RENEWABLE ENERGY TECHNOLOGIES

Why Renewable Energy?

Most of the energy we use today comes from fossil fuels. Coal, oil, and natural gas are all fossil fuels created several millions of years before by the decay of plants and animals. These fuels lie buried between layers of earth and rock. While fossil fuels are still being created today by underground heat and pressure, they are being consumed much more rapidly than they are created. For that reason, fossil fuels are considered as non-renewable; that is, they are not replaced as soon as we use them. So, we will run out of them sometime in the future. Moreover burning fossil fuels leads to pollution and many environmental impacts. Because our world depends so much on energy, we need to use sources of energy that will last forever. These sources are called renewable energy. These renewable energy sources are much more environmentally friendly than fossil fuels when they are burned.

During the last few decades, concern has been growing internationally that increasing concentrations of greenhouse gases in the atmosphere will change our climate in ways detrimental to our social and economic well being. Climate change or global warming means a gradual increase in the global average air temperature at the earth's surface. Abundant data demonstrate that global climate has warmed during the past 150 years. The majority of scientists now believe that global warming is taking place, at a rate of around 0,3 deg. C per decade, and that it is caused by increases in the concentration of so-called "greenhouse gases" in the atmosphere. The most important single component of these greenhouse gas emissions is carbon dioxide (CO_2). The major source of emissions of CO_2 is power plants, automobiles, and industry. Combustion of fossil fuels contributes around 80 percent to total worldwide anthropogenic CO_2 emissions.

Renewable Energy Resources

Fortunately, solutions exist to cut greenhouse gas emissions, reduce acid deposition, improve air quality and to solve social problems related to recent energy use. Shifting investment from fossil fuels like coal and oil to renewable energy and energy efficiency would allow cleaner, more sustainable sources of energy to take their rightful place as market leaders.

Renewable energy systems use resources that are constantly replaced and are usually less polluting. All renewable energy sources – solar energy, hydro power, biomass and wind energy have their origin in activity of the Sun. Geothermal energy which, because of its inexhaustible potential, is sometimes considered as renewable source is getting energy from the heat of the earth.

Renewable energy is a domestic resource, which has the potential to contribute to or provide complete security of energy supply. Countries that depend on imports of fossil fuel resources are in danger due to the risk of sharp rise of the cost of imported energy (mainly oil). This is particularly so for developing countries, where the oil import bill adds every year to the problem of financing an already large external deficit.

Renewables are virtually uninterruptible and is of infinite availability because of its wide spread of complementary technologies - thus fitting well into a policy of diversification of energy supplies. Renewable resources are well recognized as a good way to protect the economy against price fluctuations and against future environmental costs. Technologies based on renewables are largely pollution-free and make zero or little contribution to the greenhouse effect with its predicted drastic climatic changes. In addition, they produce no nuclear waste and are thus consistent with environmental protection policies, building towards a better environment and sustainable development.

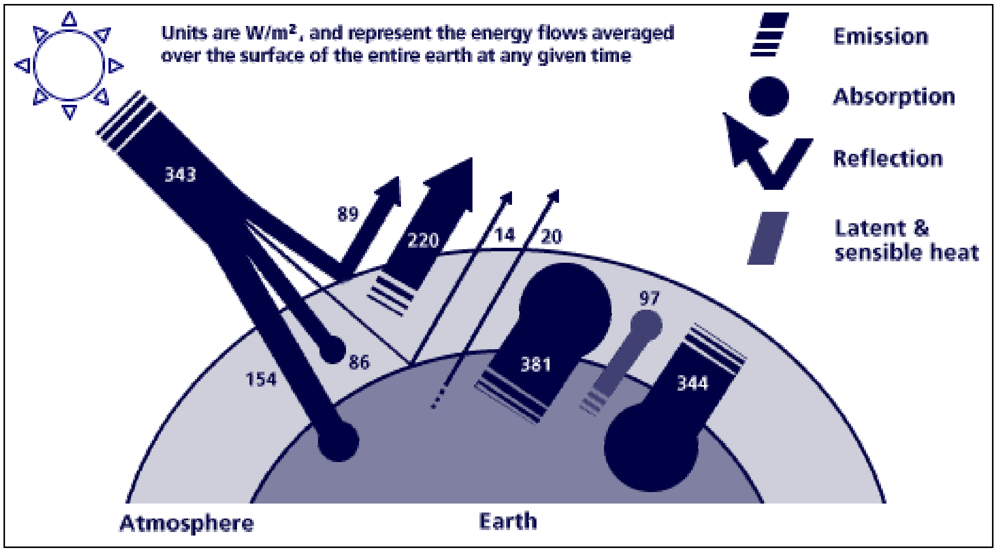
Renewable Energy Technologies

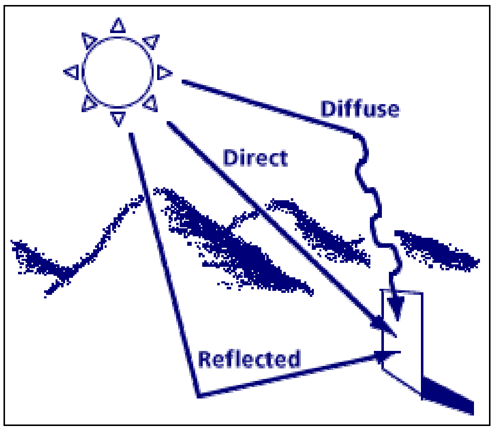
SOLAR

How Much Solar Energy Strikes the Earth?

The sun generates an enormous amount of energy - approximately 1.1 x 10^{20} kilowatt-hours[1] every second. The earth's outer atmosphere intercepts about one two-billionth of the energy generated by the sun, or about 1500 quadrillion (1.5 x 10^{18}) kilowatt-hours per year. Because of reflection, scattering, and absorption by gases and aerosols in the atmosphere, however, only 47% of this, or approximately 700 quadrillion (7 x 10^{17}) kilowatt-hours, reaches the surface of the earth.

[1] A kilowatt-hour is the amount of energy needed to power a 100-watt light bulb for ten hours





In the earth's atmosphere, solar radiation is received directly (direct radiation) and by diffusion in air, dust, water, etc., contained in the atmosphere (diffuse radiation). The sum of the two is referred to as global radiation.

The amount of incident energy per unit area and day depends on a number of factors,
Example:

- latitude
- local climate
- season of the year
- inclination of the collecting surface in the direction of the sun.

Solar Energy Utilisation

Harnessing this sun's light and heat is a clean, simple, and natural way to provide all forms of energy we need. It can be absorbed in solar collectors to provide hot water or space heating in households and commercial buildings. It can be concentrated by parabolic mirrors to provide heat at up to several thousands degrees Celsius. This heat can be used either for heating purposes or to generate electricity. There exist also another way to produce power from the sun - through photovoltaics. Photovoltaic cells are devices that convert solar radiation directly into electricity.

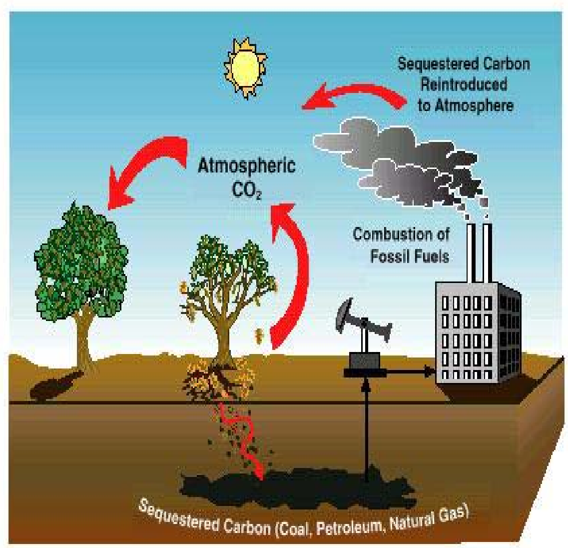
Solar radiation can be converted into useful energy using active systems and passive solar design. Active systems are generally those that are very visible like solar collectors or photovoltaic cells. Passive systems are defined as those where the heat moves by natural means due to house design, which entails the arrangement of basic building materials to maximize the sun's energy.

Solar energy can also be converted to useful energy indirectly, through other energy forms like biomass, wind or hydropower. Solar energy drives the earth's weather. A large fraction of the incident radiation is absorbed by the oceans and the seas, which are warmed than evaporate and give the power to the rains, which feed hydropower plants. Winds, which are harnessed by wind turbines, are getting its power due to uneven heating of the air. Another category of solar-derived renewable energy source is biomass. Green plants absorb sunlight and convert it through photosynthesis into organic matter that can be used to produce heat and electricity as well. Thus wind, hydropower and biomass are all indirect forms of solar energy.

<u>Biomass</u>

Where does Biomass come from?

Carbon dioxide from the atmosphere and water from the earth are combined in the photosynthetic process to produce carbohydrates (sugars) that form the building blocks of biomass. The solar energy that drives photosynthesis is stored in the chemical bonds of the structural components of biomass. If we burn biomass efficiently (extract the energy stored in the chemical bonds) oxygen from the atmosphere combines with the carbon in plants to produce carbon dioxide and water. The process is cyclic because the carbon dioxide is then available to produce new biomass.



Simplified carbon cycle. *Unlike fossil fuels, biomass does not increase atmospheric green house gases when burned.*

In addition to the aesthetic value of the planet's flora, biomass represents a useful and valuable resource to man. For millennia humans have exploited the solar energy stored in the chemical bonds by burning biomass as fuel and eating plants for the nutritional energy of their sugar and starch content. More recently, in the last few hundred years, humans have exploited fossilized biomass in the form of coal. This fossil fuel is the result of very slow chemical transformations that convert the sugar polymer fraction into a chemical composition that resembles the lignin fraction. Thus, the additional chemical bonds in coal represent a more concentrated source of energy as fuel. All of the fossil fuels we consume - coal, oil and natural gas - are simply ancient biomass. Over millions of years, the earth has buried ages-old plant material and converted it into these valuable fuels. But while fossil fuels contain the same constituents - hydrogen and carbon - as those found in fresh biomass, they are not considered renewable because they take such a long time to create. Environmental impacts pose another significant distinction between biomass and fossil fuels. When a plant decays, it releases most of its chemical matter back into the atmosphere. In contrast, fossil fuels are locked away deep in the ground and do not affect the earth's atmosphere unless they are burned.

Wood may be the best-known example of biomass. When burned, the wood releases the energy the tree captured from the sun's rays. But wood is just one example of biomass. Various biomass resources such as agricultural residues (e.g. bagasse from sugarcane, corn fibre, rice straw and hulls, and nutshells), wood waste (e.g. sawdust, timber slash, and mill scrap), the paper trash and urban yard clippings in municipal waste, energy crops (fast growing trees like poplars, willows, and grasses like switch grass or elephant grass), and the methane captured from landfills, municipal waste water treatment, and manure from cattle or poultry, can also be used.

Biomass is considered to be one of the key renewable resources of the future at both small- and large-scale levels. It already supplies 14% of the world's primary energy consumption. But for three quarters of the world's population living in developing countries biomass is the most important source of energy. With increases in population and per capita demand, and depletion of fossil-fuel resources, the demand for biomass is expected to increase rapidly in developing countries. On average, biomass produces 38 % of the primary energy in developing countries (90%

in some countries). Biomass is likely to remain an important global source in developing countries well into the next century.

Biomass Fuels in Developing Countries

Fuelwood

The term fuelwood describe all types of fuels derived from forestry and plantation. It is the major source of energy, in particular for domestic purposes, in poor developing countries: in 22 countries - fuelwood accounted for 25 to 49 %, in 17 countries, 50-74 %, and in 26 countries, 75-100 % of their respective national consumption.

More than half of the total wood harvested in the world is used as fuelwood. For specific countries, for example in Tanzania, the contribution can be as high as 97%. Although fuelwood is the major source of for most rural and low-income people in the developing world, the potential supply of fuelwood is dwindling rapidly, leading to scarcity of and environmental degradation. It is estimated that, for more than a third of the world population, the real crisis is the daily scramble to obtain fuelwood to meet domestic use.

Several studies on fuelwood supply in developing countries have concluded that fuelwood scarcities are real and will continue to exist, unless appropriate approaches to resource management are undertaken. The increase of fuelwood production through efficient techniques, can, therefore, be considered as one of the major pre-requisites for attaining sustainable development in developing countries.

Charcoal

The main expansion in the use of charcoal in Europe came with the industrial revolution in England in the 17th and 18th centuries. In Sweden, charcoal consumption for iron making grew through most of the 19th century, and was the basis of the good quality tradition of Swedish steel. Today charcoal is an important household fuel and to a lesser extent, industrial fuel in many developing countries. It is mainly used in the urban areas where its ease of storage, high content (30 MJ/kg as compared with 15 MJ/kg in fuelwood), lower levels of smoke emissions, and, resistance to insect attacks make it more attractive than fuelwood. In the United Republic of Tanzania, charcoal accounts for an estimated 90 per cent of biofuels consumed in urban centres.

Residues

Agricultural residues have an enormous potential for production. In favourable circumstances, biomass power generation could be significant given the vast quantities of existing forestry and agricultural residues - over 2 billion t/yr worldwide. This potential is currently under-utilised in many areas of the world. In wood-scarce areas, such as Bangladesh, China, the northern plains of India, and Pakistan, as much as 90 per cent of household in many villages covers their energy needs with agricultural residues. It has been estimated that about 800 million people world-wide rely on agricultural residues and dung for cooking, although reliable figures are difficult to obtain. Contrary to the general belief, the use of animal manure as an source is not confined to developing countries alone, e.g., in California a commercial plant generates about 17.5 MW of electricity from cattle manure, and a number of plants are operating in the Europe.

There is 54 EJ of biomass energy theoretically available from recoverable residues in developing countries and 42 EJ in industrialized regions. The amount of potentially recoverable residues includes the three main sources: forestry, crops and dung. The calculations assume only 25 per cent of the potentially harvestable residues are likely to be used. Developing countries could theoretically derive 15 per cent of present energy consumption from this source and industrialized countries could derive 4 per cent.

Sugarcane residues (bagasse, and leaves) - are particularly important and offer an enormous potential for generation of electricity. Generally, residues are still used very inefficiently for electricity production, in many cases deliberately to prevent their accumulation, but also because of lack of technical and financial capabilities in developing countries.

Obviously, to achieving such goals, these are theoretical calculations with country- and site specific problems. They do however emphasise the potential which many countries have to provide a substantial proportion of theirs from biomass grown on a sustainable basis.

BIOGAS

The largest potential for biogas is in manure from agriculture. Other potential raw materials for biogas are:

- sludge from mechanical and biological waste-water treatment (sludge from chemical waste-water treatment has often low biogas potential)
- organic household waste
- organic, bio-degradable waste from industries, in particular slaughter-houses and food-processing industries

Care should be taken not to include waste with heavy metals or harmful chemical substances when the resulting sludge is to be used as fertilizer. These kinds of polluted sludge can be used in biogas plants, where the resulting sludge is treated as waste and e.g. incinerated.

Another biogas source is landfills with large amounts of organic waste, where the gas can be extracted directly from drillings in the landfill, so called landfill gas. Such drillings will reduce uncontrolled methane emission from landfills.

Energy Content

The biogas-production will normally be in the range of 0.3 - 0.45 m^3 of biogas (60% methane) per kg of solid (total solid, TS) for a well functioning process with a typical retention time of 20 - 30 days at 32^{o}C. The lower heating value of this gas is about 6.6 kWh/m^3. Often is given the production per kg of volatile solid (VS), which for manure without straw, sand or others is about 80% of total solids (TS).

A biogas plant has a self-consumption of energy to keep the manure warm. This is typically 20% of the energy production for a well-designed biogas plant. If the gas is used for co-generation, the available electricity will be 30-40% of the energy in the gas, the heat will be 40-50% and the remaining 20% will be self-consumption.

Barriers

A number of barriers hold back a large-scale development of biogas plants in CEEC:

- commercial technology for agriculture (the largest resource base) is not available and have to be developed from existing prototypes or imported.
- it is difficult to make biogas plants cost-effective with sale of energy as the only income. The most likely applications are when other effects of the sludge-treatment have a value. This can e.g. be better hygiene, easier handling, reduced smell, and treatment of industrial waste.
- little knowledge on biogas technology among planners and decision-makers.

The environmental effects of biogas plants are:

- production of energy that can replace fossil fuels, reducing CO2 emissions
- reduce smell and hygiene problems of sludge and manure
- treatment of certain kinds of organic waste that would otherwise pose an environmental problem reduce potential methane emissions from uncontrolled anaerobic degradation of the sludge.
- easier handling of sludge, which can increase the fraction used as fertilizer and facilitate a more accurate use as fertilizer

Methods of generating Energy from Biomass

Nearly all types of raw biomass decompose rather quickly, so few are very good long-term energy stores; and because of their relatively low energy densities, they are likely to be rather expensive to transport over appreciable distances. Recent years have therefore seen considerable effort devoted to the search for the best ways to use these potentially valuable sources of energy.

In considering the methods for extracting the energy, it is possible to order them by the complexity of the processes involved:

- Direct combustion of biomass.
- Thermochemical processing to upgrade the biofuel. Processes in this category include pyrolysis, gasification and liquefaction.
- Biological processing. Natural processes such as anaerobic digestion and fermentation that lead to a useful gaseous or liquid fuel.

The immediate product, of some of these processes is heat - normally used at place of production or at not too great a distance, for chemical processing or district heating, or to generate steam for power production. For other processes the product is a solid, liquid or gaseous fuel: charcoal, liquid fuel as a petrol substitute or additive, gas for sale or for power generation using either steam or gas turbines.

WIND

Energy in the Wind

Wind resources are best along coastlines and on hills, but usable wind resources can be found in most other areas as well. As a power source wind energy is less predictable than solar energy, but it is also typically available for more hours in a given day. Wind resources are influenced by the ground surface and obstacles at altitudes up to 100 metres. The wind energy is thus much more site-specific than solar energy. In hilly terrain, for example, two places are likely to have the exact same solar resource. But it is quite possible that wind resource can be different at both places because of site condition and different exposure to the prevailing wind direction. In this regard, wind turbines planning must be considered more carefully than solar technology. Wind energy follows seasonal patterns that provide the best performance in the winter months and the lowest performance in the summer months. This is just the opposite of solar energy.

For this reason small wind and solar systems work well together in hybrid systems. These hybrid systems provide a more consistent year-round output than either wind-only or PV-only systems.

It is important to know that the amount of wind power generated is proportional to the density of air, area swept by the rotor blades of the wind turbine, and to the cube of the wind speed.

<u>Air density</u>

Blades of the wind generator rotate because air mass is moving them. The more air can move the blades, the faster the blades will rotate, and the more electricity the wind generator will produce. From the physics comes out that the kinetic energy of a moving body (e.g. air) is proportional to its mass (or weight) so the energy in the wind depends on the density of the air. Density refers to the amount of molecules in unit volume of air. At normal atmospheric pressure and at 15° Celsius air weighs some 1,225 kg per cubic metre, but the density decreases slightly with increasing humidity. Air is denser in winter than in the summer. Therefore, a wind generator will produce more power in winter than in summer at the same wind speed. At high altitudes, (in mountains) the air pressure is lower, and the air is less dense. It is obvious that the density of air is variable that we can't do anything about.

Rotor area

The rotor of the wind turbine "captures" the power in the mass of the air that is passing through. It is clear that the larger area covered by a rotor means, the more electricity it can produce. The rotor area determines how much energy a wind turbine is able to use from the wind. Since the rotor area increases with the square of the rotor diameter, a turbine, which is twice as large, will receive four times as much energy. But increasing rotor area is not as simple as putting bigger blades on a wind generator. At first glance, this appears to be a very easy way to increase the amount of energy that a wind generator can capture. But by increasing the swept area we have also increased all of the stresses on the wind system at any given wind speed. In order to compensate for this change and let the wind system survive, it is important to make all of the mechanical components stronger. Obviously this approach is going to get very expensive.

Wind speed

The wind speed is most important factor influencing the amount of energy a wind turbine can convert to electricity. Increasing wind velocity increases the amount of air mass passing the rotor, so increasing wind speed will also have an effect on the power output of the wind system. The energy content of the wind varies with the cube of the average wind speed. Thus, if wind speed doubles, the kinetic power gained by the rotor increases eight times.

From the following table you can estimate the power of the wind for standard conditions (dry air, density 1.225 kg/m^3, at sea level pressure).

The formula for the power is

$$W/m^2 = 0.5 \times 1.225 \times v^3,$$

where v is the wind speed in m/s

m/s	W/m^2
1	1
3	17
5	77
9	477
11	815
15	2067
18	3572
21	5672
23	7452

The Technology

Wind turbines are moved by the wind and convert this kinetic energy directly into electricity by spinning a generator. Usually they use blades like the wing of a plane to turn a central hub, which is connected through a series of gears to an electrical generator. The generator is similar in construction to the generators used in traditional fossil fuel power plants. The variety of machines that has been devised or proposed to harness wind energy is considerable and includes many unusual devices. Nevertheless modern wind turbines come in two basic configurations:

1. Horizontal axis turbines (HAT) are the most common type seen sitting on top of towers with two or three blades. The orientation of the drive shaft, the part of the turbine connecting the blades to the generator, is what decides the axis of a machine. Horizontal axis turbines have a horizontal drive shaft. The blades may be facing into the wind, upwind turbine, or the wind may hit the supporting tower first, downwind turbine. Horizontal axis wind turbines generally have one, two or three blades or else a large number of blades. Wind turbines with large numbers of blades have what appears to be virtually a solid disc covered by solid blades and are described as high-solidity devices. These include the multi-blades wind turbines used for water pumping. In contrast, the swept area of wind turbines with few blades is largely void and only a very small fraction appears to be 'solid'. These are referred to as low-solidity devices. Extracting energy from the wind as efficiently as possible means that the blades have to interact with as much as possible of the wind passing through the swept area of rotor. The blades of a high-solidity, multi-blade wind turbine interact with all the wind at a very low tip speed ratio, whereas the blades of a low-solidity turbine

have to travel much faster to virtually fill up the swept area, in order to interact with all the wind passing through. Theoretically, the more blades a wind turbine rotor has, the more efficient it is. However, large numbers of blades interfere with each other, so high-solidity wind turbines tend to be less efficient overall than low-solidity turbines. The pumps that are used with water pumping wind turbines require a high starting torque to function. Multi-bladed turbines are therefore generally used for water pumping because of their low tip speed ratios and resulting high torque characteristics.

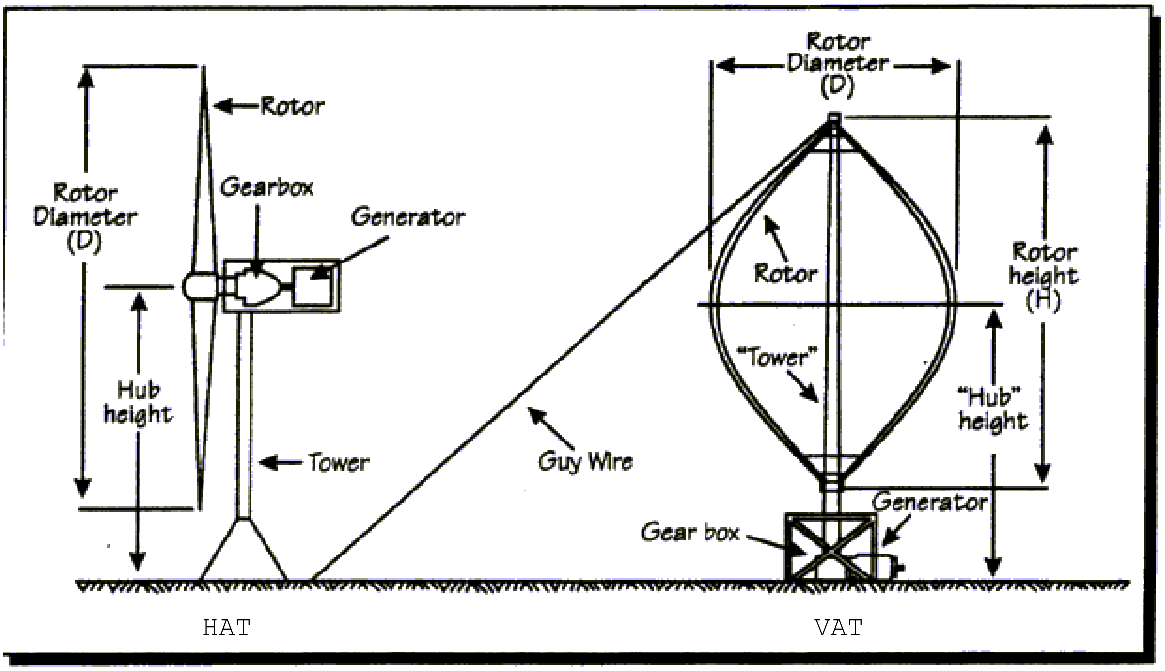
2. Vertical axis turbines[2] (VAT) have vertical drive shafts. The blades are long, curved and attached to the tower at the top and bottom. There are not so many manufacturers of such turbines in the world. Flowind is the most noted manufacturer of them. Vertical axis wind turbines have an axis of rotation that is vertical, and so, unlike their horizontal counterparts, they can harness winds from any direction without the need to reposition the rotor when the wind direction changes.

Despite the different appearances of HAT and VAT, the basic mechanics of the two systems are very similar. Wind passing over the blades is converted into mechanical power, which is fed through a transmission to an electrical generator. The transmission is used to keep the generator operating efficiently throughout a range of different wind speeds. The electricity generated can be used directly, fed into a transmission grid or stored for later use.

Wind turbines can be built with two different forms of operation: pitch- or stall-regulation. Both systems have advantages and disadvantages. With pitch regulation, the blades can be pitched, which means better utilisation of the wind and more energy from the wind turbine; on the other hand, the turbine has to be equipped with blade bearings, a blade-pitch regulation system, etc- parts which experience shows can give rise to operating problems. With stall regulation the blades are fixed and there is no pitch- adjusting system. A stall-regulated wind turbine is so to speak self-

[2] The modern VAT evolved from the ideas of the French engineer G. Darrieus

regulating and thus simpler, and it requires less maintenance and service; on other hand, one cannot utilise the wind quite as well as with pitch regulation.



Major Components of Horizontal and Vertical Axis Wind Turbines

HYDROPOWER

In hydro power plants the kinetic energy of falling water is captured to generate electricity. A turbine and a generator convert the energy from the water to mechanical and then electrical energy. The turbines and generators are installed either in or adjacent to dams, or use pipelines to carry the pressured water below the dam or diversion structure to the powerhouse.

The power capacity of a hydropower plant is primarily the function of two variables:

(1) Flow rate expressed in cubic meters per second (m^3/s), and

(2) The hydraulic head, which is the elevation difference the water, falls in passing through the plant. Plant design may concentrate on either of these variables or both.

From the energy conversion point of view, hydropower is a technology with very high efficiencies, in most cases more than double that of conventional thermal power plants. This is due to the fact that a volume of water that can be made to fall a vertical distance, represents kinetic energy which can more easily be converted into the mechanical rotary power needed to generate electricity, than caloric energies. Equipment associated with hydropower is well developed, relatively simple, and very reliable. Because no heat (as e.g. in combustion) is involved, equipment has a long life and malfunctioning is rare. The service life of a hydroelectric plant is well in excess of 50 years. Many plants built in the twenties - the first heyday of hydroelectric power - are still in operation.

Since all essential operating conditions can be remotely monitored and adjusted by a central control facility, few operating personnel are required on site. Experience is considerable with the operation of hydropower plants in output ranges from less than one kW up to hundreds of MW for a single unit.

Types of Hydropower Facilities

Hydropower technology can be categorised into two types: conventional and pumped storage. Another way of classification of hydropower plants is according to:

- Rated power capacity (big or small)
- Head of water (low, medium and high heads)
- The type of turbine used (Kaplan, Francis, Pelton etc.)
- The location and type of dam / reservoir.

Conventional hydropower plants use the available water energy from a river, stream, canal system, or reservoir to produce electrical energy. Conventional hydropower can be further divided between impoundment and diversion hydropower. Impoundment hydropower uses dam to store water. Water may be released either to meet changing electricity needs or to maintain a constant water level. Diversion hydropower channels a portion of the river through a canal or penstock, but may require a dam. In conventional multipurpose reservoirs and run-of-river systems, hydropower production is just one of many competing purposes for which the water resources may be used. Competing water uses include irrigation, flood control, navigation, and municipal and industrial water supply.

Pumped storage hydro-electricity is a remarkably simple principle. To start with, two reservoirs at different altitudes are required. Water stored at height offers valuable potential energy. During periods of high electrical demand, the water is released to the lower reservoir to generate electricity. When the water is released, kinetic energy is created by the discharge through high-pressure shafts, which direct the water through turbines connected to generator/motors. The turbines power the generators to create electricity. After the generation process is complete, water is pumped back to the upper reservoir for storage and readiness for the next cycle. The process usually takes place overnight when electricity demand is at its lowest.

While pumped storage facilities are net energy consumers, they are valued by a utility because they can be rapidly brought on-line to operate in a peak power production mode. This process benefits the utility by increasing the load factor and reducing the cycling of its base load units. In most cases, pumped storage plants run a full cycle every 24 hours.

Components of a Hydropower Plant

Most conventional hydropower plants include the following major components:

- Dam - controls the flow of water and increases the elevation to create the head. The reservoir that is formed is, in effect, stored energy.
- Turbine - turned by the force of water pushing against its blades.
- Generator - connects to the turbine and rotates to produce the electrical energy.
- Transformer - converts electricity from the generator to usable voltage levels.
- Transmission lines - conduct electricity from the hydropower plant to the electric distribution system.

In some hydro power plants also another component is present – penstock, which carries water from the water source or reservoir to the turbine in a power plant.

Determining Power

At most sites, what is called run of river is the best mode of operation. This means that power is produced at a constant rate according to the amount of water available. Usually the power is generated as electricity and can be eventually stored in batteries. The power can take other forms: shaft power for a saw, pump, grinder, etc. Both head and flow are necessary to produce power. Even a few litres per second can be useful if there is sufficient head. Since power = Head x Flow, the more you have of either, the more power is available.

To calculate available power, head losses due to friction of flow in conduits and the conversion efficiency of machines employed must also be considered. The simple formula for potential power output is:

Power (kW) = Head (metres) x Flow (m^3/second) x Gravity (9.81) x Efficiency (0.6)

Head = Net head = Gross head -losses (m). Here the overall efficiency was set at 60%.

For small outputs of interest here, and as a first approximation, the formula can be simplified:

Power (kW)= Head (m) x Flow (litres/second)/200

Here the overall efficiency of 50% is implied. The “rule of thumb” calculation is therefore on the conservative side.

Keep in mind that hydropower is produced 24 hours a day. So 100 W in hydropower plant is equivalent to a PV system of 400-500 W if the sun shines every day. Of course, the water may not run year round either.

The efficiencies (including turbine and generator efficiencies), which were chosen in above-mentioned equations between 50-60%, depend on make and operating conditions (head and flow). Generally, low head, low speed water wheels are less efficient than high head, high-speed turbines. The overall efficiency of a system can range between 40% and 70%. A well-designed system will achieve an average efficiency of 75%. Turbine manufacturers should be able to provide a close estimate of potential power output for their turbine, given the head and flow conditions at your site. There will also be “line” losses in any power lines used to transmit the electricity from the generator to the site of use.

A turbine/generator that produces 500 watts continuously (12 kWh per day), and includes batteries for power storage, will be sufficient to meet the power requirements of a small house for lighting, entertainment, a refrigerator, and other kitchen appliances. Remember that using energy conservatively in energy-efficient appliances can reduce energy requirements significantly.

Estimation of annual electricity production E:

E (kWh) = Power (kW) x Time (hours)

where time is estimated number of operational hours in the year. Mostly it is supposed to be 5000 hours.

Rule of Thumb In a typical small hydro power plant every litre per second (0.001 m^3/s) of water falling down from 1-meter height can produce 20 - 30 kWh of electricity per year.

WAVE ENERGY

A large part of the major influx of energy to this planet, solar energy, is converted by natural processes, i.e. through wind generation, to energy associated with waves. Waves are generated by the wind as it blows across the ocean surface. The energy thus contained is significant, in favoured latitudes with values of around 70 MW/km of wave frontage.

Ocean waves represent a considerable renewable energy resource. They travel great distances without significant losses and so act as an efficient energy transport mechanism across thousands of kilometres. Waves generated by a storm in mid-Atlantic will travel all the way to the coast of Europe without significant loss of energy. All of the energy is concentrated near the water surface with little wave action below 50 metres depth. This makes wave power a highly concentrated energy source with much smaller hourly and day-to-day variations than other renewable resources such as wind or solar.

The highest concentration of wave power can be found in the areas of the strongest winds, i.e. between latitudes 40 deg. and 60 deg. in both the northern and southern hemispheres on the eastern sides of the oceans. Countries like the United Kingdom are thus the world's most favoured locations for the extraction of wave power.

Technology

Typically ocean wave devices capture the energy of waves and convert their energy to electricity. Wave energy devices include hydro-piezoelectric, oscillating water columns, wave run up (tapered channel) and sea clams. Particularly 'sea clams' involve wave action forcing air between blades located on the perimeter of a circular barge structure. The air is then run through air turbines, which rotate at a shaft connected to an electrical generator.

Europe, and in particular the United Kingdom, are looking at wave power. A recent review by the UK government has shown that there are now types of wave power devices which can produce electricity at a cost of under USD 0,10/kWh, the point at which production of electricity becomes economically viable. The most efficient of the devices, the "Salter" Duck can produce electricity for less than USD 0,05/kWh. The "Salter" Duck was developed in the 1970s by Professor Stephen Salter at the University of Edinburgh in Scotland and generates electricity by bobbing up and down with the waves. Although it can produce energy extremely efficiently it was effectively killed off in the mid 1980s when a European Union report miscalculated the cost of the electricity it produced by a factor of 10. In the last few years, the error has been realised, and interest in the Duck is becoming intense.

The “Clam” is another device which, like the “Salter” Duck can make energy from sea swell. The Clam is an arrangement of six airbags mounted around a hollow circular spine. As waves impact on the structure air is forced between the six bags via the hollow spine which is equipped with self-rectifying turbines. Even allowing for cabling to shore, it is calculated that the Clam can produce energy for around USD 0,06 /kWh.

Both the Duck and the Clam generate energy from waves at sea. This is useful for generating energy for offshore structures and low-lying islands. However, where islands offer suitable sites, cliff-mounted oscillating water column (OWC) generators have a number of advantages, not the least of which is the fact that generators and all cabling are shore-based, making maintenance of the former and replacement of the latter much simpler. The OWC works on a simple principle. As a wave pours into the main chamber, air is forced up a funnel, which houses a turbine. As the wave retreats, air is sucked down into the main chamber again, spinning the turbine in the opposite direction

TIDAL POWER

Tidal energy differs from all other energy sources in that the energy is extracted from the potential and kinetic energies of the earth-moon-sun system. The well-known ocean tides result from this interaction, producing variations in ocean water levels along the shores of all continents. As the water level fluctuates twice daily through this range, it alternately fills and empties natural basins along the shoreline, suggesting that the currents flowing in and out of these basins could be used to drive water turbines connected to generators and thus to produce electricity. The higher the tides, the more electricity can be generated from a given site, and the lower the cost of electricity produced. The technology employing this energy source is very similar to that of low head hydropower.

Potential

Worldwide, approximately 3000 GW of energy is continuously available from the action of tides. Experts estimated that only 2% (60 GW), which is about 50 times less than the world's potential of hydroelectric power capacity, can potentially be recovered from tides for electricity generation. Currently, only in places with large tidal range (greater than 5 meters) can tidal power be extracted economically.

In some places of the world tidal energy is quite attractive. For coastal areas, usually at the entrances to large estuaries, resonance can occur, leading to far greater than average tidal ranges which could relatively conveniently be blocked off. Such circumstances are found e.g. in Canada, with a mean tidal range of 10.8 metres or in the Severn Estuary in Britain with a mean range of 8.8 metres, making large scale projects at both these locations economical.

Development

Over the past forty years, there has been constant interest in harnessing tidal power. Initially, this interest focused on estuaries, where large volumes of water pass through narrow channels generating high current velocities. Engineers felt that blocking estuaries with a barrage and forcing water through turbines would be an effective way to generate electricity. From an engineering point of view they were right. But, increasingly the environmental costs of such a design became clear.

There are three commercial-scale tidal power plants (barrages) in operation: a 240 MW plant which was completed on the estuary of the La Rance River near St. Malo, France in 1967, a 1MW plant on the White Sea in Russia completed in 1969 and a 16 MW plant in Nova Scotia, Canada. The environmental problems have prevented further development of the barrage technology.

Tidal power plant in La Rance.

Tidal power plant at La Rance River has turbines that can also serve as pumps; thus, the installation can function as a pumped hydro storage facility to even out the loads on a large electricity generating and distribution system. In this way water pumped into the basin during times of low power demand increases the head on the turbines at other times. Tidal range there is up to 13.4 meters. The dam's width is 760 meters. At high tide, the dam traps Atlantic waters in the bay. At low tide, the water flows back to the sea. En route, it passes through 24 turbines connected to generators that produce 240 megawatts of power. This provides enough electricity for a city of 300,000. In 1997, they began installing turbines that can spin on both the incoming and outgoing tides.

Technology

Tidal power is a proven technology: it has been used for centuries in small mill-type applications where natural conditions make it possible. Tidal energy can be converted into electrical energy in several ways. Conventional systems such as barrages (or low dams) store water in inlets from high tides for release through hydraulic turbines during lower tides. The newest technology, which converts tidal or coastal currents to power, seems to be very promising because it is less environmentally destructive.

The usual technique (referred to as "barrage" technology) is to dam a tidally-effected estuary or inlet, allowing the tidal flow to build up on the ocean side of the dam and then generating power during the few hour high tide period. In this way it is functioning in La Rance. After the water level reaches maximum high tide, gate valves are closed and the water is impounded and awaits low tide when it is released and produces power. The gates can be opened or closed in sequence with the tides permitting water flow only when there is sufficient head to power the turbines. The basic technology of power production is similar to that for low head hydro power plants what means that the head drives the water through the turbine generators. The main difference, apart from the salt-water environment, is that the turbines in tidal barrages have to deal with regularly varying heads of water. The turbines are designed so that the flow of water both into and out of the basin produces electricity. Because of the intermittent nature of this flow, the effective duty factor of such an installation is less than 100%. A tidal power station produces only about one third as much electrical energy as would a hydroelectric power plant of the same peak capacity operating continuously. Tidal barrages are effectively fences, which completely block an estuary channel.

Future of Renewables

The shape of our future will be largely determined by how we generate and apply technological innovation the most powerful force for progress in the modern world. The renewable energy sources are able to have a strong transformative effect on the whole of society in the coming decades. By virtually all accounts, renewable energy resources will be an increasingly important part of the power generation mix over the next several decades. Not only do these technologies help reduce global carbon emissions, but they also add some much-needed flexibility to the energy resource mix by decreasing our dependence on limited reserves of fossil fuels. Experts agree that hydropower and biomass will continue to dominate the renewables arena for some time. However, the rising stars of the renewables world - wind power and photovoltaics - are on track to become strong players in the energy market of the next century. Wind power is the fastest-growing electricity technology currently available. Wind-generated electricity is already competitive with fossil fuel based electricity in some locations, and installed wind power capacity now exceeds 10,000 MW worldwide. Meanwhile, PV electricity - although currently three to four times the cost of conventional, delivered electricity - is seeing impressive growth worldwide. PV is particularly attractive for applications not served by the power grid. Advanced thin-film technology (a much less expensive option than crystalline silicon technology) is rapidly entering commercial-scale production.

Additional notes on Renewable Energy Technologies were provided as hard copies in the respective folders.