require adjustment of the mirrors.

Parabolic trough power plants use a curved, mirrored trough which reflects the direct solar radiation onto a glass tube containing a fluid (also called a receiver, absorber or collector) running the length of the trough, positioned at the focal point of the reflectors. The trough is parabolic along one axis and linear in the orthogonal axis. For change of the daily position of the sun perpendicular to the receiver, the trough tilts east to west so that the direct radiation remains focused on the receiver. However, seasonal changes in the angle of sunlight parallel to the trough does not require adjustment of the mirrors, since the light is simply concentrated elsewhere on the receiver. Thus the trough design does not require tracking on a second axis. The receiver may be enclosed in a glass vacuum chamber. The vacuum significantly reduces convective heat loss.

A fluid (also called heat transfer fluid) passes through the receiver and becomes very hot. Common fluids are synthetic oil, molten salt and pressurized steam. The fluid containing the heat is transported to a heat engine where about a third of the heat is converted to electricity.

Full-scale parabolic trough systems consist of many such troughs laid out in parallel over a large area of land. Since 1985 a solar thermal system using this principle has been in full operation in California in the United States. It is called the Solar Energy Generating Systems(SEGS) system.[30] Other CSP designs lack this kind of long experience and therefore it can currently be said that the parabolic trough design is the most thoroughly proven CSP technology.

The SEGS is a collection of nine plants with a total capacity of 354 MW and has been the world's largest solar power plant, both thermal and non-thermal, for many years. A newer plant is Nevada Solar One plant with a capacity of 64 MW. The 150 MW Andasol solar power stations are in Spain with each site having a capacity of 50 MW. Note however, that those plants have heat storage which requires a larger field of solar collectors relative to the size of the steam turbine-generator to store heat and send heat to the steam turbine at the same time. Heat storage enables better utilization of the steam turbine. With day and some nighttime operation of the steam-turbine Andasol 1 at 50 MW peak capacity produces more energy than Nevada Solar One at 64 MW peak capacity, due to the former plant's thermal energy storage system and larger solar field. The 280MW Solana Generating Stationcame online in Arizona in 2013 with 6 hours of power storage. Hassi R'Mel integrated solar combined cycle power station in Algeria and Martin Next Generation Solar Energy Centerboth use parabolic troughs in a combined cycle with natural gas.

Enclosed trough

Inside an enclosed trough system

The enclosed trough architecture encapsulates the solar thermal system within a greenhouse-like glasshouse. The glasshouse creates a protected environment to withstand the elements that can negatively impact reliability and efficiency of the solar thermal system.[31]

Lightweight curved solar-reflecting mirrors are suspended within the glasshouse structure. A single-axis tracking system positions the mirrors to track the sun and focus its light onto a network of stationary steel pipes, also suspended from the glasshouse structure.[32] Steam is generated directly, using oil field-quality water, as water flows from the inlet throughout the length of the pipes, without heat exchangers or intermediate working fluids.

The steam produced is then fed directly to the field’s existing steam distribution network, where the steam is continuously injected deep into the oil reservoir. Sheltering the mirrors from the wind allows them to achieve higher temperature rates and prevents dust from building up as a result from exposure to humidity.[31] GlassPoint Solar, the company that created the Enclosed Trough design, states its technology can produce heat for EOR for about $5 per million British thermal units in sunny regions, compared to between $10 and $12 for other conventional solar thermal technologies.[33]

Power tower designs

Ivanpah Solar Electric Generating System with all three towers under load, Feb., 2014. Taken from I-15 in San Bernardino County, California. The Clark Mountain Range can be seen in the distance.

Power towers (also known as 'central tower' power plants or 'heliostat' power plants) capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in roughly a two square mile field. A tower resides in the center of the heliostat field. The heliostats focus concentrated sunlight on a receiver which sits on top of the tower. Within the receiver the concentrated sunlight heats molten salt to over 1,000 °F (538 °C). The heated molten salt then flows into a thermal storage tank where it is stored, maintaining 98% thermal efficiency, and eventually pumped to a steam generator. The steam drives a standard turbine to generate electricity. This process, also known as the "Rankine cycle" is similar to a standard coal-fired power plant, except it is fueled by clean and free solar energy.

The advantage of this design above the parabolic trough design is the higher temperature. Thermal energy at higher temperatures can be converted to electricity more efficiently and can be more cheaply stored for later use. Furthermore, there is less need to flatten the ground area. In principle a power tower can be built on the side of a hill. Mirrors can be flat and plumbing is concentrated in the tower. The disadvantage is that each mirror must have its own dual-axis control, while in the parabolic trough design single axis tracking can be shared for a large array of mirrors.

A cost/performance comparison between power tower and parabolic trough concentrators was made by the NREL which estimated that by 2020 electricity could be produced from power towers for 5.47 ¢/kWh and for 6.21 ¢/kWh from parabolic troughs. The capacity factor for power towers was estimated to be 72.9% and 56.2% for parabolic troughs.[34] There is some hope that the development of cheap, durable, mass producible heliostat power plant components could bring this cost down.[35]

The first commercial tower power plant was PS10 in Spain with a capacity of 11 MW, completed in 2007. Since then a number of plants have been proposed, several have been built on a number of countries (Spain, Germany, U.S., Turkey, China, India) but several proposed plants were cancelled as photovoltaic solar prices plummeted. A solar power tower is expected to come online in South Africa in 2014.[36] Ivanpah Solar Power Facility in California generates 392 MW of electricity from three towers, making it the largest solar power tower plant when it came online in late 2013.

Dish designs

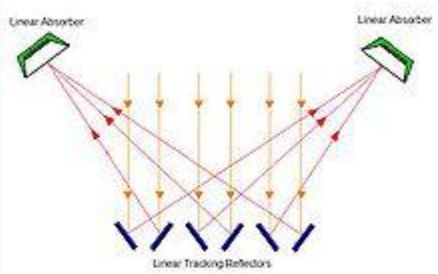
A parabolic solar dish concentrating the sun's rays on the heating element of a Stirling engine. The entire unit acts as a solar tracker.

CSP-Stirling is known to have the highest efficiency of all solar technologies (around 30%, compared to solar photovoltaic's approximately 15%), and is predicted to be able to produce the cheapest energy among all renewable energy sources in high-scale production and hot areas, semi-deserts, etc. A dish Stirling system uses a large, reflective, parabolic dish (similar in shape to a satellite television dish). It focuses all the sunlight that strikes the dish up onto a single point above the dish, where a receiver captures the heat and transforms it into a useful form. Typically the dish is coupled with a Stirling engine in a Dish-Stirling System, but also sometimes a steam engine is used.[37]These create rotational kinetic energy that can be converted to electricity using an electric generator.[38]

In 2005 Southern California Edison announced an agreement to purchase solar powered Stirling engines from Stirling Energy Systems over a twenty-year period and in quantities (20,000 units) sufficient to generate 500 megawatts of electricity. In January 2010, Stirling Energy Systems and Tessera Solar commissioned the first demonstration 1.5-megawatt power plant ("Maricopa Solar") using Stirling technology in Peoria, Arizona.[39] At the beginning of 2011 Stirling Energy's development arm, Tessera Solar, sold off its two large projects, the 709 MW Imperial project and the 850 MW Calico project to AES Solar and K.Road, respectively.[40][41] In 2012 the Maricopa plant was bought and dismantled by United Sun Systems.[42] United Sun Systems released a new generation system, based on a V-shaped Stirling engine and a peak production of 33 kW. The new CSP-Stirling technology brings down LCOE to USD 0.02 in utility scale.[*citation needed*]

According to its developer, Rispasso Energy, a Swedish firm, in 2015 its Dish Sterling system being tested in the Kalahari Desert in South Africa showed 34% efficiency.[43]

Fresnel technologies



Fresnel reflector

A linear Fresnel reflector power plant uses a series of long, narrow, shallow-curvature (or even flat) mirrors to focus light onto one or more linear receivers positioned above the mirrors. On top of the receiver a small parabolic mirror can be attached for further focusing the light. These systems aim to offer lower overall costs by sharing a receiver between several mirrors (as compared with trough and dish concepts), while still using the simple line-focus geometry with one axis for tracking. This is similar to the trough design (and different from central towers and dishes with dual-axis). The receiver is stationary and so fluid couplings are not required (as in troughs and dishes). The mirrors also do not need to support the receiver, so they are structurally simpler. When suitable aiming strategies are used (mirrors aimed at different receivers at different times of day), this can allow a denser packing of mirrors on available land area.

Rival single axis tracking technologies include the relatively new linear Fresnel reflector (LFR) and compact-LFR (CLFR) technologies. The LFR differs from that of the parabolic trough in that the absorber is fixed in space above the mirror field. Also, the reflector is composed of many low row segments, which focus collectively on an elevated long tower receiver running parallel to the reflector rotational axis.[44]

Prototypes of Fresnel lens concentrators have been produced for the collection of thermal energy by International Automated Systems.[45] No full-scale thermal systems using Fresnel lenses are known to be in operation, although products incorporating Fresnel lenses in conjunction with photovoltaic cells are already available.[46]

MicroCSP

MicroCSP is used for community-sized power plants (1 MW to 50 MW), for industrial, agricultural and manufacturing 'process heat' applications, and when large amounts of hot water are needed, such as resort swimming pools, water parks, large laundry facilities, sterilization, distillation and other such uses.

Enclosed parabolic trough

The enclosed parabolic trough solar thermal system encapsulates the components within an off-the-shelf greenhouse type of glasshouse. The glasshouse protects the components from the elements that can negatively impact system reliability and efficiency. This protection importantly includes nightly glass-roof washing with optimized water-efficient off-the-shelf automated washing systems.[31] Lightweight curved solar-reflecting mirrors are suspended from the ceiling of the glasshouse by wires. A single-axis tracking system positions the mirrors to retrieve the optimal amount of sunlight. The mirrors concentrate the sunlight and focus it on a network of stationary steel pipes, also suspended from the glasshouse structure.[32] Water is pumped through the pipes and boiled to generate steam when intense sun radiation is applied. The steam is available for process heat. Sheltering the mirrors from the wind allows them to achieve higher temperature rates and prevents dust from building up on the mirrors as a result from exposure to humidity.[31]

Heat collection and exchange

More energy is contained in higher frequency light based upon the formula of , where h is the Planck constant and is frequency. Metal collectors down convert higher frequency light by producing a series of Compton shifts into an abundance of lower frequency light. Glass or ceramic coatings with high transmission in the visible and UV and effective absorption in the IR (heat blocking) trap metal absorbed low frequency light from radiation loss. Convection insulation prevents mechanical losses transferred through gas. Once collected as heat, thermos containment efficiency improves significantly with increased size. Unlike Photovoltaic technologies that often degrade under concentrated light, Solar Thermal depends upon light concentration that requires a clear sky to reach suitable temperatures.

Heat in a solar thermal system is guided by five basic principles: heat gain; heat transfer; heat storage; heat transport; and heat insulation.[47] Here, heat is the measure of the amount of thermal energy an object contains and is determined by the temperature, mass and specific heat of the object. Solar thermal power plants use heat exchangers that are designed for constant working conditions, to provide heat exchange. Copper heat exchangers are important in solar thermal heating and cooling systems because of copper's high thermal conductivity, resistance to atmospheric and water corrosion, sealing and joining by soldering, and mechanical strength. Copper is used both in receivers and in primary circuits (pipes and heat exchangers for water tanks) of solar thermal water systems.[48]

Heat gain is the heat accumulated from the sun in the system. Solar thermal heat is trapped using the greenhouse effect; the greenhouse effect in this case is the ability of a reflective surface to transmit short wave radiation and reflect long wave radiation. Heat and infrared radiation (IR) are produced when short wave radiation light hits the absorber plate, which is then trapped inside the collector. Fluid, usually water, in the absorber tubes collect the trapped heat and transfer it to a heat storage vault.

Heat is transferred either by conduction or convection. When water is heated, kinetic energy is transferred by conduction to water molecules throughout the medium. These molecules spread their thermal energy by conduction and occupy more space than the cold slow moving molecules above them. The distribution of energy from the rising hot water to the sinking cold water contributes to the convection process. Heat is transferred from the absorber plates of the collector in the fluid by conduction. The collector fluid is circulated through the carrier pipes to the heat transfer vault. Inside the vault, heat is transferred throughout the medium through convection.

Heat storage enables solar thermal plants to produce electricity during hours without sunlight. Heat is transferred to a thermal storage medium in an insulated reservoir during hours with sunlight, and is withdrawn for power generation during hours lacking sunlight. Thermal storage mediums will be discussed in a heat storage section. Rate of heat transfer is related to the conductive and convection medium as well as the temperature differences. Bodies with large temperature differences transfer heat faster than bodies with lower temperature differences.

Heat transport refers to the activity in which heat from a solar collector is transported to the heat storage vault. Heat insulation is vital in both heat transport tubing as well as the storage vault. It prevents heat loss, which in turn relates to energy loss, or decrease in the efficiency of the system.

Heat storage for space heating

A collection of mature technologies called seasonal thermal energy storage (STES) is capable of storing heat for months at a time, so solar heat collected primarily in Summer can be used for all-year heating. Solar-supplied STES technology has been advanced primarily in Denmark,[49] Germany,[50] and Canada,[51] and applications include individual buildings and district heating networks. Drake Landing Solar Community in Alberta, Canada has a small district system and in 2012 achieved a world record of providing 97% of the community's all-year space heating needs from the sun.[52] STES thermal storage mediums include deep aquifers; native rock surrounding clusters of small-diameter, heat exchanger equipped boreholes; large, shallow, lined pits that are filled with gravel and top-insulated; and large, insulated and buried surface water tanks.

Heat storage to stabilize solar-electric power generation

Heat storage allows a solar thermal plant to produce electricity at night and on overcast days. This allows the use of solar power for baseload generation as well as peak power generation, with the potential of displacing both coal- and natural gas-fired power plants. Additionally, the utilization of the generator is higher which reduces cost. Even short term storage can help by smoothing out the "duck curve" of rapid change in generation requirements at sunset when a grid includes large amounts of solar capacity.

Heat is transferred to a thermal storage medium in an insulated reservoir during the day, and withdrawn for power generation at night. Thermal storage media include pressurized steam, concrete, a variety of phase change materials, and molten salts such as calcium, sodium and potassium nitrate.

Steam accumulator

The PS10 solar power tower stores heat in tanks as pressurized steam at 50 bar and 285 °C. The steam condenses and flashes back to steam, when pressure is lowered. Storage is for one hour. It is suggested that longer storage is possible, but that has not been proven yet in an existing power plant.

Molten salt storage

The 150 MW Andasol solar power station is a commercial parabolic trough solar thermal power plant, located in Spain. The Andasol plant uses tanks of molten salt to store solar energy so that it can continue generating electricity even when the sun isn't shining.[56]

A variety of fluids have been tested to transport the sun's heat, including water, air, oil, and sodium, but Rockwell International[57] selected molten salt as best.[58] Molten salt is used in solar power tower systems because it is liquid at atmospheric pressure, provides a low-cost medium to store thermal energy, its operating temperatures are compatible with today's steam turbines, and it is non-flammable and nontoxic. Molten salt is used in the chemical and metals industries to transport heat, so industry has experience with it.

The first commercial molten salt mixture was a common form of saltpeter, 60% sodium nitrate and 40% potassium nitrate. Saltpeter melts at 220 °C (430 °F) and is kept liquid at 290 °C (550 °F) in an insulated storage tank. Calcium nitrate can reduce the melting point to 131 °C, permitting more energy to be extracted before the salt freezes. There are now several technical calcium nitrate grades stable at more than 500 °C.

This solar power system can generate power in cloudy weather or at night using the heat in the tank of hot salt. The tanks are insulated, able to store heat for a week. Tanks that power a 100-megawatt turbine for four hours would be about 9 m (30 ft) tall and 24 m (80 ft) in diameter.

The Andasol power plant in Spain is the first commercial solar thermal power plant using molten salt for heat storage and nighttime generation. It came on line March 2009.[59] On July 4, 2011, a company in Spain celebrated an historic moment for the solar industry: Torresol's 19.9 MW concentrating solar power plant became the first ever to generate uninterrupted electricity for 24 hours straight, using a molten salt heat storage.[60]

In 2016 SolarReserve proposed a 2 GW, $5 billion concentrated solar plant with storage in Nevada.

Phase-change materials for storage

Phase Change Material (PCMs) offer an alternative solution in energy storage. Using a similar heat transfer infrastructure, PCMs have the potential of providing a more efficient means of storage. PCMs can be either organic or inorganic materials. Advantages of organic PCMs include no corrosives, low or no undercooling, and chemical and thermal stability. Disadvantages include low phase-change enthalpy, low thermal conductivity, and flammability. Inorganics are advantageous with greater phase-change enthalpy, but exhibit disadvantages with undercooling, corrosion, phase separation, and lack of thermal stability. The greater phase-change enthalpy in inorganic PCMs make hydrate salts a strong candidate in the solar energy storage field.

Use of water

A design which requires water for condensation or cooling may conflict with location of solar thermal plants in desert areas with good solar radiation but limited water resources. The conflict is illustrated by plans of Solar Millennium, a German company, to build a plant in the Amargosa Valley of Nevada which would require 20% of the water available in the area. Some other projected plants by the same and other companies in the Mojave Desert of California may also be affected by difficulty in obtaining adequate and appropriate water rights. California water law currently prohibits use of potable water for cooling.

Other designs require less water. The Ivanpah Solar Power Facility in south-eastern California conserves scarce desert water by using air-cooling to convert the steam back into water. Compared to conventional wet-cooling, this results in a 90% reduction in water usage at the cost of some loss of efficiency. The water is then returned to the boiler in a closed process which is environmentally friendly.

Conversion rates from solar energy to electrical energy

Of all of these technologies the solar dish/Stirling engine has the highest energy efficiency. A single solar dish-Stirling engine installed at Sandia National Laboratories National Solar Thermal Test Facility (NSTTF) produces as much as 25 kW of electricity, with a conversion efficiency of 31.25%.[64]

Solar parabolic trough plants have been built with efficiencies of about 20%.[*citation needed*] Fresnel reflectors have an efficiency that is slightly lower (but this is compensated by the denser packing).

The gross conversion efficiencies (taking into account that the solar dishes or troughs occupy only a fraction of the total area of the power plant) are determined by net generating capacity over the solar energy that falls on the total area of the solar plant. The 500-megawatt (MW) SCE/SES plant would extract about 2.75% of the radiation (1 kW/m²; see Solar power for a discussion) that falls on its 4,500 acres (18.2 km²).[65] For the 50 MW AndaSol Power Plant[66] that is being built in Spain (total area of 1,300×1,500 m = 1.95 km²) gross conversion efficiency comes out at 2.6%.

The different types of solar thermal panel collectors

Evacuated tube solar thermal systems

The **evacuated tube solar thermal system** is one of the most popular solar thermal systems in operation. An evacuated solar system is the **most efficient** and a common means of solar thermal energy generation with a rate of efficiency of 70 per cent. As an example, if the collector generates 3000 kilowatt hours of energy in a year then 2100 kilowatt hours would be utilised in the system for heating water. The rate of efficiency is achieved because of the way in which the evacuated tube systems are constructed, meaning they have excellent insulation and are virtually unaffected by air temperatures. The collector itself is made up of rows of insulated glass tubes that contain copper pipes at their core. Water is heated in the collector and is then sent through the pipes to the water tank. This type of collector is the most efficient, but also the most expensive.
There are two main types of tubes that are used inside the collector which are glass-glass and glass-metal. The glass-glass version uses two layers of glass fused together at both ends. The double glass tubes have a very reliable vacuum but reduce the amount of light that reaches the absorber inside. The double glass system may also experience more absorber corrosion due to moisture or condensation forming in the non-evacuated area of the tube. The second kind of tube is a glass-metal combination. The glass-metal combination allows more light to reach the absorber and reduces the chances of moisture corroding the absorber.

The cylindrical shape of evacuated tubes means that they are able to collect sunlight throughout the day and at all times in the year. Evacuated tube collectors are also easier to install as they are light, compact and can be carried onto the roof individually. What’s more, the tubes can be replaced individually if one becomes faulty, avoiding the need to replace the whole collector. The system is an efficient and durable system with the vacuum inside the collector tubes having been proven to last for over twenty years. The reflective coating on the inside of the tube will also not degrade unless the vacuum is lost.

Flat plate solar thermal systems

are another common type of solar collector which have been in use since the 1950s. The main components of a flat plate panel are a dark coloured flat plate absorber with an insulated cover, a heat transferring liquid containing antifreeze to transfer heat from the absorber to the water tank, and an insulated backing. The flat plate feature of the solar panel increases the surface area for heat absorption. The heat transfer liquid is circulated through copper or silicon tubes contained within the flat surface plate.

Some panels are manufactured with a flooded absorber that involves having two sheets of metal and allowing the liquid to flow between them. Using a flooded absorber increases surface area and gives a marginal boost in efficiency. The absorber plates themselves are usually made from copper or aluminium and are painted with a selective heat coating which is much better at absorbing and retaining heat than ordinary paints.

In an area that produces an average level of solar energy, the amount of energy a flat plate solar collector generates equates to around one square foot panel generating one gallon of one day's hot water.

The flat plate panel design utilises many different absorber configurations with the main design being the harp configuration. The harp design is usually used in low pressure thermosyphon systems or pumped systems. Other configurations include the serpentine which uses a continuous S shaped absorber and is used in compact hot water only systems which do not utilise space heating. There are also the flooded absorber systems and boundary absorbers which use multiple layers of absorber sheet where the heat is then collected in the boundary layer of the sheets.

Polymer flat plate collectors are an alternative to metal plate collectors. Metal plates are more prone to freezing whereas the polymer plates themselves are freeze tolerant so can dispense with antifreeze and simply use water as a heat transferring liquid. Any antifreeze that is added to the heat transfer liquid will reduce its heat carrying capacity at a marginal rate. A benefit of polymer plates is that they can be plumbed straight into an existing water tank removing the need for a heat exchanger which increases efficiency. Some polymer panels are painted with matte black paint rather than a selective heat coating. This is done to prevent overheating although high temperature silicone is now normally used to prevent overheating.

This design of solar panel is, overall, slightly less compact and less efficient when compared with an evacuated tube system, however this is reflected in a cheaper price. This design of solar can work well in all climates and can have a life expectancy of over 25 years.

Thermodynamic panels

Thermodynamic solar panels are a new development in solar thermal technology. They are closely related to air source heat pumps in their design but are deployed on the roof or walls like regular solar thermal panels and do not have to be south facing. The concept behind thermodynamic solar technology is that it acts like a reverse freezer and they differ from conventional solar thermal in that they do not use solar radiation to heat up heat transferring liquids.

The panels have a refrigerant passing through them which will absorb heat. The heat that passes through the panel will then in turn become a gas. The gas is then compressed which raises its temperature and it will then be passed on to a heat exchanging coil that is located within a hot water cylinder. The heated water in the cylinder is heated to 55 degrees and can then be used around the property. The system has a built in immersion which occasionally raises the temperature to 60 degrees to eliminate the risk of legionella.

A thermodynamic system can produce up to 100% of domestic heating needs. A system that uses thermodynamic panels will in theory be able to generate energy all year round due to it not being reliant on having optimal climate conditions to reach its maximum output potential. A thermodynamic panel can work in temperatures as low as -5 degrees Celsius although there are not as yet any official performance figures for systems operating in the UK. The main manufactures of thermodynamic systems are in Spain and Portugal and these systems were not designed for the UK initially. More companies are now developing more UK specific models and bringing them to market. As an example of performance, a four person family would need to utilise one panel and a 250 litre cylinder.

What’s more, thermodynamic panels are also not currently approved by the Micro generation Certification Scheme, which means that they are not eligible for government green heat payments such as the Renewable Heat Incentive (RHI). This is sure to change however, and it is probable that thermodynamic panels will be eligible for the RHI in the future. The government says that it is currently gathering information on standards and performance.

Solar thermal air collectors

Solar air heaters are mostly used for space heating and can be both glazed and unglazed. They are among the **most efficient and economical** solar thermal technologies available and are mostly used in the commercial sector. The top sheet of a glazed system has a transparent top layer and an insulated surrounding frame and back panel to prevent heat loss to the surrounding air. An unglazed system uses an absorber plate which air passes over while heat is taken from the absorber.

Solar thermal bowl collectors

A **solar thermal bowl** is similar in fashion to a parabolic dish but has a fixed mirror instead of a tracking mirror which a parabolic dish would use. A tracking mirror is designed to track the sun's movement which is very costly on a large scale. A spherical or bowl mirror gets around the problem of tracking the sun in order to focus the light in one spot. A fixed mirror is at a disadvantage with regard to energy output as it cannot track the sun in order to focus the sunlight, however a fixed bowl will save the energy output that is associated with having to move a giant mirror to track the sun.

Domestic Solar Hot Water Systems

Low temperature solar thermal technologies, especially those that do not generate electricity, rely on the scientific principles behind the Greenhouse Effect to generate heat. Electromagnetic radiation from the sun, including visible and infrared wavelengths, penetrates into the collector that is absorbed by the surfaces inside the collector. Once the radiation is absorbed by the surfaces within the collector, the temperature rises. This increase in temperature can be used to heat water.

Domestic Solar Water Heating Systems

Solar Water Heating (SWH) is an effective method of utilising available energy sources to perform useful work. The energy from the sun can provide hot water for many domestic and industrial applications, displacing the need to burn fossil fuels. In Australia, around 25% of domestic energy consumption is devoted to the heating of water to low temperatures, of less than 100oC.

Two main components of SWH systems are collectors and storage tanks. There are many different types of configurations and collectors. The most commonly used type of collector is the flat plate.

Flat Plate Collectors

These collectors consist of airtight boxes with a glass, or other transparent materia,l cover. There are several designs on the arrangement of the internal tubing of flat plate collectors as shown in Figure 1.

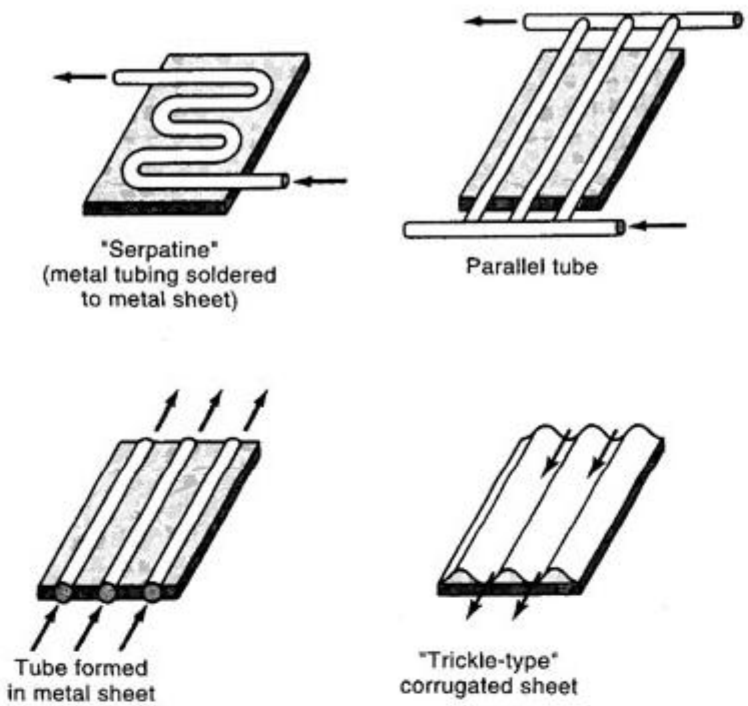


Figure 1 Internal tubing arrangement in flat plate collectors (copyright Saunders College Publishing)

Traditional collectors, like the Serpatine and Parallel tube examples above, consist of a number of copper tubes, known as risers that are orientated vertically with respect to the collector and placed in thermal contact with a black coloured, metal absorbing plate. The use of selective surfaces on absorbers improves the efficiency of solar water heaters significantly due to a very high absorbance (percentage of incoming energy that a material can absorb) and low emittance (percentage of energy that a material radiates away) of electromagnetic radiation. At the top and bottom of the metal absorbing plate, thicker copper pipes, known as headers, assist in the removal of heated water and the arrival of colder water to be heated. Insulation is placed between the absorbing plate and the external wall to prevent heat losses.

Whilst the principles of operation for flat plate collectors are fairly consistent, significant improvements in the design of systems, particularly absorber plates have occurred. Flooded plate collectors are similar to their tubed cousins, except that two metal absorbing plates are sandwiched together, allowing the water to flow through the whole plate. The increased thermal contact results in significant improvements in the efficiency of the system. In recent years, much research has been conducted on selective surfaces, which has seen significant improvements in the efficiency of solar water heaters. Today, a majority of absorber plates are composed of solar selective surfaces, made of materials that strongly absorb electromagnetic radiation (i.e. sunlight) but only weakly emit.

Batch Water Heaters

Batch water heaters, also known as ‘breadboxes’ are very simple passive systems for heating water using solar energy and have been used since the early 1900s. Batch systems consist of black storage tanks contained within an insulated box that has a transparent cover. Cold water is added to the hot water stored in the tanks whenever hot water is removed. Modern batch systems are used as preheating systems, where the water is then heated further by conventional gas, electric or wood systems. To retain the heat within the water, the system requires insulated covering to be placed over the glazing at night to prevent the heat being lost to the environment. Figure 2 shows a typical Breadbox water heater.

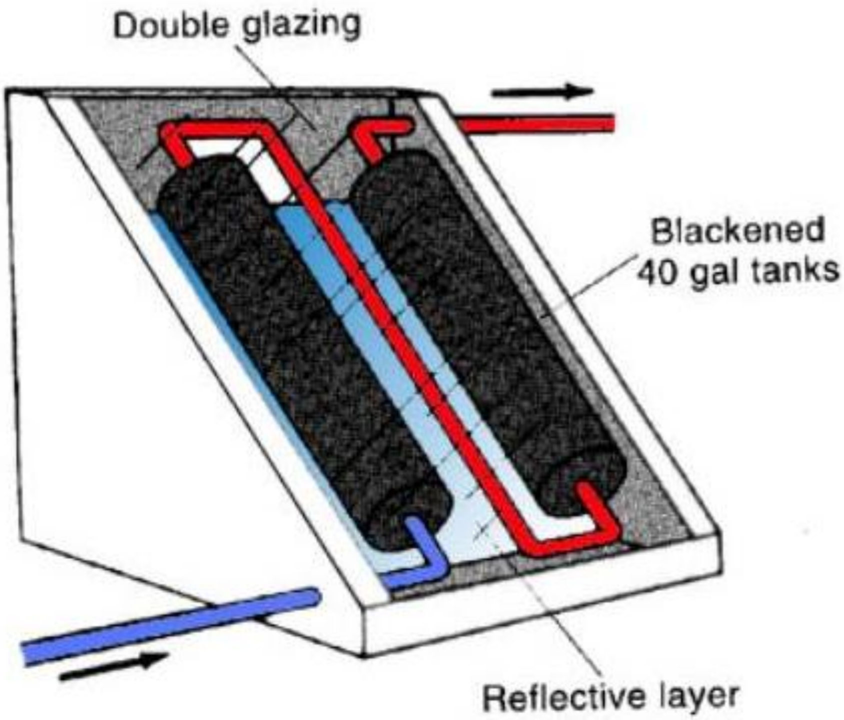


Figure 2 Breadbox water heater
(copyright Saunders College Publishing)

Selective Surfaces

According to Planck's Law, the wavelength of radiation emitted from a surface is proportional to the temperature of the surface. Therefore, an ideal selective surface (the dark coloured material that lines the inside of the collector) for solar collectors should strongly absorb electromagnetic radiation (light) in the visible range and only weakly emit radiation back in the infrared range of the spectrum, so that the maximum amount of energy from the incoming sunlight is used to heat water.
Several coating methods for selective surfaces are used in the manufacture of solar collector absorber plates:

- **Chemical**
- **Electroplated**
- **Vapour deposited**
- **Oxide**

Chemical coatings are usually sprayed onto the absorber plate metal, with or without the use of electricity. These coatings do not alter the re-radiative properties of the plate metal, only enhance the absorption of the solar radiation. The thickness of the chemical coating is proportional to the selectivity of the surface. That is, the coating thickness influences not only the absorptivity of the surface, but also the emissivity (how easily the surface emits the longer wavelength IR radiation). Despite the low relative cost and ease of application, chemical coatings are often undesirable because of the temperatures reached inside collectors, which can cause a degradation in the chemical coatings. For example, black paint applied to the plate is considered to be a chemical coating. At high temperatures, the paint is likely to melt or burn off the surface, releasing volatile organic compounds into the environment.

Electroplated coatings are the most widely used coatings in the solar collector industry. These coatings are applied to the absorber plate metal using traditional electroplating technology. Prolonged exposure to elevated temperatures (around 200oC) and humidity can cause slow degradation in the selective coating as oxidation and crystal lattice reconstruction occurs. Black Chrome, a common electroplated coating used in the manufacture of solar collectors is relatively stable, particularly in humid, tropical conditions. Vapour deposited coatings are not traditionally used in flat plate collectors, as there are a number of significant engineering problems which are yet to be overcome. However, they are used extensively in evacuated collectors, which utilise a partial vacuum, such as the receivers in high temperature solar thermal systems.

Oxide coatings were the first type of coating used in solar collectors. Metals used in early solar collectors, such as copper and iron underwent natural oxidation, which have desirable absorptivity. However, as the oxidation processes occur naturally, they are difficult to control, which results in a change in the emissivity of the material and eventual degradation of the efficiency of the collector.

Evacuated tube solar thermal systems

The evacuated tube solar thermal system is one of the most popular solar thermal systems in operation. An evacuated solar system is the most efficient and a common means of solar thermal energy generation with a rate of efficiency of 70 per cent. As an example, if the collector generates 3000 kilowatt hours of energy in a year then 2100 kilowatt hours would be utilised in the system for heating water. The rate of efficiency is achieved because of the way in which the evacuated tube systems are constructed, meaning they have excellent insulation and are virtually unaffected by air temperatures. The collector itself is made up of rows of insulated glass tubes that contain copper pipes at their core. Water is heated in the collector and is then sent through the pipes to the water tank. This type of collector is the most efficient, but also the most expensive.

Storage Tanks

Depending on the water supply system, the system can be either a closed-coupled system or a gravity fed system. The most common tank in solar hot water systems is the close-coupled system, where the storage tanks are mounted with the collector on the roof. Tanks are located above the collectors to take advantage of thermosiphoning. Thermosiphoning utilises flat plate collectors to heat the water, which returns to the storage tank, located above the collector. Cold, denser water flows through the collector heating up and is then returned to the tank. As the heated water is less dense, it rises to the top of the tank. For thermosiphoning to be successful, it is essential that a constant rise in the pipe work is maintained and that the correct diameter pipes are used as risers and headers. In full sun a single pass through the collector can heat the water by as much as 20oC. Roof mounted flat plate collectors that utilise thermosiphoning are extremely popular in the Middle East, with 70% of the population using water heated by these systems. Figure 3 shows a typical thermosiphon water heater.

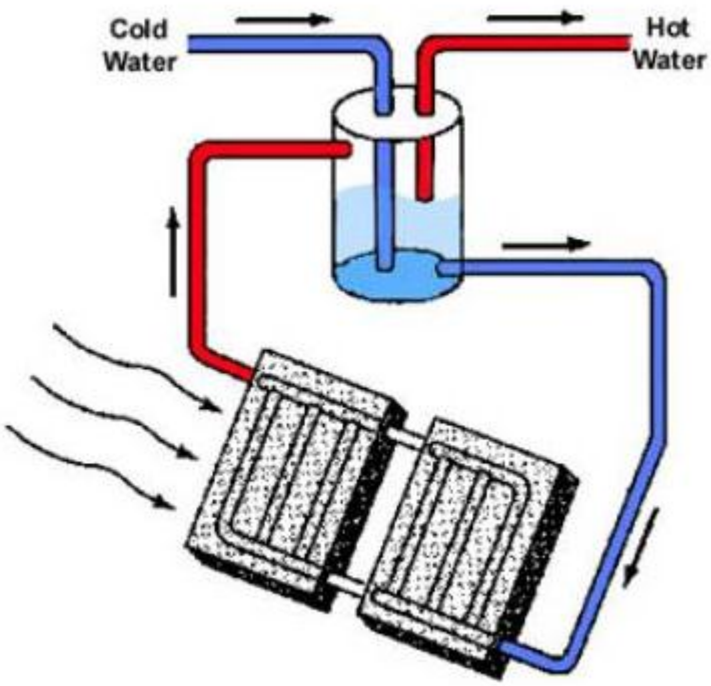


Figure 3 Thermosiphon water heater
(copyright Saunders College Publishing)

The density of water changes with respect to temperature. Generally, water is less dense at higher temperatures than at lower temperatures. Thermosiphoning uses this principle to circulate water through the collector, as cooler water from the mains will be drawn through the collector as the heated water is removed from the storage tanks. Two significant advantages exist with the close coupled system: this arrangement is the most cost effective system for installation and heated water is provided at mains pressure.

In gravity fed systems, the tank is installed in the roof cavity, with only the collector exposed to the sun. Positioning of the solar collectors must allow natural thermosiphoning to occur. Whilst these systems are usually the cheapest to purchase, household plumbing must be suitable for gravity feeding, i.e. larger pipes in the ceiling and down to the taps.

In forced circulation systems a mains pressure tank is located at ground level with the collector on the roof. In these systems, a pump is activated when the sun shines and cold water is pushed through the collector. Forced circulation systems are more expensive to purchase than either the close coupled or gravity feed systems, and electricity is required to provide power for the circulating pump.

Solar thermal heat storage

A thermal heat store will be necessary to retain the heat generated by a solar thermal installation unit until the heat is ready to be used. Thermal heat stores also work particularly well in conjunction with solar thermal panels. The main storage option in a domestic setting would be a large insulated cylinder that contains copper coils or plate heat exchangers. The system can also include a heating element like an immersion heater. A thermal storage unit can utilise a number of different and combined technologies for hot water generation and space heating. Thermal heat stores work at their best when managing input and output for a number of different systems and allowing flexibility in how you use both your solar thermal and current heating system together.

It may be necessary to also fit a new hot water tank as your existing tank may not be suitable, but this will vary depending on a number of factors such as what kind of solar thermal system you choose to install, your existing heating components and how many people the system will be designed to accommodate

solar pump.

Scope of the work and specifications:

1) P V Modules as per MNRE/IEC specifications

   a) 3 HP - Minimum 2700 watts capacity

   b) 5 HP - Minimum 4500 watts capacity

2) Motor Pump set with 5 star rated (Surface or Submersible)as per MNRE specification.

AC induction Motor pump set with a suitable inverter

3) Electronics: Solar inverter/VFD with remote monitoring facility as per MNRE specification

4) G I mounting structure with manual tracking facility as per MNRE norms arrangement for seasonal tilt angle adjustment and three times manual tracking in a day should be provided.

Suitable foundation shall be provided to with stand for high wind speeds as per MNRE norms.

5) HDPE pipe of6Kgs/sqcm â?? 63mmOD-PE 100 grade of 100 feet length. The cost of over and above 100 ft length shall be collected from beneficiary / farmer as per SSR rates i.e. Rs.91/- per meter length

for HDPE pipe and Rs.83.60 per meter length forelectrical cable.

6) Submersible cable of 3 core 2.5 sq.mm flat cable as per ISI standards of 120 feet length.The cost of over and above 120 ft length shall be collected from beneficiary /farmer as per SSR rates.

7) A good reliable switch suitable to operate the system will be provided with the Motor pump set.

8) In general ata total head of 50 mtrs, the 3 HP pump set shall deliver 57000 liters per day and 5 HP pump sets 91000 liters per day.

9) An operation and manual in English and Telugu languages shall be provided with information about solar PV pump set, tracking system, mounting structure, electronics,switches, DOâ??s and DONTâ??s,

regular maintenance and troubleshooting of the pumping system. Name and Address of the person or center to be contacted in case of failure or complaint and warranty card shall also be provided.

Important Information:

1. The NREDCAP had called for tenders and the price discovered is as follows.

- 5 HP AC solar pump-set system:Rs.4,90,000
- 3 HP AC solar pump-set system:Rs.3,20,360
- 5 HP DC solar pump-set system:Rs.5,40,000
- 3 HP DC solar pump-set system:Rs.3,84,015

2. The cost system will cover

- Solar panels of appropriate size
- High quality ISI pump-set
- Transportation of all equipmentâ??s to beneficiary site
- Mounting structures & civil works as required at the site
- Electrical cables
- Water pipes of different sizes, up to 100 feet depth
- Cost of installation and commissioning
- Charges for annual maintenance contract (AMC) for 5 years
- Insurance premium for 5 years
- All taxes as applicable
- All other accessories, please refer to the technical specifications for details

3. The cost will be borne by various stake holders, as follows

Case-1:Beneficiary funded pump-set

MNRE would provide Rs.32, 400 per HP for AC pumps & Rs.40, 500 HP for DC pumps for 3HP & 5 HP pump-sets. Remaining costs will be borne by the farmer.

The following table provides the cost estimates.

Type of pump-set	**MNRE subsidy(A)**	**Beneficiary contribution(B)**	**Total**
3 HP AC solar pump-set	97,200	2,23,160	3,20,360
5 HP AC solar pump-set	1,62,000	3,28,000	4,90,000
5 HP DC solar pump-set	1,21,500	2,62,515	3,84,015
5 HP DC solar pump-set	2,02,500	3,37,500	5,40,000

Case-2:Additional Finance from other Govt. Departments

The Departments like ITDA, Agriculture, Horticulture etc., may provide additional financial assistance for the Pump sets in addition to the MNRE subsidy so as to reduce

the burden on the beneficiary / farmer.

Case-3:Pump-sets funded by APDISCOMS:

For the farmers who do not possess agricultural connection, Farmers whose applications for release of connections are pending with the APDISCOMS would be given priority under this

scheme. The following table provides the cost estimates.

Particulars	**unit**	**MNRE Subsidy @32,400/HP (A)**	**Beneficiary share (B)**	**Discom Contribution (C)**	**Funding Requirement (D)**	**Total**
Contribution	%	32%	10%	15%	43%	100%
5 HP AC solar pump-set	Rs.	1,62,000	49,000	73,500	2,10,700	4,90,000
3 HP AC solar pump-set	Rs.	97,200	32,036	48,054	1,43,070	3,20,360

4. If the solar pump-set is funded by through the scheme as mentioned in Case-1(through beneficiary funding model) the ownership & title will lie with the farmer.

If the solar pump-set is funded through the scheme as mentioned in Case-3, then the title & ownership will lie with the respective APDISCOM,

as the loan from funding agency will be paid by the respective APDISCOM.

5. The farmer will be responsible for the safety & security as the system is located in the premises of the farmer.Secondly, the solar pump-set is utilized to supply water to the farmer only, so the beneficiary

would be customary guardian of the system. Thirdly, the insurance does not cover any kind of physical damages caused to the solar panels, pump-set or the associated equipment due to negligence and /or

mollified intentions. The farmer has to take adequate precautions such as fencing the area to keep of cattle or stray animals away from the system.

6.Technical feasibility will be granted after a joint inspection of the farmerâ??s premises/land by a team of DISCOM & NREDCAP officials. They will inspect various things such as

- Availability of 270/450 sqft shade free land for 3 HP/5 HP system
- Willingness of farmer to forego agricultural use of the land
- Depth of water table (Between 150-200 feet depth from ground level)
- Distance from the coastline(At least 20 kms straight line distance from the coastline)
- The farmer shall not possess any agricultural service connection from respective DISCOM for case-3 beneficiaries.

7. The solar panels & associated pump-set are based on advanced technology that requires minimum manual intervention. The system operates automatically when the switch is pushed on

manually.Therefore no dedicated operations personnel is required. However, the solar pump-set would require routine cleaning of the panels that can be attended by the beneficiary. As per the requirements,

the supplier company will open service centres and will recruit technicians for every district. The cost of the system covers AMC charges & insurance charges for first 5 years.Thereafter the cost of servicing,

maintenance, and repair, insurance has to be borne by the farmer. It is advisable (but not mandatory) that on completion of 5 year AMC, the farmer extends the AMC period at his/her cost. In a few words,

the company which has supplied /installed the solar pump-set will be responsible for maintaining. The farmer does not have to pay anything up to 5 years period, but will have to bear any charges (as applicable) thereafter.

Solar water heating

From Wikipedia, the free encyclopedia

Roof-mounted close-coupled thermosiphon solar water heater.

A solar water heater installed on a house in Belgium

Part of a series about

Sustainable energy

Energy conservation

Cogeneration
Efficient energy use
Green building
Heat pump
Low-carbon power
Microgeneration
Passive solar building design

Renewable energy

Anaerobic digestion
Biofuel
Geothermal
Hydroelectricity
Solar
Tidal
Wave
Wind

Sustainable transport

Carbon-neutral fuel
Electric vehicle
Fossil fuel phase-out
Green vehicle
Plug-in hybrid

Sustainable development portal

Renewable energy portal
Environment portal

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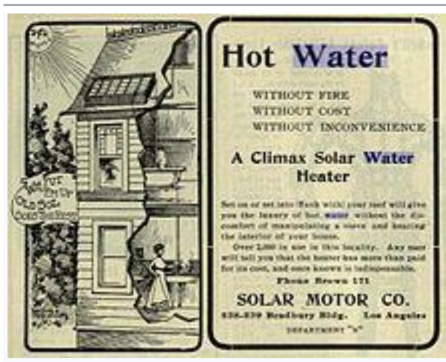
Solar water heating (SWH) is the conversion of sunlight into heat for water heating using a solar thermal collector. A variety of configurations are available at varying cost to provide solutions in different climates and latitudes. SWHs are widely used for residential and some industrial applications.[1]

A sun-facing collector heats a working fluid that passes into a storage system for later use. SWH are active (pumped) and passive (convection-driven). They use water only, or both water and a working fluid. They are heated directly or via light-concentrating mirrors. They operate independently or as hybrids with electric or gas heaters.[2] In large-scale installations, mirrors may concentrate sunlight onto a smaller collector.

The global solar thermal market is dominated by China, Europe, Japan and India, although Israel was one of the first countries to mandate installation of SWH in 1980, leading to a flourishing industry.[3]

History



An advertisement for a **Solar Water Heater** dating to 1902

Frank Shumansunengine on the March 1916 cover of The Electrical Experimenter

Records of solar collectors in the U.S. date to before 1900,[4] involving a black-painted tank mounted on a roof. In 1896 Clarence Kemp of Baltimore enclosed a tank in a wooden box, thus creating the first 'batch water heater' as they are known today. Frank Shuman built the world's first solar thermal power station in Maadi, Egypt, using parabolic troughs to power a 60-70 horsepower engine that pumped 6,000 gallons of water per minute from the Nile River to adjacent cotton fields.

Flat-plate collectors for solar water heating were used in Florida and Southern California in the 1920s. Interest grew in North America after 1960, but especially after the 1973 oil crisis.

See Appendix 1 for country-specific statistics on the "Use of solar water heating worldwide". Solar power is in use in Australia, Canada, China, Germany, India, Israel, Japan, Portugal, Romania, Spain, the United Kingdom and the United States.

Mediterranean

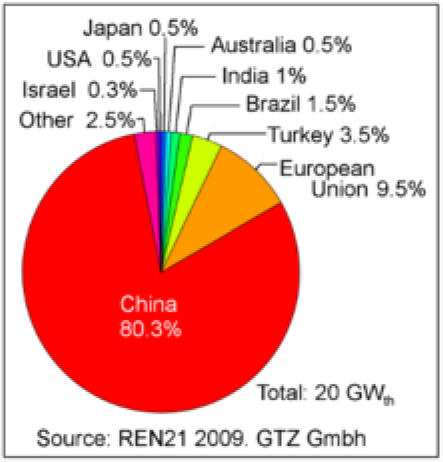
Passive (thermosiphon) solar water heaters on a rooftop in Jerusalem

Israel, Cyprus and Greece are the *per capita* leaders in the use of solar water heating systems supporting 30%–40% of homes.[5]

Flat plate solar systems were perfected and used on a large scale in Israel. In the 1950s a fuel shortage led the government to forbid heating water between 10 pm and 6 am. Levi Yissar built the first prototype Israeli solar water heater and in 1953 he launched the NerYah Company, Israel's first commercial manufacturer of solar water heating.[6] Solar water heaters were used by 20% of the population by 1967. Following the energy crisis in the 1970s, in 1980 Israel required the installation of solar water heaters in all new homes (except high towers with insufficient roof area).[7] As a result, Israel became the world leader in the use of solar energy *per capita* with 85% of households using solar thermal systems (3% of the primary national energy consumption),[8] estimated to save the country 2 million barrels (320,000 m^3) of oil a year.[9]

In 2005, Spain became the world's first country to require the installation of photovoltaic electricity generation in new buildings, and the second (after Israel) to require the installation of solar water heating systems, in 2006.[10]

Asia-Pacific



New solar hot water installations during 2007, worldwide.

After 1960 systems were marketed in Japan and Australia.[4]

Australia has a variety of national and state and regulations for solar thermal starting with MRET in 1997.[11][12][13]

Solar water heating systems are popular in China, where basic models start at around 1,500 yuan (US$235), around 80% less than in Western countries for a given collector size. At least 30 million Chinese households have one. The popularity is due to efficient evacuated tubes that allow the heaters to function even under gray skies and at temperatures well below freezing.[14]

Latin America

Colombia developed a local solar water heating industry thanks to the designs of Las Gaviotas, directed by Paolo Lugari. Driven by a desire to reduce costs in social housing, the team studied the best systems from Israel and made adaptations to meet the specifications set by Banco Central Hipotecario (BCH) which required the system to operate in cities such as Bogotá that are overcast for more than 200 days annually. The ultimate designs were so successful that Las Gaviotas offered a 25-year warranty on its installations in 1984. Over 40,000 were installed and still function a quarter of a century later.

Design requirements[

The type, complexity and size of a solar water heating system is mostly determined by:

- Changes in ambient temperature and solar radiation between summer and winter
- Changes in ambient temperature during the day-night cycle
- Possibility of the potable water or collector fluid overheating or freezing

The minimum requirements of the system are typically determined by the amount or temperature of hot water required during winter, when a system's output and incoming water temperature are typically at their lowest. The maximum output of the system is determined by the need to prevent the water in the system from becoming too hot.

Freeze protection

Freeze protection measures prevent damage to the system due to the expansion of freezing transfer fluid. Drainback systems drain the transfer fluid from the system when the pump stops. Many indirect systems use antifreeze (e.g., propylene glycol) in the heat transfer fluid.

In some direct systems, collectors can be manually drained when freezing is expected. This approach is common in climates where freezing temperatures do not occur often, but is somewhat unreliable since it relies on an operator.

A third type of freeze protection is freeze-tolerance, where low pressure polymer water channels made of silicone rubber simply expand on freezing. One such collector now has European Solar Keymark accreditation.

Overheat protection

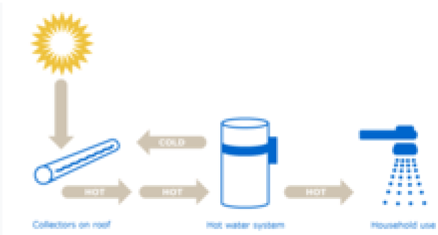
When no hot water has been used for a day or two, the fluid in the collectors and storage can reach high temperatures in all non-drainback systems. When the storage tank in a drainback system reaches its desired temperature, the pumps stop, ending the heating process and thus preventing the storage tank from overheating.

Some active systems deliberately cool the water in the storage tank by circulating hot water through the collector at times when there is little sunlight or at night, losing heat. This is most effective in direct or thermal store plumbing and is virtually ineffective in systems that use evacuated tube collectors, due to their superior insulation. Any collector type may still overheat. High pressure, sealed solar thermal systems ultimately rely on the operation of temperature and pressure relief valves. Low pressure, open vented heaters have simpler, more reliable safety controls, typically an open vent.

Systems

Sample designs include a simple glass-topped insulated box with a flat solar absorber made of sheet metal, attached to copper heat exchanger pipes and dark-colored, or a set of metal tubes surrounded by an evacuated (near vacuum) glass cylinder. In industrial cases a parabolic mirror can concentrate sunlight on the tube. Heat is stored in a hot water storage tank. The volume of this tank needs to be larger with solar heating systems to compensate for bad weather[*clarification needed*] and because the optimum final temperature for the solar collector[*clarification needed*] is lower than a typical immersion or combustion heater. The heat transfer fluid (HTF) for the absorber may be water, but more commonly (at least in active systems) is a separate loop of fluid containing anti-freeze and a corrosion inhibitor delivers heat to the tank through a heat exchanger (commonly a coil of copper heat exchanger tubing within the tank). Copper is an important component in solar thermal heating and cooling systems because of its high heat conductivity, atmospheric and water corrosion resistance, sealing and joining by soldering and mechanical strength. Copper is used both in receivers and primary circuits (pipes and heat exchangers for water tanks).[15]

Another lower-maintenance concept is the 'drain-back'. No anti-freeze is required; instead, all the piping is sloped to cause water to drain back to the tank. The tank is not pressurized and operates at atmospheric pressure. As soon as the pump shuts off, flow reverses and the pipes empty before freezing can occur.



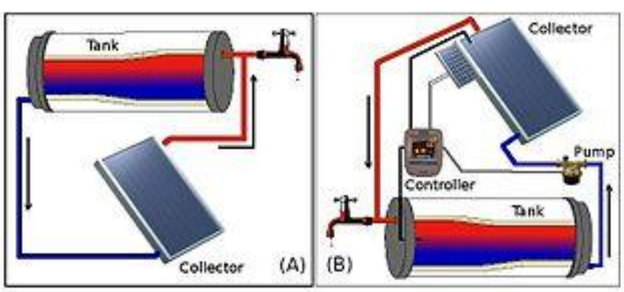
How a Solar Hot Water system works

Residential solar thermal installations fall into two groups: passive (sometimes called "compact") and active (sometimes called "pumped") systems. Both typically include an auxiliary energy source (electric heating element or connection to a gas or fuel oil central heating system) that is activated when the water in the tank falls below a minimum temperature setting, ensuring that hot water is always available. The combination of solar water heating and back-up heat from a wood stove chimney[16] can enable a hot water system to work all year round in cooler climates, without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity.

When a solar water heating and hot-water central heating system are used together, solar heat will either be concentrated in a pre-heating tank that feeds into the tank heated by the central heating, or the solar heat exchanger will replace the lower heating element and the upper element will remain to provide for supplemental heat. However, the primary need for central heating is at night and in winter when solar gain is lower. Therefore, solar water heating for washing and bathing is often a better application than central heating because supply and demand are better matched. In many climates, a solar hot water system can provide up to 85% of domestic hot water energy. This can include domestic non-electric concentrating solar thermal systems. In many northern European countries, combined hot water and space heating systems (solar combisystems) are used to provide 15 to 25% of home heating energy. When combined with storage, large scale solar heating can provide 50-97% of annual heat consumption for district heating.[17][18]

Heat transfer

Direct



Direct systems: (A) Passive CHS system with tank above collector. (B) Active system with pump and controller driven by a photovoltaic panel.

Direct or *open loop* systems circulate potable water through the collectors. They are relatively cheap. Drawbacks include:

- They offer little or no overheat protection unless they have a heat export pump.
- They offer little or no freeze protection, unless the collectors are freeze-tolerant.
- Collectors accumulate scale in hard water areas, unless an ion-exchange softener is used.

The advent of freeze-tolerant designs expanded the market for SWH to colder climates. In freezing conditions, earlier models were damaged when the water turned to ice, rupturing one or more components.

Indirect

Indirect or *closed loop* systems use a heat exchanger to transfer heat from the "heat-transfer fluid" (HTF) fluid to the potable water. The most common HTF is an antifreeze/water mix that typically uses non-toxic propylene glycol. After heating in the panels, the HTF travels to the heat exchanger, where its heat is transferred to the potable water. Indirect systems offer freeze protection and typically overheat protection.

Propulsion

Passive

Passive systems rely on heat-driven convection or heat pipes to circulate the working fluid. Passive systems cost less and require low or no maintenance, but are less efficient. Overheating and freezing are major concerns.

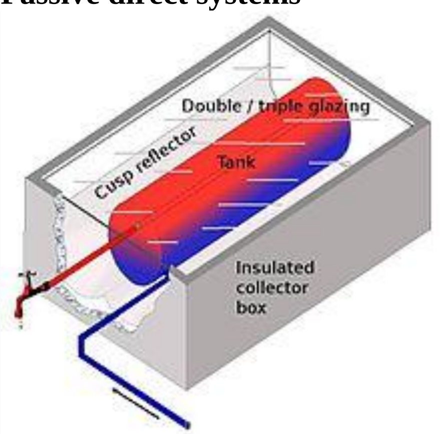
Active

Active systems use one or more pumps to circulate water and/or heating fluid. This permits a much wider range of system configurations.

Pumped systems are more expensive to purchase and to operate. However, they operate at higher efficiency can be more easily controlled.

Active systems have controllers with features such as interaction with a backup electric or gas-driven water heater, calculation and logging of the energy saved, safety functions, remote access and informative displays.

Passive direct systems



An integrated collector storage (ICS) system

An *integrated collector storage* (ICS or Batch Heater) system uses a tank that acts as both storage and collector. Batch heaters are thin rectilinear tanks with a glass side facing the sun at noon. They are simple and less costly than plate and tube collectors, but they may require bracing if installed on a roof (to support 400–700 lb (180–320 kg) lbs of water), suffer from significant heat loss at night since the side facing the sun is largely uninsulated and are only suitable in moderate climates.

A *convection heat storage unit* (CHS) system is similar to an ICS system, except the storage tank and collector are physically separated and transfer between the two is driven by convection. CHS systems typically use standard flat-plate type or evacuated tube collectors. The storage tank must be located above the collectors for convection to work properly. The main benefit of CHS systems over ICS systems is that heat loss is largely avoided since the storage tank can be fully insulated. Since the panels are located below the storage tank, heat loss does not cause convection, as the cold water stays at the lowest part of the system.

Active indirect systems

Pressurized antifreeze systems use a mix of antifreeze (almost always non-toxic propylene glycol) and water mix for HTF in order to prevent freeze damage.

Though effective at preventing freeze damage, antifreeze systems have drawbacks:

- If the HTF gets too hot the glycol degrades into acid and then provides no freeze protection and begins to dissolve the solar loop's components.
- Systems without drainback tanks must circulate the HTF – regardless of the temperature of the storage tank – to prevent the HTF from degrading. Excessive temperatures in the tank cause increased scale and sediment build-up, possible severe burns if a tempering valve is not installed, and if used for storage, possible thermostat failure.
- The glycol/water HTF must be replaced every 3–8 years, depending on the temperatures it has experienced.
- Some jurisdictions require more-expensive, double-walled heat exchangers even though propylene glycol is non-toxic.
- Even though the HTF contains glycol to prevent freezing, it circulates hot water from the storage tank into the collectors at low temperatures (e.g. below 40 °F (4 °C)), causing substantial heat loss.

A *drainback system* is an active indirect system where the HTF (usually pure water) circulates through the collector, driven by a pump. The collector piping is not pressurized and includes an open drainback reservoir that is contained in conditioned or semi-conditioned space. The HTF remains in the drainback reseervoir unless the pump is operating and returns there (emptying the collector) when the pump is switched off. The collector system, including piping, must drain via gravity into the drainback tank. Drainback systems are not subject to freezing or overheating. The pump operates only when appropriate for heat collection, but not to protect the HTF, increasing efficiency and reducing pumping costs.[19]

Do-it-yourself (DIY)

Plans for solar water heating systems are available on the Internet.[20] DIY SWH systems are usually cheaper than commercial ones, and they are used both in the developed and developing world.[21]

Comparison

Characteristic	ICS (Batch)	Thermosiphon	Active direct	Active indirect	Drainback	Bubble Pump
Low profile-unobtrusive			✓	✓	✓	✓
Lightweight collector			✓	✓	✓	✓
Survives freezing weather			✓	✓	✓	✓
Low maintenance	✓	✓	✓		✓	✓
Simple: no ancillary control	✓	✓				✓
Retrofit potential to existing store			✓	✓	✓	✓
Space saving: no extra storage tank	✓	✓				
Comparison of SWH systems. Source: *Solar Water Heating Basics—homepower.com*'[22]						

Components

Collector

Solar thermal collectors capture and retain heat from the sun and use it to heat a liquid.[23] Two important physical principles govern the technology of solar thermal collectors:

- Any hot object ultimately returns to thermal equilibrium with its environment, due to heat loss from conduction, convection and radiation.[24] Efficiency (the proportion of heat energy retained for a predefined time period) is directly related to heat loss from the collector surface. Convection and radiation are the most important sources of heat loss. Thermal insulation is used to slow heat loss from a hot object. This follows the Second law of thermodynamics (the 'equilibrium effect').
- Heat is lost more rapidly if the temperature difference between a hot object and its environment is larger. Heat loss is predominantly governed by the thermal gradient between the collector surface and the ambient temperatures. Conduction, convection and radiation all occur more rapidly over large thermal gradients[24] (the delta-*t* effect).

Flat-plate solar thermal collector, viewed from roof-level

Flat plate

Flat plate collectors are an extension of the idea to place a collector in an 'oven'-like box with glass directly facing the Sun.[1] Most flat plate collectors have two horizontal pipes at the top and bottom, called headers, and many smaller vertical pipes connecting them, called risers. The risers are welded (or similarly connected) to thin absorber fins. Heat-transfer fluid (water or water/antifreeze mix) is pumped from the hot water storage tank or heat exchanger into the collectors' bottom header, and it travels up the risers, collecting heat from the absorber fins, and then exits the collector out of the top header. Serpentine flat plate collectors differ slightly from this "harp" design, and instead use a single pipe that travels up and down the collector. However, since they cannot be properly drained of water, serpentine flat plate collectors cannot be used in drainback systems.

The type of glass used in flat plate collectors is almost always low-iron, tempered glass. Such glass can withstand significant hail without breaking, which is one of the reasons that flat-plate collectors are considered the most durable collector type.

Unglazed or formed collectors are similar to flat-plate collectors, except they are not thermally insulated nor physically protected by a glass panel. Consequently, these types of collectors are much less efficient. For pool heating applications, the water to be heated is often colder than the ambient roof temperature, at which point the lack of thermal insulation allows additional heat to be drawn from the surrounding environment.

Evacuated tube

Evacuated tube solar water heater on a roof

Evacuated tube collectors (ETC) are a way to reduce the heat loss,[1] inherent in flat plates. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes.[26] Since two flat glass sheets are generally not strong enough to withstand a vacuum, the vacuum is created between two concentric tubes. Typically, the water piping in an ETC is therefore surrounded by two concentric tubes of glass separated by a vacuum that admits heat from the sun (to heat the pipe) but that limits heat loss. The inner tube is coated with a thermal absorber.[27] Vacuum life varies from collector to collector, from 5 years to 15 years.

Flat plate collectors are generally more efficient than ETC in full sunshine conditions. However, the energy output of flat plate collectors is reduced slightly more than ETCs in cloudy or extremely cold conditions.[1] Most ETCs are made out of annealed glass, which is susceptible to hail, failing given roughly golf ball -sized particles. ETCs made from "coke glass," which has a green tint, are stronger and less likely to lose their vacuum, but efficiency is slightly reduced due to reduced transparency. ETCs can gather energy from the sun all day long at low angles due to their tubular shape.[28]

Pump

PV pump

One way to power an active system is via a photovoltaic (PV) panel. To ensure proper pump performance and longevity, the (DC) pump and PV panel must be suitably matched. Although a PV-powered pump does not operate at night, the controller must ensure that the pump does not operate when the sun is out but the collector water is not hot enough.

PV pumps offer the following advantages:

- Simpler/cheaper installation and maintenance
- Excess PV output can be used for household electricity use or put back into the grid.
- Can dehumidify living space.[29]
- Can operate during a power outage.
- Avoids the carbon consumption from using grid-powered pumps.

Bubble pump

The bubble separator of a bubble-pump system

A bubble pump (also known as geyser pump) is suitable for flat panel as well as vacuum tube systems. In a bubble pump system, the closed HTF circuit is under reduced pressure, which causes the liquid to boil at low temperature as the sun heats it. The steam bubbles form a geyser, causing an upward flow. The bubbles are separated from the hot fluid and condensed at the highest point in the circuit, after which the fluid flows downward toward the heat exchanger caused by the difference in fluid levels.[30][31][32] The HTF typically arrives at the heat exchanger at 70 °C and returns to the circulating pump at 50 °C. Pumping typically starts at about 50 °C and increases as the sun rises until equilibrium is reached.

Controller

A *differential controller*senses temperature differences between water leaving the solar collector and the water in the storage tank near the heat exchanger. The controller starts the pump when the water in the collector is sufficiently about 8–10 °C warmer than the water in the tank, and stops it when the temperature difference reaches 3–5 °C. This ensures that stored water always gains heat when the pump operates and prevents the pump from excessive cycling on and off. (In direct systems the pump can be triggered with a difference around 4 °C because they have no heat exchanger.)

Tank

The simplest collector is a water-filled metal tank in a sunny place. The sun heats the tank. This was how the first systems worked.[4] This setup would be inefficient due to the equilibrium effect: as soon as heating of the tank and water begins, the heat gained is lost to the environment and this continues until the water in the tank reaches ambient temperature. The challenge is to limit the heat loss.

- The storage tank can be situated lower than the collectors, allowing increased freedom in system design and allowing pre-existing storage tanks to be used.
- The storage tank can be hidden from view.
- The storage tank can be placed in conditioned or semi-conditioned space, reducing heat loss.
- Drainback tanks can be used.

Insulated tank

ICS or batch collectors reduce heat loss by thermally insulating the tank.[1][33] This is achieved by encasing the tank in a glass-topped box that allows heat from the sun to reach the water tank.[34] The other walls of the box are thermally insulated, reducing convection and radiation.[35] The box can also have a reflective surface on the inside. This reflects heat lost from the tank back towards the tank. In a simple way one could consider an ICS solar water heater as a water tank that has been enclosed in a type of 'oven' that retains heat from the sun as well as heat of the water in the tank. Using a box does not eliminate heat loss from the tank to the environment, but it largely reduces this loss.

Standard ICS collectors have a characteristic that strongly limits the efficiency of the collector: a small surface-to-volume ratio.[36] Since the amount of heat that a tank can absorb from the sun is largely dependent on the surface of the tank directly exposed to the sun, it follows that the surface size defines the degree to which the water can be heated by the sun. Cylindrical objects such as the tank in an ICS collector have an inherently small surface-to-volume ratio. Collectors attempt to increase this ratio for efficient warming of the water. Variations on this basic design include collectors that combine smaller water containers and evacuated glass tube technology, a type of ICS system known as an Evacuated Tube Batch (ETB) collector.[1]

Applications

Evacuated tube

ETSCs can be more useful than other solar collectors during winter season. ETCs can be used for heating and cooling purposes in industries like pharmaceutical and drug, paper, leather and textile and also for residential houses, hospitals nursing home, hotels swimming pool etc.

An ETC can operate at a range of temperatures from medium to high for solar hot water, swimming pool, air conditioning and solar cooker.

ETCs higher temperature (up to 200 °C (392 °F)) making them suitable for industrial applications such as steam generation, heat engine and solar drying.

Swimming pools

Floating pool covering systems and separate STCs are used for pool heating.

Pool covering systems, whether solid sheets or floating disks, act as insulation and reduce heat loss. Much heat loss occurs through evaporation, and using a cover slows evaporation.

STCs for nonpotable pool water use are often made of plastic. Pool water is mildly corrosive due to chlorine. Water is circulated through the panels using the existing pool filter or supplemental pump. In mild environments, unglazed plastic collectors are more efficient as a direct system. In cold or windy environments evacuated tubes or flat plates in an indirect configuration are used in conjunction with a heat exchanger. This reduces corrosion. A fairly simple differential temperature controller is used to direct the water to the panels or heat exchanger either by turning a valve or operating the pump. Once the pool water has reached the required temperature, a diverter valve is used to return water directly to the pool without heating.[37] Many systems are configured as drainback systems where the water drains into the pool when the water pump is switched off.

The collector panels are usually mounted on a nearby roof, or ground-mounted on a tilted rack. Due to the low temperature difference between the air and the water, the panels are often formed collectors or unglazed flat plate collectors. A simple rule-of-thumb for the required panel area needed is 50% of the pool's surface area.[37] This is for areas where pools are used in the summer season only. Adding solar collectors to a conventional outdoor pool, in a cold climate, can typically extend the pool's comfortable usage by months and more if an insulating pool cover is used.[25] An active solar energy system analysis program may be used to optimize the solar pool heating system before it is built.

Energy production

A laundromat in California with panels on the roof providing hot washing water.

The amount of heat delivered by a solar water heating system depends primarily on the amount of heat delivered by the sun at a particular place (insolation). In the tropics insolation can be relatively high, e.g. 7 kWh/m2 per day, versus e.g., 3.2 kWh/m2 per day in temperate areas. Even at the same latitude average insolation can vary a great deal from location to location due to differences in local weather patterns and the amount of overcast. Calculators are available for estimating insolation at a site.

Below is a table that gives a rough indication of the specifications and energy that could be expected from a solar water heating system involving some 2 m^2 of absorber area of the collector, demonstrating two evacuated tube and three flat plate solar water heating systems. Certification information or figures calculated from those data are used. The bottom two rows give estimates for daily energy production (kWh/day) for a tropical and a temperate scenario. These estimates are for heating water to 50 °C above ambient temperature.

With most solar water heating systems, the energy output scales linearly with the collector surface area.

Daily energy production (kW_{th}.h) of five solar thermal systems. The evac tube systems used below both have 20 tubes

Technology	Flat plate	Flat plate	Flat plate	ETC	ETC
Configuration	Direct active	Thermosiphon	Indirect active	Indirect active	Direct active

Overall size (m^2)	2.49	1.98	1.87	2.85	2.97
Absorber size (m^2)	2.21	1.98	1.72	2.85	2.96
Maximum efficiency	0.68	0.74	0.61	0.57	0.46
Energy production (kWh/day): *– Insolation 3.2 kWh/m^2/day (temperate)* *– e.g. Zurich, Switzerland*	5.3	3.9	3.3	4.8	4.0
– Insolation 6.5 kWh/m^2/day (tropical) *– e.g. Phoenix, USA*	11.2	8.8	7.1	9.9	8.4

The figures are fairly similar between the above collectors, yielding some 4 kWh/day in a temperate climate and some 8 kWh/day in a tropical climate when using a collector with a 2 m^2 absorber. In the temperate scenario this is sufficient to heat 200 litres of water by some 17 °C. In the tropical scenario the equivalent heating would be by some 33 °C. Many thermosiphon systems have comparable energy output to equivalent active systems. The efficiency of evacuated tube collectors is somewhat lower than for flat plate collectors because the absorbers are narrower than the tubes and the tubes have space between them, resulting in a significantly larger percentage of inactive overall collector area. Some methods of comparison[42] calculate the efficiency of evacuated tube collectors based on the actual absorber area and not on the 'space occupied as has been done in the above table. Efficiency is reduced at higher temperatures.

Costs

In sunny, warm locations, where freeze protection is not necessary, an ICS (batch type) solar water heater can be cost effective.[35] In higher latitudes, design requirements for cold weather add to system complexity and cost. This increases *initial* costs, but not life-cycle costs. The biggest single consideration is therefore the large initial financial outlay of solar water heating systems.[43] Offsetting this expense can take years.[44] The payback period is longer in temperate environments.[45] Since solar energy is free, operating costs are small. At higher latitudes, solar heaters may be less effective due to lower insolation, possibly requiring larger and/or dual-heating systems.[45] In some countries government incentives can be significant.

Cost factors (positive and negative) include:

- Price of solar water heater (more complex systems are more expensive)
- Efficiency
- Installation cost
- Electricity used for pumping
- Price of water heating fuel (e.g. gas or electricity) saved per kWh
- Amount of water heating fuel used
- Initial and/or recurring government subsidy
- Maintenance cost (e.g. antifreeze or pump replacements)
- Savings in maintenance of conventional (electric/gas/oil) water heating system

Payback times can vary greatly due to regional sun, extra cost due to frost protection needs of collectors, household hot water use etc. For instance in central and southern Florida the payback period could easily be 7 years or less rather than the 12.6 years indicated on the chart for the U.S

Costs and payback periods for residential SWH systems with savings of 200 kWh/month (using 2010 data), ex maintenance costs, subsidies and installation costs

Country	Currency	System cost	Subsidy(%)	Effective cost	Electricity cost/kWh	Electricity savings/month	Payback period(y)
Brazil	BRL	2500[47]	0	2500	0.25	50	4.2
South Africa	ZAR	14000	15[48]	11900	0.9	180	5.5
Australia	AUD	5000[49]	40[50]	3000	0.18[51]	36	6.9
Belgium	EUR	4000[52]	50[53]	2000	0.1[54]	20	8.3
United	USD	5000[55	30[56]	3500	0.1158[57]	23.16	12.6

States		]					
United Kingdom	GBP	4800[58]	0	4800	0.11[59]	22	18.2

The payback period is shorter given greater insolation. However, even in temperate areas, solar water heating is cost effective. The payback period for photovoltaic systems has historically been much longer.[45] Costs and payback period are shorter if no complementary/backup system is required.[44] thus extending the payback period of such a system.

Subsidies

Australia operates a system of Renewable Energy Credits, based on national renewable energy targets.[50]

Energy footprint and life cycle assessment

Energy footprint

The source of electricity in an active SWH system determines the extent to which a system contributes to atmospheric carbon during operation. Active solar thermal systems that use mains electricity to pump the fluid through the panels are called 'low carbon solar'. In most systems the pumping reduces the energy savings by about 8% and the carbon savings of the solar by about 20%.[60] However, low power pumps operate with 1-20W.[61][62] Assuming a solar collector panel delivering 4 kWh/day and a pump running intermittently from mains electricity for a total of 6 hours during a 12-hour sunny day, the potentially negative effect of such a pump can be reduced to about 3% of the heat produced.

However, PV-powered active solar thermal systems typically use a 5–30 W PV panel and a small, low power diaphragm pump or centrifugal pump to circulate the water. This reduces the operational carbon and energy footprint.

Alternative non-electrical pumping systems may employ thermal expansion and phase changes of liquids and gases.

Life Cycle Energy Assessment

Recognised standards can be used to deliver robust and quantitative life cycle assessments (LCA). LCA considers the financial and environmental costs of acquisition of raw materials, manufacturing, transport, using, servicing and disposal of the equipment. Elements include:

- Financial costs and gains
- Energy consumption
- CO_2 and other emissions

In terms of energy consumption, some 60% goes into the tank, with 30% towards the collector[63] (thermosiphon flat plate in this case). In Italy,[64] some 11 giga-joules of electricity are used in producing SWH equipment, with about 35% goes toward the tank, with another 35% towards the collector. The main energy-related impact is emissions. The energy used in manufacturing is recovered within the first 2–3 years of use (in southern Europe).

By contrast the energy payback time in the UK is reported as only 2 years. This figure was for a direct system, retrofitted to an existing water store, PV pumped, freeze tolerant and of 2.8 sqm aperture. For comparison, a PV installation took around 5 years to reach energy payback, according to the same comparative study.[65]

In terms of CO_2 emissions, a large fraction of the emissions saved is dependent on the degree to which gas or electricity is used to supplement the sun. Using the Eco-indicator 99 points system as a yardstick (i.e. the yearly environmental load of an average European inhabitant) in Greece,[63] a purely gas-driven system may have fewer emissions than a solar system. This calculation assumes that the solar system produces about half of the hot water requirements of a household.

A test system in Italy produced about 700 kg of CO_2, considering all the components of manufacture, use and disposal. Maintenance was identified as an emissions-costly activity when the heat transfer fluid (glycol-based) was replaced. However, the emissions cost was recovered within about two years of use of the equipment.[64]

In Australia, life cycle emissions were also recovered. The tested SWH system had about 20% of the impact of an electrical water heater and half that of a gas water heater.[44]

Analysing their lower impact retrofit freeze-tolerant solar water heating system, Allen *et al.* (qv) reported a production CO_2 impact of 337 kg, which is around half the environmental impact reported in the Ardente *et al.* (qv) study.

System specification and installation

- Most SWH installations require backup heating.
- The amount of hot water consumed each day must be replaced and heated. In a solar-only system, consuming a high fraction of the water in the reservoir implies significant reservoir temperature variations. The larger the reservoir the smaller the daily temperature variation.
- SWH systems offer significant scale economies in collector and tank costs.[63] Thus the most economically efficient scale meets 100% of the heating needs of the application.
- Direct systems (and some indirect systems using heat exchangers) can be retrofitted to existing stores.
- Equipment components must be insulated to achieve full system benefits. The installation of efficient insulation significantly reduces heat loss.
- The most efficient PV pumps start slowly in low light levels, so they may cause a small amount of unwanted circulation while the collector is cold. The controller must prevent stored hot water from this cooling effect.
- Evacuated tube collector arrays can be adjusted by removing/adding tubes or their heat pipes, allowing customization during/after installation.
- Above 45 degrees latitude, roof mounted sun-facing collectors tend to outproduce wall-mounted collectors. However, arrays of wall-mounted steep collectors can sometimes produce more useful energy because gains in used energy in winter can offset the loss of unused (excess) energy in summer.

Standards

Europe

- EN 806: Specifications for installations inside buildings conveying water for human consumption. General.
- EN 1717: Protection against pollution of potable water in water installations and general requerements of devices to prevent pollution by backflow.
- EN 60335: Specification for safety of household and similar electrical appliances. (2–21)
- UNE 94002:2005 Thermal solar systems for domestic hot water production. Calculation method for heat demand.

United States

- OG-300: OG-300 Certification of Solar Water Heating Systems.[66]

Canada

- CAN/CSA-F378 Series 11 (Solar collectors)
- CAN/CSA-F379 Series 09 (Packaged solar domestic hot water systems)
- SRCC Standard 600 (Minimum standard for solar thermal concentrating collectors)

Australia

- Renewable Energy (Electricity) Act 2000
- Renewable Energy (Electricity) (Large-scale Generation Shortfall Charge) Act 2000
- Renewable Energy (Electricity) (Small-scale Technology Shortfall Charge) Act 2010
- Renewable Energy (Electricity) Regulations 2001
- Renewable Energy (Electricity) Regulations 2001 - STC Calculation Methodology for Solar Water Heaters and Air Source Heat Pump Water Heaters
- Renewable Energy (Electricity) Amendment (Transitional Provision) Regulations 2010
- Renewable Energy (Electricity) Amendment (Transitional Provisions) Regulations 2009

All relevant participants of the Large-scale Renewable Energy Target and Small-scale Renewable Energy Scheme must comply

UNIT 3

WIND ENERGY

Wind energy

Wind energy is a form of solar **energy**. **Wind energy**(or **wind power**) describes the process by which **wind** is used to generate electricity. **Wind** turbines convert the kinetic **energy** in the **wind** into mechanical **power**. A generator can convert mechanical **power** into electricity.

Energy from wind

Wind is a form of **solar energy**. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern **wind turbines**, can be used to generate **electricity**.

How Wind Power Is Generated

The terms "**wind energy**" or "**wind power**" describe the process by which the wind is used to generate **mechanical power or electricity**. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

Wind Turbines

Wind turbines, like aircraft propeller blades, turn in the moving air and power an **electric generator** that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

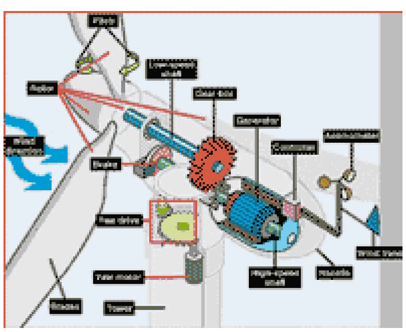
Wind Turbine Types

Modern wind turbines fall into two basic groups; the **horizontal-axis** variety, like the traditional farm windmills used for pumping water, and the **vertical-axis** design, like the eggbeater-style Darrieus model, named after its French inventor. Most large modern wind turbines are horizontal-axis turbines.

Turbine Components

Horizontal turbine components include:

- **blade** or **rotor**, which converts the energy in the wind to rotational shaft energy;
- a **drive train**, usually including a gearbox and a generator;
- a **tower** that supports the rotor and drive train; and
- other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.



Turbine Configurations

Wind turbines are often grouped together into a single wind power plant, also known as a **wind farm**, and generate bulk electrical power. Electricity from these turbines is fed into a utility grid and distributed to customers, just as with conventional power plants.

See Wind Energy Photos page for wind farm photographs.

Wind Turbine Size and Power Ratings

Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine has blades that span more than the length of a football field, stands 20 building stories high, and produces enough electricity to power 1,400 homes. A small home-sized wind machine has rotors between 8 and 25 feet in diameter and stands upwards of 30 feet and can supply the power needs of an all-electric home or small business. **Utility-scale turbines** range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

See Wind Energy Photos page for wind turbine photographs.

Wind Energy Resources in the United States

Wind energy is very abundant in many parts of the United States. Wind resources are characterized by **wind-power density classes**, ranging from class 1 (the lowest) to class 7 (the highest). Good wind resources (e.g., class 3 and above, which have an average annual wind speed of at least 13 miles per hour) are found in many locations (see United States Wind Energy Resource Map). Wind speed is a critical feature of wind resources, because the energy in wind is proportional to the **cube** of the wind speed. In other words, a stronger wind means a lot more power.

Advantages and Disadvantages of Wind-Generated Electricity

A Renewable Non-Polluting Resource

Wind energy is a **free, renewable resource**, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of **clean, non-polluting, electricity**. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. According to the U.S. Department of Energy, in 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality.

Cost Issues

Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a **higher initial investment** than fossil-fueled generators. Roughly 80% of the cost is the machinery, with the balance being site preparation and installation. If wind generating systems are compared with fossil-fueled systems on a "life-cycle" cost basis (counting fuel and operating expenses for the life of the generator), however, wind costs are much more competitive with other generating technologies because there is no fuel to purchase and minimal operating expenses.

Environmental Concerns

Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, there is some concern over the **noise** produced by the rotor blades, **aesthetic (visual) impacts**, and birds and bats having been killed (**avian/bat mortality**) by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

Supply and Transport Issues

The major challenge to using wind as a source of power is that it is **intermittent** and does not always blow when electricity is needed. Wind cannot be stored (although wind-generated electricity can be stored, if batteries are used), and not all winds can be harnessed to meet the timing of electricity demands. Further, good wind sites are often located in **remote locations** far from areas of electric power demand (such as cities). Finally, wind resource development may compete with other uses for the land, and those **alternative uses** may be more highly valued than electricity generation. However, wind turbines can be located on land that is also used for grazing or even farming.

For More Information

Much additional information on wind energy science and technology and wind energy development issues is available through the Web. Visit the Wind Energy Links page to access sites with more information. In particular, the DOE Wind Energy Technologies page has good information on wind energy basics, and is the source for much of the information presented here. The American Wind Energy Association web site has an excellent FAQ page with information about wind technology, and the The Danish Wind Industry Association web site has extensive information about wind energy and technology, including a 28-minute video introducing wind technology.

General theory of wind mill

Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land.[2] The net effects on the environment are far less problematic than those of nonrenewable power sources.

Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electric power, competitive with or in many places cheaper than coal or gas plants.[3][4][5] Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electric power to isolated off-grid locations.[6]

Wind power gives variable power which is very consistent from year to year but which has significant variation over shorter time scales. It is therefore used in conjunction with other electric power sources to give a reliable supply. As the proportion of wind power in a region increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur.[7][8] Power management techniques such as having excess capacity, geographically distributed turbines, dispatchable backingsources, sufficient hydroelectric power, exporting and importing power to neighboring areas, or reducing demand when wind production is low, can in many cases overcome these problems.[9][10] In addition, weather forecasting permits the electric power network to be readied for the predictable variations in production that occur.[11][12][13]

As of 2015, Denmark generates 40% of its electric power from wind,[14][15] and at least 83 other countries around the world are using wind power to supply their electric power grids.[16] In 2014, global wind power capacity expanded 16% to 369,553 MW.[17] Yearly wind energy production is also growing rapidly and has reached around 4% of worldwide electric power usage,[18] 11.4% in the EU.[19]

Wind power has been used as long as humans have put sails into the wind. For more than two millennia wind-powered machines have ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. Wind-powered pumps drained the polders of the Netherlands, and in arid regions such as the American mid-west or the Australian outback, wind pumps provided water for live stock and steam engines.

The first windmill used for the production of electric power was built in Scotland in July 1887 by Prof James Blyth of Anderson's College, Glasgow (the precursor of Strathclyde University).[20] Blyth's 10 metres (33 ft) high, cloth-sailed wind turbine was installed in the garden of his holiday cottage at Marykirk in Kincardineshire and was used to charge accumulators developed by the Frenchman Camille Alphonse Faure, to power the lighting in the cottage,[20] thus making it the first house in the world to have its electric power supplied by wind power.[21] Blyth offered the surplus electric power to the people of Marykirk for lighting the main street, however, they turned down the offer as they thought electric power was "the work of the devil."[20] Although he later built a wind turbine to supply emergency power to the local Lunatic Asylum, Infirmary and Dispensary of Montrose the invention never really caught on as the technology was not considered to be economically viable.[20]

Across the Atlantic, in Cleveland, Ohio a larger and heavily engineered machine was designed and constructed in the winter of 1887–1888 by Charles F. Brush,[22] this was built by his engineering company at his home and operated from 1886 until 1900.[23] The Brush wind turbine had a rotor 17 metres (56 ft) in diameter and was mounted on an 18 metres (59 ft) tower. Although large by today's standards, the machine was only rated at 12 kW. The connected dynamo was used either to charge a bank of batteries or to operate up to 100 incandescent light bulbs, three arc lamps, and various motors in Brush's laboratory.[24]

With the development of electric power, wind power found new applications in lighting buildings remote from centrally-generated power. Throughout the 20th century parallel paths developed small wind stations suitable for farms or residences, and larger utility-scale wind generators that could be connected to electric power grids for remote use of power. Today wind powered generators operate in every size range between tiny stations for battery charging at isolated residences, up to near-gigawatt sized offshore wind farms that provide electric power to national electrical networks

Types of wind mill

www.eia.gov

Horizontal-axis wind turbines (HAWT) have the main **rotor shaft** and electrical generator at the top of a tower, and must be pointed into the wind. **Small turbines** are pointed by a simple**wind vane**, while **large** turbines generally use a wind sensor coupled with a **servo motor**.

Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of when we think of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis.

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

HAWT advantages

- The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.
- High efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

HAWT disadvantages

- Massive tower construction is required to support the heavy blades, gearbox, and generator.
- Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.
- Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.
- Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower).
- HAWTs require an additional yaw control mechanism to turn the blades toward the wind.
- HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.

Cyclic stresses and vibration

When the turbine turns to face the wind, the rotating blades act like a gyroscope. As it pivots, gyroscopic precession tries to twist the turbine into a forward or backward somersault. For each blade on a wind generator's turbine, force is at a minimum when the blade is horizontal and at a maximum when the blade is vertical. This cyclic twisting can quickly fatigue and crack the blade roots, hub and axle of the turbines.

Vertical axis

Verticalaxis wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds.

With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT generally create drag when rotating into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

VAWT subtypes

Darrieus wind turbine

Darrieus wind turbines are commonly called "Eggbeater" turbines, because they look like a giant eggbeater. They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Also, they generally require some external power source, or an additional Savonius rotor, to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area over the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.

Savonius wind turbine

A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers. Because they are a drag type turbine they are less efficient than the common HAWT. Savonius are excellent in areas of turbulent wind and self starting.

VAWT advantages

- No yaw mechanisms is needed.
- A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
- VAWTs have lower wind startup speeds than the typical the HAWTs.
- VAWTs may be built at locations where taller structures are prohibited.
- VAWTs situated close to the ground can take advantage of locations where rooftops, mesas, hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT disadvantages

- Most VAWTs have a average decreased efficiency from a common HAWT, mainly because of the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.
- Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.
- Because VAWTs are not commonly deployed due mainly to the serious disadvantages mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

Performance of wind machine

$$\eta_0 = \frac{\text{Useful Output Power}}{\text{Wind Power Input}} = \eta_A \cdot \eta_G \cdot \eta_C \cdot \eta_{Gen}$$

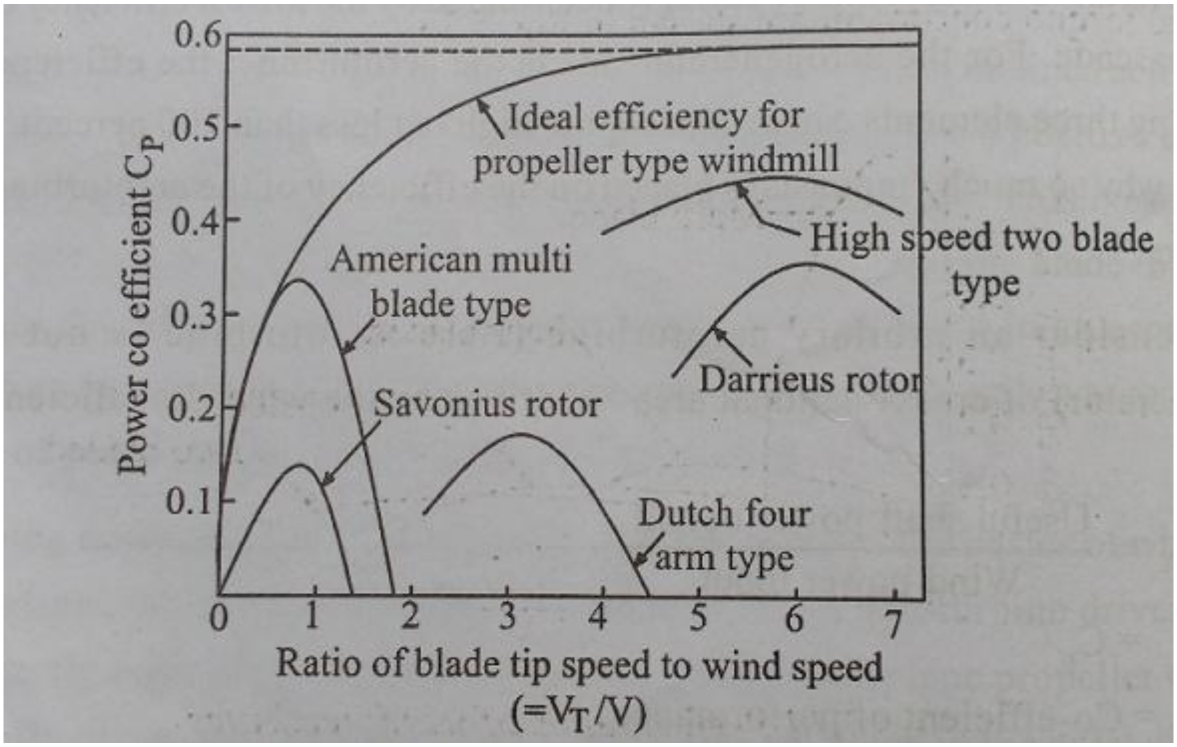
Where,

η_A → Efficiency of the aeroturbine,

η_G → Efficiency of gearing,

η_C → Efficiency of the mechanical coupling, and

η_{Gen} → Efficiency of the generator.



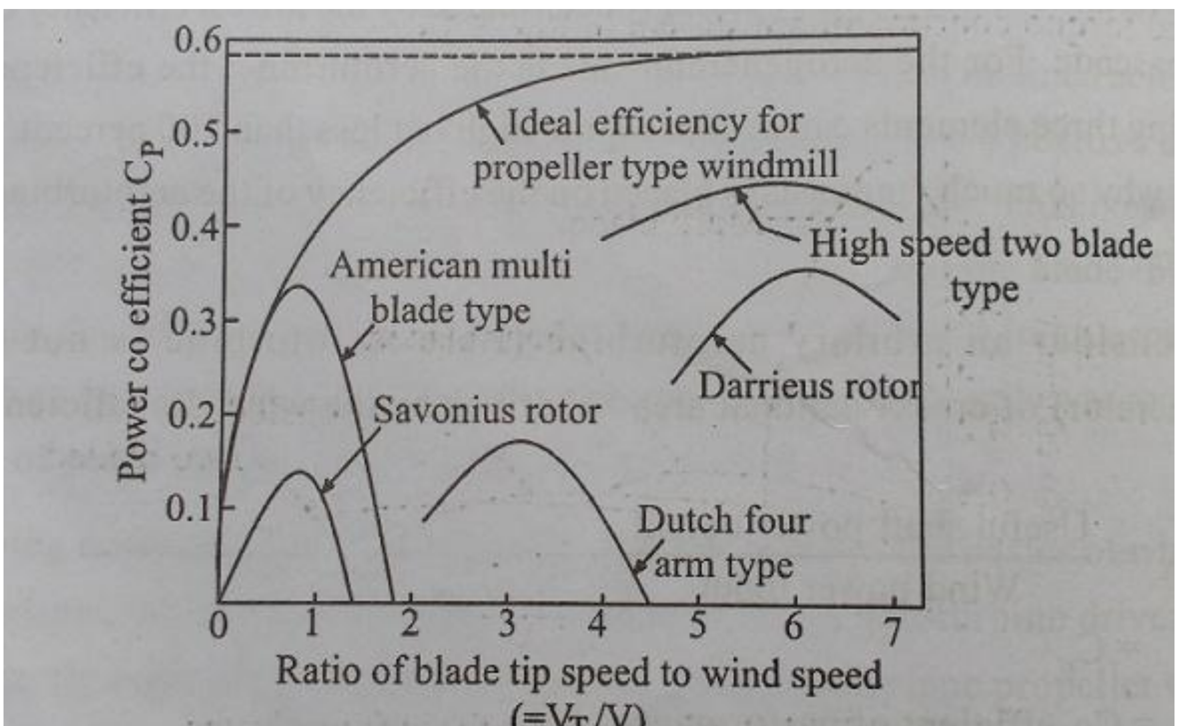


Fig. 5.13 Typical performance of wind machines

Thus the coefficient of performance of an aeroturbine is the fraction of power in the wind through the swept area which is converted into useful mechanical shaft power. The coefficient of performance is widely utilized throughout the recent wind research. We have seen that C_p for horizontal axis wind machine has theoretical maximum value = 0.593.

This theoretical efficiency limitation on a wind energy conversion system is loosely analogical similar to the thermodynamic carnot efficiency limitation on a conventional thermal power plant.

We know that the convertible power of energy is proportional to the cube of the wind speed. Thus if the wind speed decreases by 20%, the power output is reduced by almost 50%. The wind speed may very considerable from day to day and from season to season. The efficiency of a wind generator depends on the design of an wind rotor and rotational speed, expressed as the ratio of blade tip speed to wind speed i.e., V_T/V (is called as TSR – Tip Speed Ratio), if n is the rotation frequency, ie., rotation per second, if a rotor diameter D meters, the tip speed is πnD m/sec.

The dependence of the power coefficient on the tip speed ratio (TSR) for some common rotor types is indicated in Fig. 5.13. It is seen that the two-bladed propeller type of rotor can attain a much higher power coefficient (i.e., it is more efficient) than the American multi-blade wind mill and the classical Dutch four-bladed windmill. In practice two-bladed propeller (horizontal axis) rotor are ound to attain a maximum power coefficient of 0.40 to 0.45 at a tip speed ratio in the range a roughly 6 to 10

Wind power

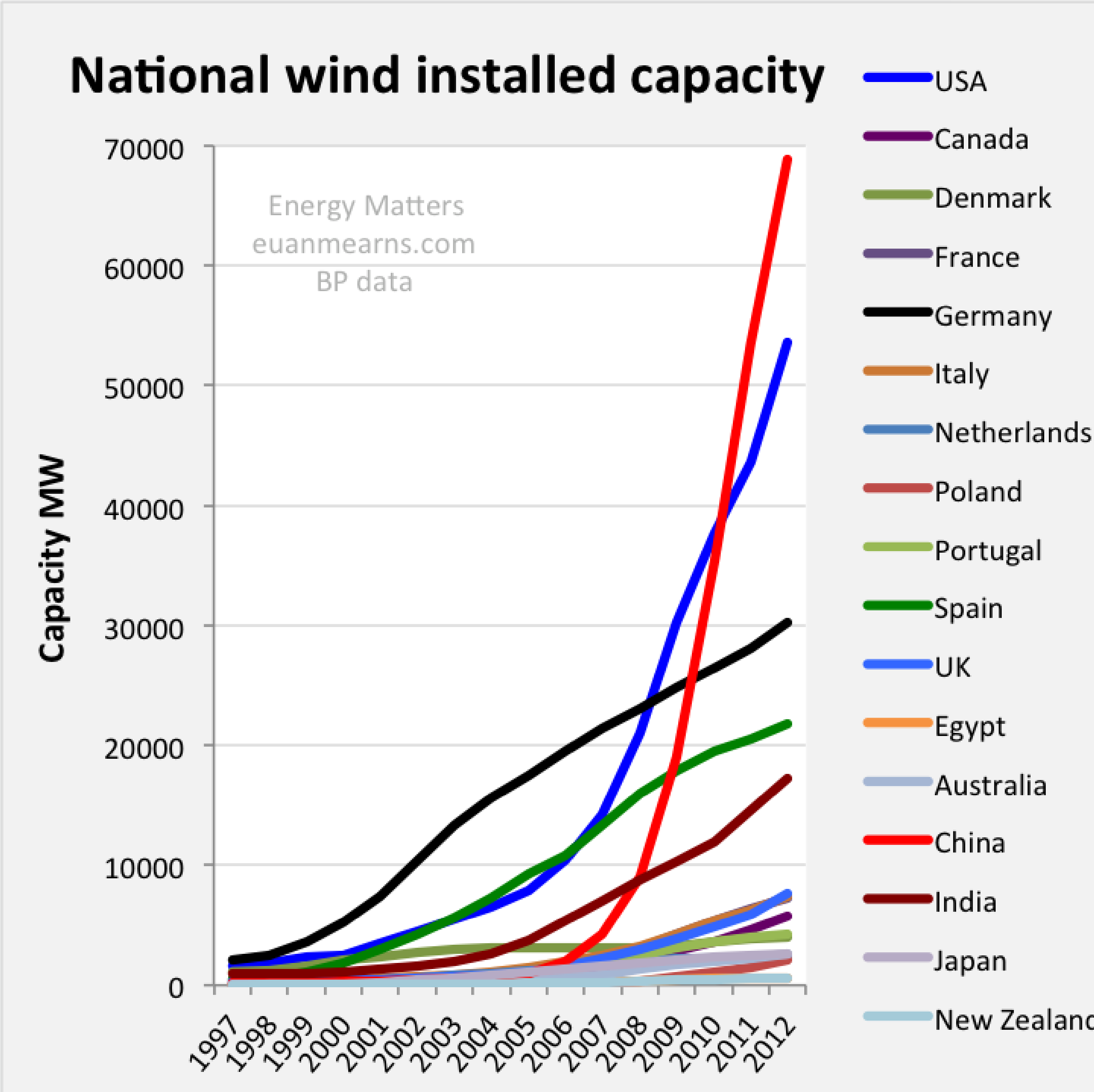
Wind Energy" redirects here. For the academic journal, see Wind Energy (journal).

Wind power stations in Xinji**Wind power** is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land.[2] The net effects on the environment are far less problematic than those of nonrenewable power sources.

Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electric power, competitive with or in many places cheaper than coal or gas plants.[3][4][5] Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electric power to isolated off-grid locations.[6]

Efficiency of wind

If a turbine's best **efficiency** is 40% at a **wind** velocity of 9 meters per second (about 20 mph), it will be 40% only at that **wind** speed. At all other **wind** speeds it will be something worse. That **wind** turbine will generally operate at lower than its best **efficiency**, because **wind** speeds are never constant or average.



National wind installed capacity
Capacity MW
70000
60000
50000
40000
30000
20000
10000
0
Energy Matters
euanmearns.com
BP data
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
USA
Canada
Denmark
France
Germany
Italy
Netherlands
Poland
Portugal
Spain
UK
Egypt
Australia
China
India
Japan
New Zealand

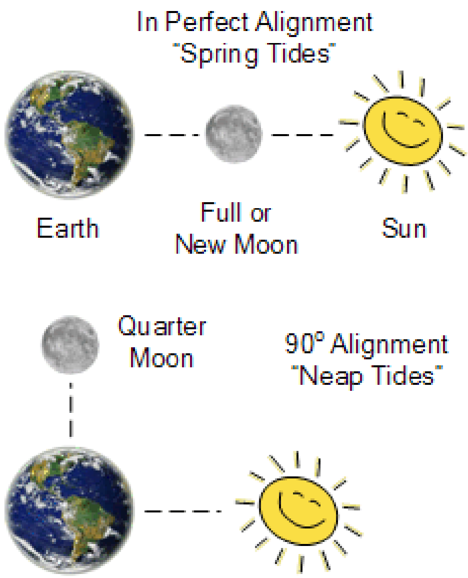
UNIT 4

TIDAL AND GEOTHERMAL ENERGY

Tidal energy from tides and waves

Tidal Energy or **Tidal Power** as it is also called, is another form of hydro power that utilises large amounts of energy within the oceans tides to generate electricity. *Tidal Energy* is an “alternative energy” that can also be classed as a “renewable energy source”, as the Earth uses the gravitational forces of both the moon and the sun everyday to move vast quantities of water around the oceans and seas producing tides.

As the Earth, its Moon and the Sun rotate around each other in space, the gravitational movement of the moon and the sun with respect to the earth, causes millions of gallons of water to flow around the Earth’s oceans creating periodic shifts in these moving bodies of water. These vertical shifts of water are called “tides”.



Alignment of the Moon and Sun on Tides

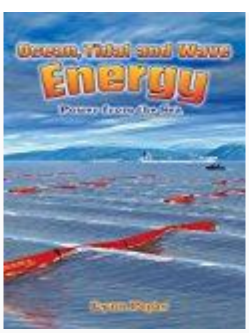
When the earth and the moons gravity lines up with each other, the influences of these two gravitational forces becomes very strong and causes millions of gallons of water to move or flow towards the shore creating a “high tide” condition. Likewise when the earth and the moons gravity are at 90^{o} to each other, the influences of these two gravitational forces is weaker and the water flows away from the shore as the mass of water moves to another location on the earth, creating a “low tide” condition. This ebbing and flowing of the tides happens twice during each period of rotation of the earth with stronger weekly and annual lunar cycles superimposed onto these tides.

When the moon is in perfect alignment with the earth and the sun, the gravitational pull of the moon and sun together becomes much stronger than normal with the high tides becoming very high and the low tides becoming very low during each tidal cycle. Such tides are known as *spring tides* (maximum). These spring tides occur during the full or new moon phase.

The other tidal situation arises during *neap tides* (minimum) when the gravitational pull of the moon and the sun are against each other, thus cancelling their effects. The net result is a smaller pulling action on the sea water creating much smaller differences between the high and low tides thereby producing very weak tides. Neap tides occur during the quarter moon phase. Then spring tides and neap tides produce different amounts of potential energy in the movement of the sea water as their effects differ from the regular high and low sea levels and we can use these tidal changes to produce renewable energy. So we can say that the tides are turning for alternative energy.

So we now know that the constant rotational movement of the earth and the moon with regards to each other causes huge amounts of water to move around the earth as the tides go in and out. These tides are predictable and regular resulting in two high tides and two low tides each day with the level of the oceans constantly moving between a high tide and a low tide, and then back to a high tide again. The time taken for a tidal cycle to happen is about 12 hours and 24 minutes (called the "diurnal cycle") between two consecutive high tides allowing Oceanographers and Meteorologist to accurately predict the ebb and flow of the tides around the oceans many years in advance.

The main big advantage of this is that the tides are therefore perfectly predictable and regular unlike wind energy or solar energy, allowing miles of coastline to be used for tidal energy exploitation and the larger the tidal influence, the greater the movement of the tidal water and therefore the more potential energy that can be harvested for power generation. Therefore **Tidal Energy** can be considered as a *renewable energy source* as the oceans energy is replenished by the sun as well as through tidal influences of the moon and suns gravitational forces.



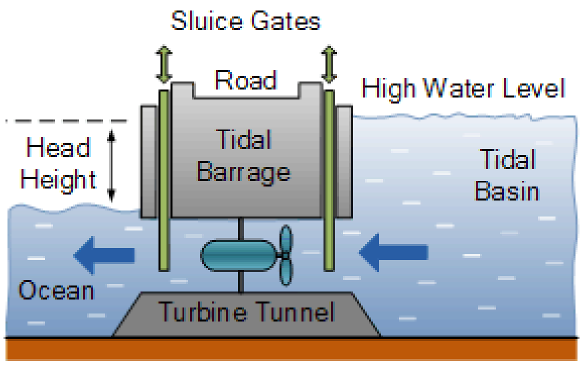
Tidal Energy Generation

Since the position of the earth and the moon with respect to the sun changes throughout the year, we can utilise the potential energy of the water contained in the daily movement of the rising and falling sea levels to generate electricity. The generation of electricity from tides is similar in many ways to hydro-electric generation we looked at in the hydro energy tutorials. The difference this time is that the water flows in and out of the turbines in both directions instead of in just one forward direction.

Tidal energy, just like hydro energy transforms water in motion into a clean energy. The motion of the tidal water, driven by the pull of gravity, contains large amounts of kinetic energy in the form of strong tidal currents called tidal streams. The daily ebbing and flowing, back and forth of the oceans tides along a coastline and into and out of small inlets, bays or coastal basins, is little different to the water flowing down a river or stream.

The movement of the sea water is harnessed in a similar way using waterwheels and turbines to that used to generate hydro electricity. But because the sea water can flow in both directions in a tidal energy system, it can generate power when the water is flowing in and also when it is ebbing out. Therefore, tidal generators are designed to produce power when the rotor blades are turning in either direction. However, the cost of reversible electrical generators are more expensive than single direction generators.

Different Types of Tidal Energy Systems



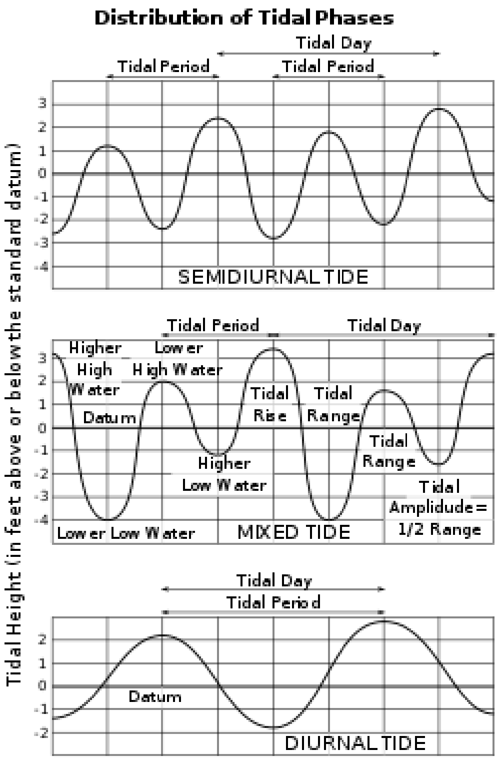
Tidal Barrage – A *Tidal Barrage* is a type of tidal power generation that involves the construction of a fairly low dam wall, known as a “barrage” and hence its name, across the entrance of a tidal inlet or basin creating a tidal reservoir. This dam has a number of underwater tunnels cut into its width allowing sea water to flow through them in a controllable way using “sluice gates”. Fixed within the tunnels are huge water turbine generators that spin as the water rushes past them generating tidal electricity.

Tidal barrages generate electricity using the difference in the vertical height between the incoming high tides and the outgoing low tides. As the tide ebbs and flows, sea water is allowed to flow in or out of the reservoir through a one way underwater tunnel system. This flow of tidal water back and forth causes the water turbine generators located within the tunnels to rotate producing tidal energy with special generators used to produce electricity on both the incoming and the outgoing tides

Workind principle of tidal power plant

Tidal power or **tidal energy** is a form of hydropower that converts the **energy** obtained from **tides** into useful forms of **power**, mainly**electricity**. Although not yet widely used, **tidal**

energy has potential for future **electricity generation**. **Tides** are more predictable than the wind and the sun.



Tide or wave is periodic rise and fall of water level of the sea. Tides occur due to the attraction of sea water by the moon.

Working principle of Tidal power plants

Tide or wave is periodic rise and fall of water level of the sea. Tides occur due to the attraction of sea water by the moon. Tides contain large amount of potential energy which is used for power generation. When the water is above the mean sea level, it is called flood tide. When the water level is below the mean level it is called ebb tide.

Working

The arrangement of this system is shown in figure. The ocean tides rise and fall and water can be stored during the rise period and it can be discharged during fall. A dam is constructed separating the tidal basin from the sea and a difference in water level is obtained between the basin and sea.

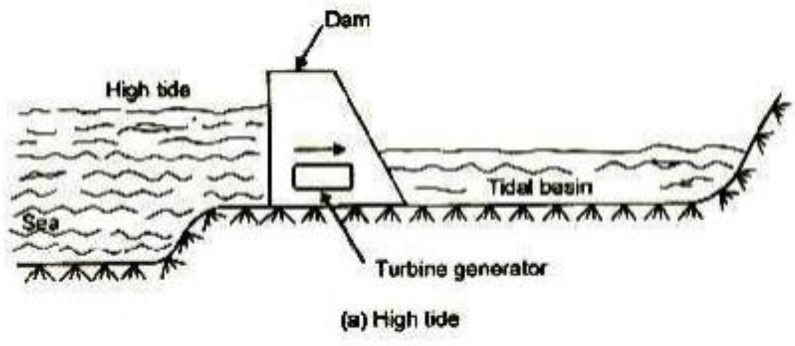


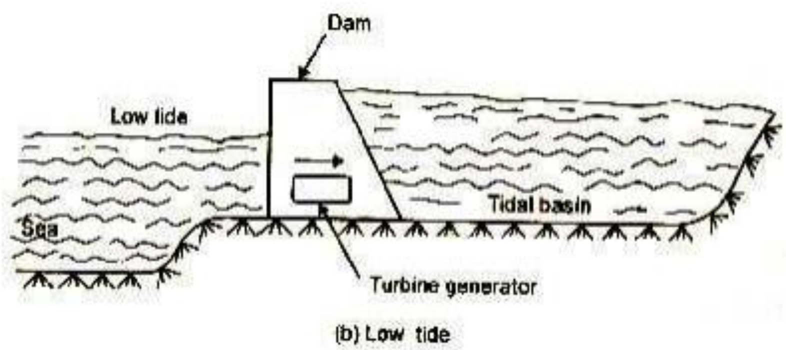
Figure: High tide

Figure: High tide

-

During high tide period, water flows from the sea into the tidal basin through the water turbine. The height of tide is above that of tidal basin. Hence the turbine unit operates and generates power, as it is directly coupled to a generator.

During low tide period, water flows from tidal basin to sea, as the water level in the basin is more than that of the tide in the sea. During this period also, the flowing water rotates the turbine and generator power.



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The generation of power stops only when the sea level and the tidal basin level are equal. For the generation of power economically using this source of energy requires some minimum tide height and suitable site. Kislaya power plant of 250 MW capacity in Russia and Rance power plant in France are the only examples of this type of power plant.

-

Advantages of tidal power plants.

1. It is free from pollution as it does not use any fuel.

2. It is superior to hydro-power plant as it is totally independent of rain.

3. It improves the possibility of fish farming in the tidal basins and it can provide recreation to visitors and holiday makers.

Disadvantages

1. Tidal power plants can be developed only if natural sites are available on the bay.

2. As the sites are available on the bays which are always far away from load centres, the power generated has to be transmitted to long distances. This increases the transmission cost and transmission losses.

Tidal power

Sihwa Lake Tidal Power Station, located in Gyeonggi Province, South Korea, is the world's largest tidal power installation, with a total power output capacity of 254 MW.

Although not yet widely used, tidal energy has potential for future electricity generation. Tides are more predictable than the wind and the sun. Among sources of renewable energy, tidal energy has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recenttechnological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

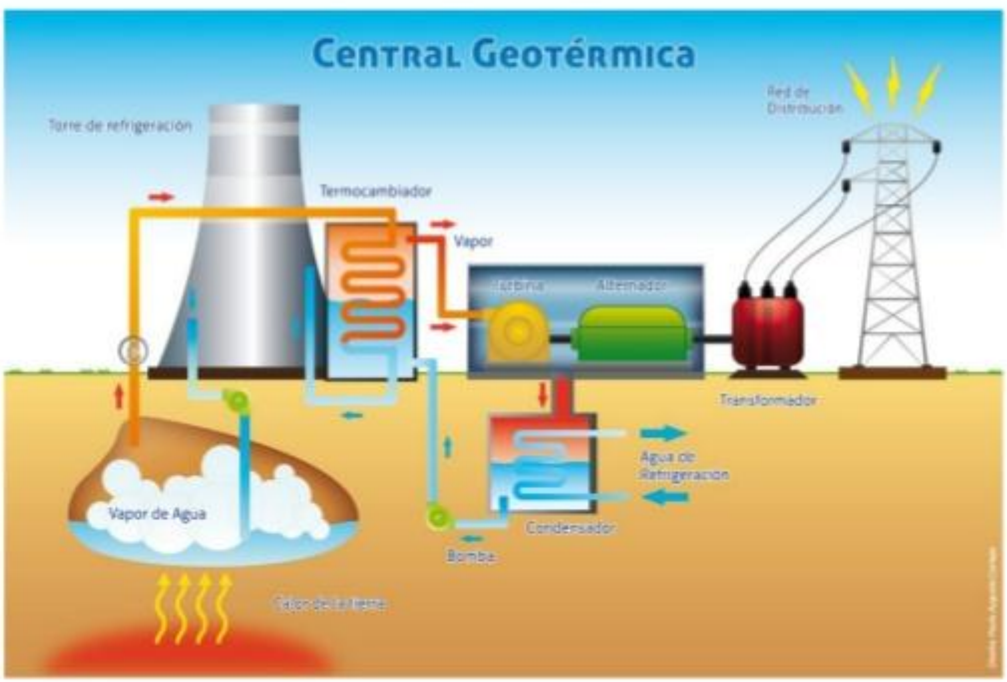
Historically, tide mills have been used both in Europe and on the Atlantic coast of North America. The incoming water was contained in large storage ponds, and as the tide went out, it turned waterwheels that used the mechanical power it produced to mill grain.[1] The earliest occurrences date from the Middle Ages, or even from Roman times.[2][3] The process of using falling water and spinning turbines to create electricity was introduced in the U.S. and Europe in the 19th century.[4]

The world's first large-scale tidal power plant was the Rance Tidal Power Stationin France, which became operational in 1966. It was the largest tidal power station in terms of output until Sihwa Lake Tidal Power Station opened in South Korea in August 2011. The Sihwa station uses sea wall defense barriers complete with 10 turbines generating 254 MW.[5]

Geothermal energy

Geothermal energy is the heat from the Earth. It's clean and sustainable. Resources of **geothermal energy** range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma.

IV:Diagram of a geothermal power plant



Geothermal power

From Wikipedia, the free encyclopedia

Geothermal power is power generated by geothermal energy. Technologies in use include dry steam power stations, flash steam power stations and binary cycle power stations. Geothermal electricity generation is currently used in 24 countries,[1] while geothermal heating is in use in 70 countries.[2]

As of 2015, worldwide geothermal power capacity amounts to 12.8 gigawatts (GW), of which 28 percent or 3,548 megawatts are installed in the United States. International markets grew at an average annual rate of 5 percent over the last three years and global geothermal power capacity is expected to reach 14.5–17.6 GW by 2020.[3] Based on current geologic knowledge and technology, the Geothermal Energy Association (GEA) estimates that only 6.5 percent of total global potential has been tapped so far, while the IPCC reported geothermal power potential to be in the range of 35 GW to 2 TW.[2] Countries generating more than 15 percent of their electricity from geothermal sources include El Salvador, Kenya, the Philippines, Iceland and Costa Rica.

Geothermal power is considered to be a sustainable, renewable source of energy because the heat extraction is small compared with the Earth's heat content.[4] The greenhouse gas emissions of geothermal electric stations are on average 45 grams of carbon dioxide per kilowatt-hour of electricity, or less than 5 percent of that of conventional coal-fired plants.[5]

Principle and working of geothermal power plants

Geothermal Energy

Heat has been radiating from the Earth's core for billions of years. This heat is originated since the formation of the Earth and it is continuously regenerated by the decay of radioactive elements. The rate of this regeneration of geothermal heat is so high that it makes the **geothermal energy a renewable resource**. Near the Earth's core, the temperature ranges about 5500 degree Celsius. This heat is basically the thermal energy stored inside the Earth's core and the Earth's crust acts like an insulator and keeps the heat trapped inside. This thermal energy is known as geothermal energy. (geo=earth and thermal=heat). This energy is estimated to be one or two orders larger than all the energy recoverable from nuclear sources. The heat trapped inside the core (by the Earth's crust) is transferred to the surface by the following ways:

1. Direct heat conduction
2. Bubble like magma that buoys up to the surface
3. Rapid injection of magma into deep, natural rifts

Direct heat conduction does not produce much heat on the surface. Also, magma buoys up to the surface only at selected locations like active volcanoes. Whereas magma is injected into deep rifts and causes heating of the underground water.

This geothermal energy rises upwards due to one of the above reasons and causes large amounts of underground water to be heated on or below the surface of the Earth. Such locations are called **Geothermal reservoirs**. Such reservoirs are either on the surface in the form of hot springs or underground reservoirs which are reached by drilling wells.

The heat energy in geothermal reservoirs can be carried up to the surface and utilized to **produce electricity by geothermal power plants**.

Geothermal Power Plants

A geothermal power plant uses steam obtained from these geothermal reservoirs to generate electricity. Wells are drilled at the appropriate locations to bring this geothermal energy up to the surface. A mixture of steam and water is collected from the production well. Steam separators are employed to separate the steam and use it to operate turbines. The further process is quite similar to a thermal power plant - steam turbines run the generators and, hence, electricity is generated. The condensed steam and the water collected from the production well are injected back into the reservoir through the injection well.

This is, however, a **general working principle of a geothermal power plant**. The particular working of the plant depends upon the type of the plant.

Types Of Geothermal Power Plants

1. Dry Steam Plant

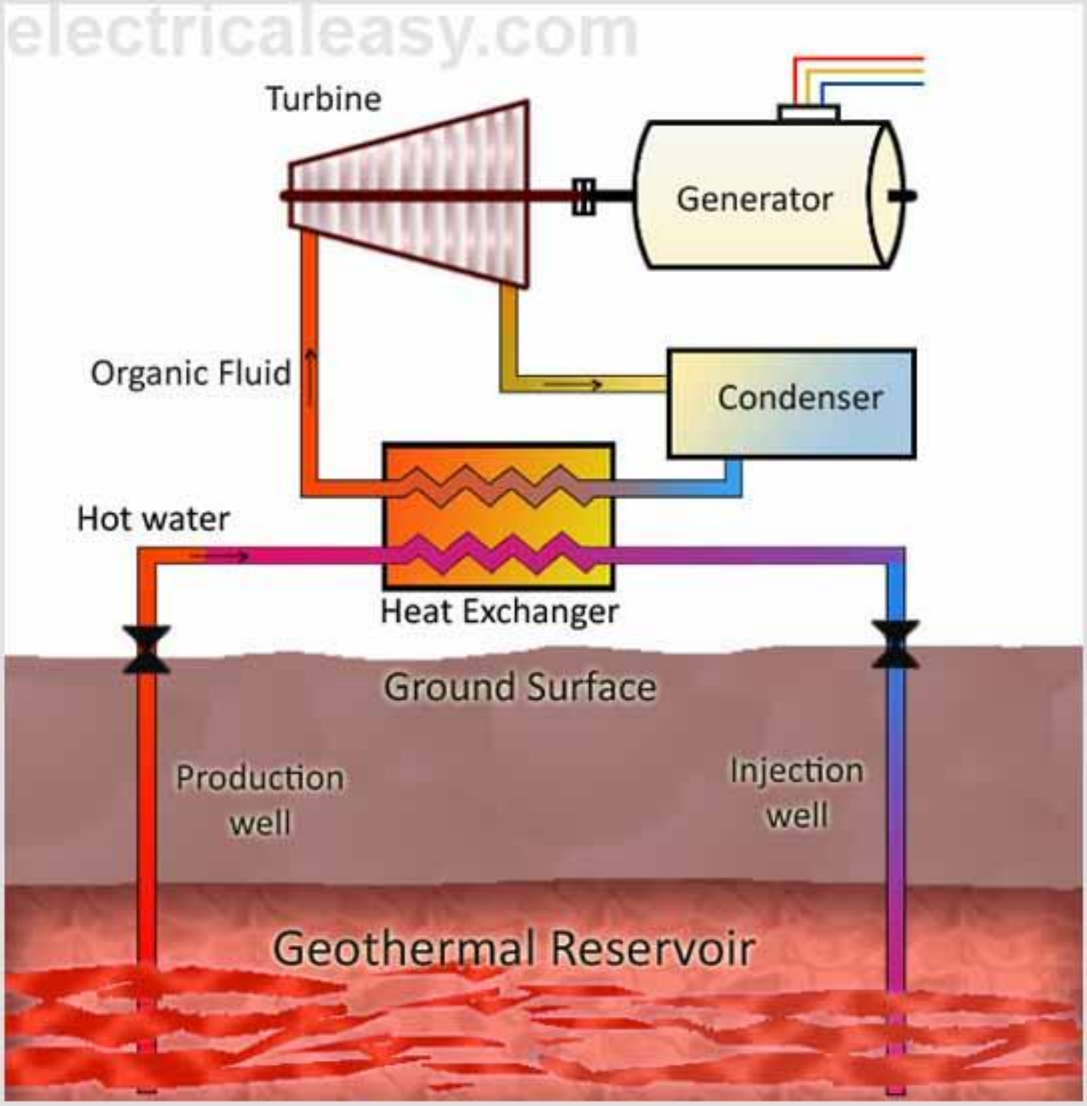
This is the simplest and oldest type of geothermal plant. It directly uses steam from the reservoir to operate the turbine. The steam is collected from the production well and used to operate low-pressure turbines. Hence, the working fluid is steam. The used steam is then condensed and injected back through the injection well.

2. Flash Steam Plant

Flash steam power plants are the most commonly employed geothermal plants today. They operate on the geothermal reservoires having water temperature greater than 180 degree celcius. The high pressure hot water from the reservoir flows up through the production well due to its own pressure. The pressure decreases as the water flows upwards and, hence, some of it gets converted into steam. The steam is seperated from the water by steam seperator and sent to drive the steam turbine. The unused water as well as the condensed steam are injected back through the injection well.

3. Binary Steam Plant

Binary power plants are the recent development. They have made it possible to produce electricity from geothermal reservoirs with temperatures lower than 150 degree celcius. In these plants, hot water from geothermal reservoir is used to heat up an another organic fluid having a lower boiling point. Thus, here, the working fluid is the secondary organic fluid and not the water from reservoir. The heat energy from the water is transferred to the working fluid in the heat exchanger. As a result, the working fluid vaporizes, and then drives the turbines. The spent fluid passes through the condenser and the cycle repeats. The water is injected back into the reservoir through the injection well.



Binary Cycle Plant

UNIT 5

BIOMASSENERGY

Bio energy

Bioenergy is renewable energy made available from materials derived from biological sources. Biomass is any organic material which has stored sunlight in the form of chemical energy. As a fuel it may include wood, wood waste, straw, manure, sugarcane, and many other by-products from a variety of agricultural processes. By 2010, there was 35 GW (47,000,000 hp) of globally installed bioenergy capacity for electricity generation, of which 7 GW (9,400,000 hp) was in the United States.[1]

In its most narrow sense it is a synonym to biofuel, which is fuel derived from biological sources. In its broader sense it includes biomass, the biological material used as a biofuel, as well as the social, economic, scientific and technical fields associated with using biological sources for energy. This is a common misconception, as bioenergy is the energy extracted from the biomass, as the biomass is the fuel and the bioenergy is the energy contained in the fuel[2]

There is a slight tendency for the word *bioenergy* to be favoured in Europe compared with *biofuel* in America.[3]

Solid biomass

Simple use of biomass fuel (Combustion of wood for heat).

Sugarcane plantation to produce ethanol in Brazil

A CHP power station using wood to supply 30,000 households in France

One of the advantages of biomass fuel is that it is often a by-product, residue or waste-product of other processes, such as farming, animal husbandry and forestry.[1]In theory this means there is no competition between fuel and food production, although this is not always the case.[1] Land use, existing biomass industries and relevant conversion technologies must be considered when evaluating suitability of developing biomass as feedstock for energy.[4]

Biomass is the material derived from recently living organisms, which includes plants, animals and their byproducts.[5] Manure, garden waste and crop residues are all sources of biomass. It is a renewable energy source based on the carbon cycle, unlike other natural resources such as petroleum, coal, and nuclear fuels. Another source includes Animal waste, which is a persistent and unavoidable pollutantproduced primarily by the animals housed in industrial-sized farms.

There are also agricultural products specifically being grown for biofuel production. These include corn, and soybeans and to some extent willow and switchgrass on a pre-commercial research level, primarily in the United States; rapeseed, wheat, sugar beet, and willow (15,000 ha or 37,000 acres in Sweden) primarily in Europe; sugarcane in Brazil; palm oil and miscanthus[6] in Southeast Asia;[7] sorghum and cassava in China; and jatropha in India. Hemp has also been proven to work as a biofuel. Biodegradable outputs from industry, agriculture, forestry and households can be used for biofuel production, using e.g. anaerobic digestion to produce biogas, gasification to produce syngas or by direct combustion. Examples of biodegradable wastes include straw, timber, manure, rice husks, sewage, and food waste. The use of biomass fuels can therefore contribute to waste management as well as fuel security and help to prevent or slow down climate change, although alone they are not a comprehensive solution to these problems.

Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Rotting garbage, and agricultural and human waste, all release methane gas—also called "landfill gas" or "biogas." Crops, such as corn and sugar cane, can be fermented to produce the transportation fuel, ethanol. Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats. Also, Biomass to liquids (BTLs) and cellulosic ethanol are still under research.

Sewage biomass

A new bioenergy sewage treatment process aimed at developing countries is now on the horizon; the Omni Processor is a self-sustaining process which uses the sewerage solids as fuel to convert sewage waste water into drinking water and electrical energy.[8][9][10]

Electricity generation from biomass

The biomass used for electricity production ranges by region.[1] Forest byproducts, such as wood residues, are popular in the United States.[1] Agricultural waste is common in Mauritius (sugar cane residue) and Southeast Asia (rice husks).[1] Animal husbandry residues, such as poultry litter, is popular in the UK.[1]

Electricity from sugarcane bagasse in Brazil[

Sugarcane (*Saccharum officinarum*) plantation ready for harvest, Ituverava, São Paulo State. Brazil.

A sugar/ethanol plant located in Piracicaba, São Paulo State. This plant produces the electricity it needs from bagasse residuals from sugarcane left over by the milling process, and it sells the surplus electricity to the public grid.

Sucrose accounts for little more than 30% of the chemical energy stored in the mature plant; 35% is in the leaves and stem tips, which are left in the fields during harvest, and 35% are in the fibrous material (bagasse) left over from pressing.

The production process of sugar and ethanol in Brazil takes full advantage of the energy stored in sugarcane. Part of the bagasse is currently burned at the mill to provide heat for distillation and electricity to run the machinery. This allows ethanol plants to be energetically self-sufficient and even sell surplus electricity to utilities; current production is 600 MW (800,000 hp) for self-use and 100 MW (130,000 hp) for sale. This secondary activity is expected to boom now that utilities have been induced to pay "fair price "(about US$10/GJ or US$0.036/kWh) for 10 year contracts. This is approximately half of what the World Bank considers the reference price for investing in similar projects (see below). The energy is especially valuable to utilities because it is produced mainly in the dry season when hydroelectric dams are running low. Estimates of potential power generation from bagasse range from 1,000 to 9,000 MW (1,300,000 to 12,100,000 hp), depending on technology. Higher estimates assume gasification of biomass, replacement of current low-pressure steam boilers and turbines by high-pressure ones, and use of harvest trash currently left behind in the fields. For comparison, Brazil's Angra I nuclear plant generates 657 MW (881,000 hp).

Presently, it is economically viable to extract about 288 MJ of electricity from the residues of one tonne of sugarcane, of which about 180 MJ are used in the plant itself. Thus a medium-size distillery processing 1,000,000 tonnes (980,000 long tons; 1,100,000 short tons) of sugarcane per year could sell about 5 MW (6,700 hp) of surplus electricity. At current prices, it would earn US$18 million from sugar and ethanol sales, and about US$1 million from surplus electricity sales. With advanced boiler and turbine technology, the electricity yield could be increased to 648 MJ per tonne of sugarcane, but current electricity prices do not justify the necessary investment. (According to one report, the World Bank would only finance investments in bagasse power generation if the price were at least US$19/GJ or US$0.068/kWh.)

Bagasse burning is environmentally friendly compared to other fuels like oil and coal. Its ash content is only 2.5% (against 30–50% of coal), and it contains very little sulfur. Since it burns at relatively low temperatures, it produces little nitrous oxides. Moreover, bagasse is being sold for use as a fuel (replacing heavy fuel oil) in various industries, including citrus juice concentrate, vegetable oil, ceramics, and tyre recycling. The state of São Paulo alone used 2,000,000 tonnes (1,970,000 long tons; 2,200,000 short tons), saving about US$35 million in fuel oil imports.

Researchers working with cellulosic ethanol are trying to make the extraction of ethanol from sugarcane bagasse and other plants viable on an industrial scale.

Electricity from electrogenic micro-organisms

Another form of bioenergy can be attained from microbial fuel cells, in which chemical energy stored in wastewater or soil is converted directly into electrical energy via the metabolic processes of electrogenic micro-organisms. The power generation capability of this technology has not been economical to date, however, and this technology has found more utility for chemical treatment processes [11] and student education.[12]

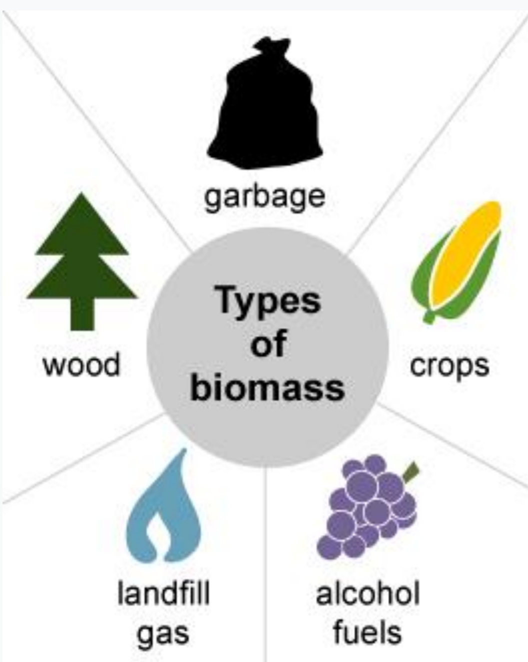
Environmental impact

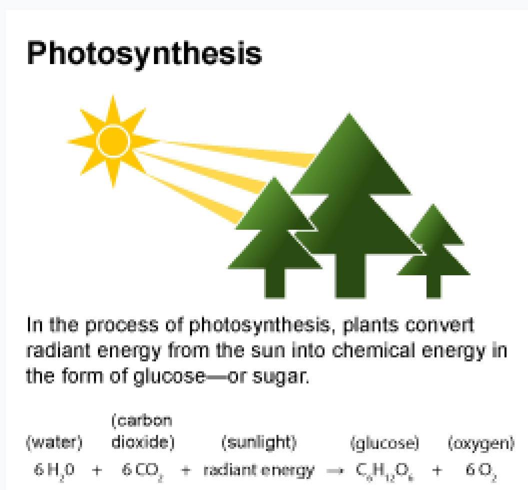
Some forms of forest bioenergy have recently come under fire from a number of environmental organizations, including Greenpeace and the Natural Resources Defense Council, for the harmful impacts they can have on forests and the climate. Greenpeace recently released a report entitled Fuelling a BioMess which outlines their concerns around forest bioenergy. Because any part of the tree can be burned, the harvesting of trees for energy production encourages Whole-Tree Harvesting, which removes more nutrients and soil cover than regular harvesting, and can be harmful to the long-term health of the forest. In some jurisdictions, forest biomass is increasingly consisting of elements essential to functioning forest ecosystems, including standing trees, naturally disturbed forests and remains of traditional logging operations that were previously left in the forest. Environmental groups also cite recent scientific research which has found that it can take many decades for the carbon released by burning biomass to be recaptured by regrowing trees, and even longer in low productivity areas; furthermore, logging operations may disturb forest soils and cause them to release stored carbon. In light of the pressing need to reduce greenhouse gas emissions in the short term in order to mitigate the effects of climate change, a number of environmental groups are opposing the large-scale use of forest biomass in energy production.

The New Scientist described a scenario in a September 2016 article which illustrated why the journal believed bioenergy can be bad: Suppose you cut down a 50-year oak tree in your garden and use the logs to heat your house instead of coal. Wood emits more carbon dioxide than coal per unit of heat gained and the roots left in the soil emit more carbon dioxide as they rot. If you plant another tree it will soak up that carbon dioxide in about 50 years. But if you had left the original tree in place it would have soaked up the carbon dioxide from the coal and more. It could take centuries before cutting down the tree would give any benefit. But the world needed to cut carbon dioxide over the next few decades if the global warming was to be kept below 3 degrees C.[15] The journal also concluded that official claimed carbon reductions from renewables had been overstated. The European Union, for example, got more 64% of its renewable energy from biomass (mostly wood) but United Nations and EU rules did not count the carbon emissions from burning biomas

Energy from bio mass

Biomass is organic material that comes from plants and animals, and it is a renewable source of **energy**. **Biomass** contains stored**energy** from the sun. Plants absorb the sun's **energy** in a process called photosynthesis. ... **Biomass** can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels.





Bio gas plant

Biogas typically refers to a mixture of different **gases**produced by the breakdown of organic matter in the absence of oxygen. **Biogas** can be produced from raw materials such as agricultural waste, manure, municipal waste, **plant** material, sewage, green waste or food waste. **Biogas** is a renewable energy source

Biogas

From Wikipedia, the free encyclopedia

Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. Biogas is a renewable energy source.

Biogas can be produced by anaerobic digestion with anaerobic organisms, which digest material inside a closed system, or fermentation of biodegradable materials.[1]

Biogas is primarily methane (CH 4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulfide (H 2S), moisture and siloxanes. The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel; it can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat.[2]

Biogas can be compressed, the same way natural gas is compressed to CNG, and used to power motor vehicles. In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel.[3] It qualifies for renewable energy subsidies in some parts of the world. Biogas can be cleaned and upgraded to natural gas standards, when it becomes bio-methane. Biogas is considered to be a renewable resource because its production-and-use cycle is continuous, and it generates no net carbon dioxide. Organic material grows, is converted and used and then regrows in a continually repeating cycle. From a carbon perspective, as much carbon dioxide is absorbed from the atmosphere in the growth of the primary bio-resource as is released when the material is ultimately converted to energy.

Industrial waste

Industrial waste is the waste produced by industrial activity which includes any material that is rendered useless during a manufacturing process such as that of factories, industries, mills, and mining operations. It has existed since the start of the Industrial Revolution.[1] Some examples of industrial wastes are chemical solvents, paints, sandpaper, paper products, industrial by-products, metals, and radioactive wastes.

Toxic waste, chemical waste, industrial solid waste and municipal solid waste are designations of industrial wastes. Sewage treatment plants can treat some industrial wastes, i.e. those consisting of conventional pollutants such as biochemical oxygen demand (BOD). Industrial wastes containing toxic pollutants require specialized treatment systems. (*See* Industrial wastewater treatment)

Thousands of small scale and bigger industrial units simply dump their waste, more often toxic and hazardous, in open spaces and nearby water sources. Over the last three decades, many cases of serious and permanent damage to environment by these industries have come to the fore.

Rapid industrialization has resulted in the generation of huge quantity of wastes, both solid and liquid, in industrial sectors such as sugar, pulp and paper, fruit and food processing, sago / starch, distilleries, dairies, tanneries, slaughterhouses, poultries, etc. Despite requirements for pollution control measures, these wastes are generally dumped on land or discharged into water bodies, without adequate treatment, and thus become a large source of environmental pollution and health hazard.

Management of Industrial Solid Waste (ISW) is not the responsibility of local bodies. Industries generating solid waste have to manage such waste by themselves and are required to seek authorizations from respective State Pollution Control Boards (SPCBs) under relevant rules. However, through joint efforts of SPCBs, local bodies and the industries, a mechanism could be evolved for better management.

Municipal wastes

The composition of municipal solid waste varies greatly from municipality to municipality,[1] and it changes significantly with time. In municipalities which have a well developed waste recycling system, the waste stream mainly consists of intractable wastes such as plastic film and non-recyclable packaging materials. At the start of the 20th century, the majority of domestic waste (53%) in the UK consisted of coal ash from open fires.[2] In developed areas without significant recycling activity it predominantly includes food wastes, market wastes, yard wastes, plastic containers and product packaging materials, and other miscellaneous solid wastes from residential, commercial, institutional, and industrial sources.[3] Most definitions of municipal solid waste do not include industrial wastes, agricultural wastes, medical waste, radioactive waste or sewage sludge.[4] Waste collection is performed by the municipality within a given area. The term *residual waste* relates to waste left from household sources containing materials that have not been separated out or sent for reprocessing.[5] Waste can be classified in several ways but the following list represents a typical classification:

- Biodegradable waste: food and kitchen waste, green waste, paper (most can be recycled although some difficult to compost plant material may be excluded[6])
- Recyclable materials: paper, cardboard, glass, bottles, jars, tin cans, aluminum cans, aluminum foil, metals, certain plastics, fabrics, clothes, tires, batteries, etc.
- Inert waste: construction and demolition waste, dirt, rocks, debris
- Electrical and electronic waste (WEEE) - electrical appliances, light bulbs, washing machines, TVs, computers, screens, mobile phones, alarm clocks, watches, etc.

- Composite wastes: waste clothing, Tetra Packs, waste plastics such as toys
- Hazardous waste including most paints, chemicals, tires, batteries, light bulbs, electrical appliances, fluorescent lamps, aerosol spray cans, and fertilizers
- Toxic waste including pesticides, herbicides, and fungicides
- Biomedical waste, expired pharmaceutical drugs, etc.

Components of solid waste management

Bins to collect paper, aluminium, glass, PET bottles and incinerable waste.

The municipal solid waste industry has four components: recycling, composting, disposal, and waste-to-energy via incineration.[7] There is no single approach that can be applied to the management of all waste streams, therefore the Environmental Protection Agency, federal agency of the United States of America, developed a hierarchy ranking strategy for municipal solid waste.[8] The Waste Management Hierarchy is made up of four levels ordered from most preferred to least preferred methods based on their environmental soundness: Source reduction and reuse; recycling or composting; energy recovery; treatment and disposal.[9]

Collection

The functional element of collection includes not only the gathering of solid waste and recyclable materials, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be a materials processing facility, a transfer station or a landfill disposal site.

Waste handling and separation, storage and processing at the source

Waste handling and separation involves activities associated with waste management until the waste is placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection. Separating different types of waste components is an important step in the handling and storage of solid waste at the source.

Segregation and processing and transformation of solid wastes

The types of means and facilities that are now used for the recovery of waste materials that have been separated at the source include curbside ('kerbside' in the UK) collection, drop-off and buy-back centers. The separation and processing of wastes that have been separated at the source and the separation of commingled wastes usually occur at a materials recovery facility, transfer stations, combustion facilities and disposal sites.

Transfer and transport

This element involves two main steps. First, the waste is transferred from a smaller collection vehicle to larger transport equipment. The waste is then transported, usually over long distances, to a processing or disposal site.

Disposal

Mixed municipal waste, Hiriya, Tel Aviv

Today, the disposal of wastes by land filling or land spreading is the ultimate fate of all solid wastes, whether they are residential wastes collected and transported directly to a landfill site, residual materials from materials recovery facilities (MRFs), residue from the combustion of solid waste, compost, or other substances from various solid waste processing facilities. A modern sanitary landfill is not a dump; it is an engineered facility used for disposing of solid wastes on land without creating nuisances or hazards to public health or safety, such as the problems of insects and the contamination of ground water.

Reusing

In the recent years environmental organizations, such as Freegle or Freecycle Network, have been gaining popularity for their online reuse networks. These networks provide a worldwide online registry of unwanted items that would otherwise be thrown away, for individuals and nonprofits to reuse or recycle. Therefore, this free Internet-based service reduces landfill pollution and promotes the gift economy.

Landfill

Landfills are created by land dumping. Land dumping methods vary, most commonly it involves the mass dumping of waste into a designated area, usually a hole or sidehill. After the waste is dumped, it is then compacted by large machines. When the dumping cell is full, it is then "sealed" with a plastic sheet and covered in several feet of dirt. This is the primary method of dumping in the United States because of the low cost and abundance of unused land in North America. Landfills pose the threat of pollution, and can intoxicate ground water. The signs of pollution are effectively masked by disposal companies and it is often hard to see any evidence.

Usually landfills are surrounded by large walls or fences hiding the mounds of debris. Large amounts of chemical odor eliminating agent are sprayed in the air surrounding landfills to hide the evidence of the rotting waste inside the plant.[10]

Energy generation

Municipal solid waste can be used to generate energy. Several technologies have been developed that make the processing of MSW for energy generation cleaner and more economical than ever before, including landfill gas capture, combustion, pyrolysis, gasification, and plasma arc *gasification*.[11] While older waste incineration plants emitted a lot of pollutants, recent regulatory changes and new technologies have significantly reduced this concern. United States Environmental Protection Agency (EPA) regulations in 1995 and 2000 under the Clean Air Act have succeeded in reducing emissions of dioxins from waste-to-energy facilities by more than 99 percent below 1990 levels, while mercury emissions have been reduced by over 90 percent.[12] The EPA noted these improvements in 2003, citing waste-to-energy as a power source "with less environmental impact than almost any other source of electricity".

Burning plants

Burning of Waste

What is Backyard Burning?

It is the:

- Burning waste in a barrel or exposed heap (bonfire) in a yard or garden
- Burning in a purchased ready-made "home incinerator"
- Burning commercial waste on a business premises or farmyard
- Burning waste on a building site

Backyard burning of waste is illegal and is subject to prosecution

Burning waste is not only a nuisance to neighbours; it can release many harmful chemicals into the air you breathe. Many people may think that they are doing the right thing in reducing the amount of waste going to landfill and saving money but they are both causing long term environmental pollution and interfering with the lives of others living in their area. Burning waste in your home or garden can damage your health, as well as that of your children and your neighbours. Such illegal practices lead to the release of toxic dioxins which are a real hazard for peoples' health and the environment.

In September 2009, a law concerning waste disposal by burning came into force. These regulations, the Waste Management (Prohibition of Waste Disposal by Burning) Regulations 2009 (SI No. 286 of 2009) make explicit the offence of disposal of waste by uncontrolled burning and prohibits such disposal within the curtilage of a dwelling.
Failure to comply with these regulations is an offence and fines of up to €3,000 may be imposed.

If your neighbour or someone else you see is illegally burning waste, then in the interest of your own health and the environment, please report the incident to the 24 hour National Environmental Complaints Line, lo-call telephone number **1850 365 121**. More information on making environmental complaints can be viewed in our leaflet 'See Something? Say something!'.

- Making an environmental complaint
- How to make an environmental complaint leaflet, 'See somthing? Say something!'
- WASTE MANAGEMENT (PROHIBITION OF WASTE DISPOSAL BY BURNING) REGULATIONS 2009, S.I. No. 286 of 2009

Energy from agriculture waste

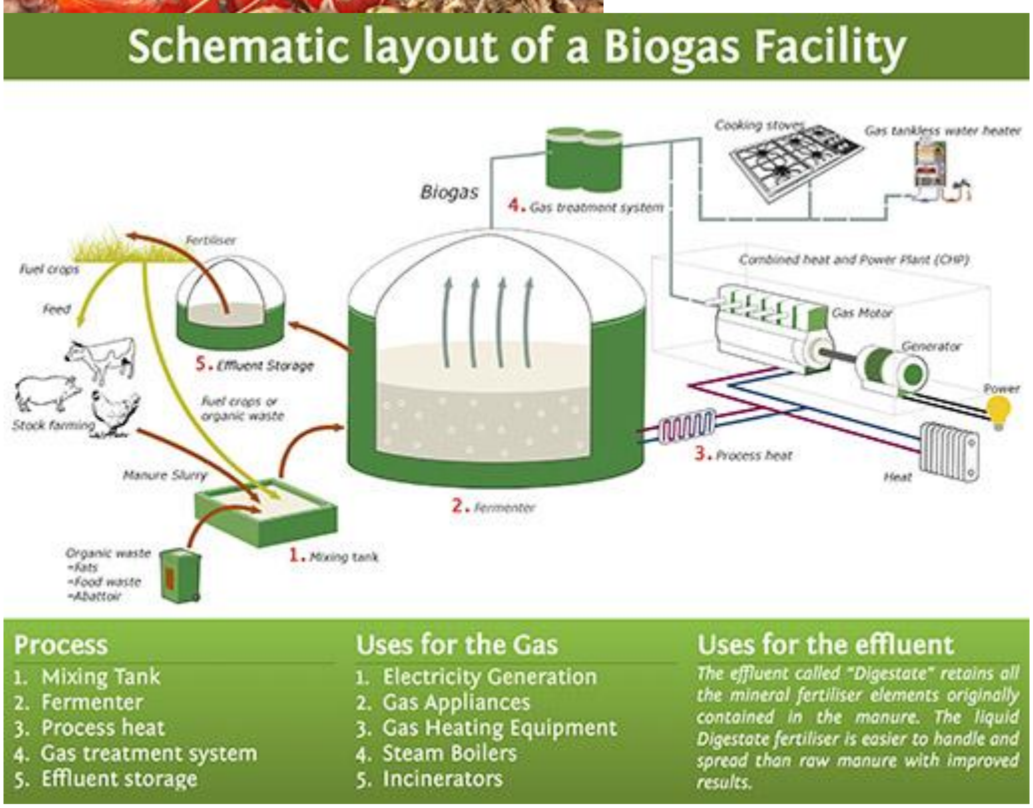
Large quantities of agricultural wastes resulting from crop cultivation activity are a promising source of energy supply for production, processing and domestic activities in rural areas of the concerned region. The available crop residues are either being used inefficiently or burnt in the open to clear the fields for subsequent crop cultivation. On an average 1.5 tons of crop residue are generated for processing 1 ton of the main product. In addition, substantial quantities of secondary residues are produced in agro-industries processing farm produce such as paddy, sugarcane, coconut, fruits and vegetables.

Agricultural crop residues often have a disposal cost associated with them. Therefore, the "waste-to-energy" conversion processes for heat and power generation, and even in some cases for transport fuel production, can have good economic and market potential. They have value particularly in rural community applications, and are used widely in countries such as Sweden, Denmark, Netherlands, USA, Canada, Austria and Finland.

The energy density and physical properties of agricultural biomass wastes are critical factors for feedstock considerations and need to be understood in order to match a feedstock and processing technology. There are six generic biomass processing technologies based on direct combustion (for power), anaerobic digestion (for methane-rich gas), fermentation (of sugars for alcohols), oil exaction (for biodiesel), pyrolysis (for biochar, gas and oils) and gasification (for carbon monoxide and hydrogen-rich syngas). These technologies can then be followed by an array of secondary treatments (stabilization, dewatering, upgrading, refining) depending on specific final products.

It is well-known that power plants based on baled agricultural residues are efficient and cost-effective energy generators. Residues such as Rice Husks, Wheat Straw and Maize Cobs are already concentrated at a point where it is an easily exploitable source of energy, particularly if it can be utilized on-site to provide heat and power.

The selection of processing technologies needs to be aligned to the nature and structure of the biomass feedstock and the desired project outputs. It can be seen that direct combustion or gasification of biomass are appropriate when heat and power are required. Anaerobic digestion, fermentation and oil extraction are suitable when specific Biomass wastes are available that have easily extractable oils and sugars or high water contents. On the other hand, only thermal processing of biomass by pyrolysis can provide the platform for all of the above forms of product. Many thermal technologies require the water content of Biomass to be low (<15 per cent) for proper operation. For these technologies the energy cost of drying can represent a significant reduction in process efficiency.Moisture content is of important interest since it corresponds to one of the main criteria for the selection of energy conversion process technology. Thermal conversion technology requires biomass fuels with low moisture content, while those with high moisture content are more appropriate for biological-based process such as fermentation or anaerobic digestion.The ash content of biomass influences the expenses related to handling and processing to be included in the overall conversion cost. On the other hand, the chemical composition of ash is a determinant parameter in the consideration of a thermal conversion unit, since it gives rise to problems of slagging, fouling, sintering and corrosion.



Application

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel; it can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat.

Biogas is a renewable gaseous fuel containing approximately 50-70% methane and 30 to 40% carbon dioxide. Biogas is produced as a by-product from the decomposition of organic waste in landfills and anaerobic digesters that process agricultural waste and municipal waste water. A key step in the processing of biogas is the separation of water and carbon dioxide present in the gas. Xebec's BGX Solutions offer compact, low-cost, separation in capacities up to 4,000 NCMH of product methane.

Xebec's compact, Fast Cycle Pressure Swing Adsorption (PSA) units are designed to upgrade biogas feed streams containing CO_2, H_2O, H_2S, and high amounts of N_2O and O_2 (total molar content of 0% to 30%) to pure, renewable natural gas (RNG). Xebec's proprietary PSA technology is highly efficient, with proven recovery rates up to 96%.

Xebec's high-performance polymer membranes are also suitable for treating biogas streams which mainly contain CH_4 and CO_2. Xebec membranes selectively separate CH_4 from CO_2 and other trace gases and upgrade biogas to pure biomethane (Renewable Natural Gas – RNG) with recoveries as high as 99.8%

Xebec's methane purifiers are used around the world to upgrade biogas to renewable natural gas. For instance, the Xebec gas purification system at Cincinnati's Rumpke Landfill, one of the largest landfills in the U.S., upgrades biogas from the landfill into pipeline-quality renewable natural gas. The purified gas is piped to more than 8,700 homes for use by Duke Energy customers

Sources of biogas are widely distributed: they include landfills, municipal wastewater treatment, livestock manure lagoons, agricultural silage, and industrial organic waste digesters. Each source produces its own particular blend of biogas with varying compositions and trace components. Biogas is useful as a fuel to operate small power generators and boilers or, after upgrading by removal of water and carbon dioxide, as a green gas supply for the natural gas pipeline network. Xebec offers other biogas treatment options depending on the source and end-use of the biogas. Products available include dryers and adsorption units for removal of carbon dioxide