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ALTERNATIVE ENERGY SOURCES

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INTRODUCTION

One of the features of quickly growing population is the increasing application for the energy. Although there are some well-developed countries, which managed to set the use of energy on the stable level, or even reduce it by means of saving energy in one hand, and improving the efficiency during the transformation of energy in the other hand, this situation presents completely different in other countries. According to expectations a lot of ways shall be used to satisfy the needs. First of all, the usage of fossil fuels will be consolidated and secondly alternative sources of energy will be more widely in use.

If the 1960's were dominated by concerns about pollution and overpopulation, the event most central to the development of environmentalism during the 1970's was the energy price shocks of 1973 and 1979. The energy crisis had two profound, and seemingly contradictory, consequences: First, the crisis instilled a notion of limits**,** second, the crisis instilled a notion of hope. In essence, the crisis brought home the recognition that certain natural resources (coal, oil, natural gas, minerals) are non-renewable. Because they take so long to make (hundreds of thousands or millions of years), when they are gone, they will be gone for good. Thus, society needs to place limits upon its use of these resources so that they will be available in the future.

Sources of oil, according to OPEC (Organization of the Petroleum Exporting Countries), will be sufficient for 100 years, while the coal deposits could be exploited for few more hundred years. What is more the fossil fuels are harmful for the environment as the source of greenhouse gases.

Perspectives of the exhaustibility and anxiety of environmental pollution made the alternative sources more interesting in 1990s. As the result the amount of energy (heat and electric energy) produced from sun radiation increased two times since 1990, and from the wind energy even four times. In 1997 there was an international climatic conference in Kioto (Japan), where the representatives of most industrial countries decided to reduce the emission of CO_2 to the atmosphere. It was a very important step for renewable resources development.

Technologies of alternative sources of energy are so developed that can be competitive to the conventional energy systems. Renewable energy sources are local sources so can increase the level of energetic safety diminishing the export of fossil fuels, can create new places of work, especially in small and medium firms, promote region development. The module character of the most of the alternative sources technologies allows to their gradual developing as the needs arises what at the same time make the financing easier. We should also remember about the benefits to the environment while applying those sources.

SOLAR ENERGY

1. Introduction

Solar radiant energy can be characterised as a clean, renewable, inexhaustible and abundant energy source. The capture of solar energy has almost no negative impact on the environment. There are no air or water emissions and therefore does not contribute to any of the environmental problems such as acid rain or global warming, which are associated with the most popular sources of energy. The positive effect of solar energy has been known for ages and it has happened only recently that our technology pushed us away from the sun, promising electrical light available whenever we want and plenty of heat from those supplies of fossil fuels that eventually will be consumed. Such behaviour leads us to action against Nature instead of with it. Utilising solar energy is one of the easiest changes we can make, which will also have a profound effect on the rest of our precious resources. It is thus an interesting alternative source of energy.

Solar heating systems can be divided into passive and active systems. Generally passive systems have no moving parts, like pumps and fans, and energy conversions are, transfer and storage are based on natural processes in building structures. Basic principles of passive solar heating were known already during the Hellenic period. Modern construction materials like transparent insulators have made it possible to construct buildings according to passive solar heating principles with extremely low energy consumption[1].

Active systems employ special collecting devices that collect solar radiation, and electric fans or pumps to distribute heat from the collectors. A liquid or air is used as the heat transfer fluid. Most systems also incorporate storage systems to provide heat when the sun is not shining. They have been developed mainly during this century.

These two applications of solar energy have proven themselves popular over a decade of use. They also illustrate the two basic methods of gaining control of solar energy: solar thermal systems and solar electric systems. The first one covert the radiant energy of the sun into heat and then use that heat energy as desired. The latter converts the radiant energy of the sun directly into electric energy. Passive solar heated homes and small stand-alone photovoltaic cells are the most popular systems, but there are also others, still effective, solar energy systems like: domestic water heating systems (are obligatory in Israel for over a decade [1]), remote solar powered water pumping systems, and remote electric power systems for radio repeater.

2. The solar resource

The Sun is the sphere of high temperature gases about 1.4 million kilometres in diameter. The temperature of the interior of the Sun is 15 million degrees Kelvin. This high temperature combined with a pressure that is 70 billion times higher than atmospheric pressure on Earth creates ideal conditions for fusion reactions. The fusion reaction in the Sun is hydrogen atoms combining to form of high-energy radiation, mainly gamma rays. As this radiation migrates from the centre to the outside of the solar sphere, it reacts with various elements inside the sun and is transformed into lower-energy radiation, primarily in the visible light and heat portions of energy spectrum [2]. Such electromagnetic radiation, including visible light, infrared light and ultra-violet radiation, streams out into space in all directions.

The sun has been producing energy in this manner for around five billion years, and will continue to do so for several more billion.

Only a very small fraction of the total radiation produced reaches Earth, but for our planet it is an enormous amount of energy. Much of this is reflected into space by clouds before it reaches the planet's surface. 99% of sunlight which does reach the ground is converted into heat (the remaining 1% is captured by plants and used in photosynthesis) and radiated back into space. If only a small energy could be used, the world's energy demand could be met. Even in cold climates like Canada, the amount of useful solar energy reaching the ground in the winter is greater than daily heating requirements of a well-insulated house [3]

3. History of solar energy

Since the dawn of times, life on Earth has relied on the Sun for energy. First evidence was observed at the end of IV millennium BC in ancient Mesopotamia. Although at that moment nobody tried to interfere in natural biological effect, when the time passed, people started to look for practical utilisation of Sun and protection against its burning radiation. The Greeks were the first who used solar architecture, orienting their houses to make use of the sun during winter, while obscuring its rays during summer. The houses in entire cities were built in this way as early as 400 BC Socrates (469-399 BC) was one of the initiators whose house was constructed taking into account the sun radiation. His 'solar house' was to assure maximum usage of winter sun and complete shield in the southern side from direct radiation in summer (fig.1) [4]. Three main rules were applied:

1. Main rooms should be faced south
2. North side of building should be shielded from cold winds
3. Eaves should be added to provide shade for south windows in summer

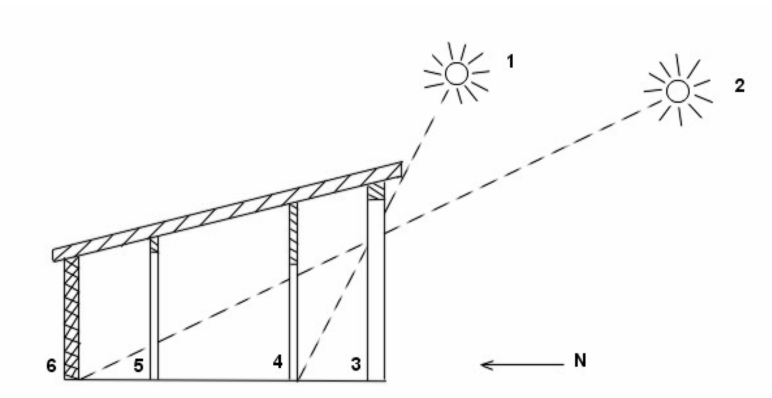

Fig.1: 1-solar radiation in south elevation in summer, 2-solar radiation in south elevation in winter, 3-terrace with a roof, 4-living room, 5-store, 6-northern isolating wall

Most famous areas of solar architecture of ancient Greece are excavations in Olynthus, Colophon, Delos and Priene. Year 212 B.C. was one of the most important in solar Greek history. In that time Archimedes reputedly set fire to attacking Roman fleet by a mean of burning glass composed of small square mirrors used to focus the sun beams toward the Roman fleet.

However, Romans went even further in expanding use of solar energy since central heating and large central baths quickly consumed forests around Rome. They even incorporated the sun into their legal system that nobody could deny their solar access. In the 1^{st} century they developed window glass, which allows sunlight to come in, but simultaneously traps solar heat, just like in the car parked in the sunlight. Furthermore they used dark colours and pottery to store thermal energy. Romans used solar energy not only in houses but also to enjoy the fruits and vegetables of their conquests. For example, when they went to Middle East or Africa, they would bring home exotic fruits and vegetables, and they would want to grow them in their colder climate by using glass covers for greenhouses. In 37 AD first greenhouse was used to grow cucumbers for Tiberius Caesar.

Other early civilisation like Chinese, Anasazi and Pueblo used solar energy for heating, water evaporation, and other applications as well.

Passive solar system was also, but much later, in use in other regions especially in South-West areas of South America. Constructions of Indian housing estates from 1100-1400 AC were found there.

Collectors began their existence when a French-Swiss scientist Horace de Saussure began to experiment how much heat window glass could actually trap. He built a little box and put several glass tops on it, and found out he could reach above boiling point inside the box. In 1767 he invented the first plat collector. A hundred years later a solar heat engine was designed by John Ericsson. The intensive research on the availability of solar energy as human future energy resource begun in 1940 when Godfray Cabot left a large sum of money for research projects at the Massachusetts Institute of Technology. In that time the first active solar house was built and since than the great progress in utilisation of solar energy can be observed.

4. Passive solar energy

Passive solar energy relates to the use of the Sun's energy for heating a solid structure or a water supply. Passive solar building features can be used to heat and to cool buildings as well as provide light. The best time to incorporate passive solar technologies in a structure is during its initial design. They can be included in a new building without significantly adding to construction costs, while at the same time providing energy savings up to 40%. Designing the buildings we live and work in, to capture the ambient energy of the sun trough passive solar feature is one of the least expensive and most environmentally friendly methods of providing for our energy needs [3].

Passive solar systems consist of three parts: collection, storage and distribution, which all work together to take the energy into the home and spread it out to be used when and where it is needed [5].

Collection is generally the intake of sunlight into the home through energy-efficient windows, which face the sun as it travels its arc across the sky. That is why planning and site selection is so crucial at this point.

Radiation from the Sun reaches earth after 8 minutes. The amount of solar energy reaching a specific location on the surface of the earth at a specific time is called 'insolation'. Its value depends on several factors. If the sun is directly overhead and the sky is clear, radiation on a horizontal surface is about 1000 watts per square meter [W/m^2]. This is the highest value insolation can have on earth's surface except by concentrating sunlight with devices such as mirror or lenses. If the sun is not directly overhead, the solar radiation received on the surface is less because there is more atmosphere between the sun and the surface (Fig.2).

Fig.2

Insolation also decreases when a surface is not oriented perpendicular to the sun's rays. This is because the surface presents a smaller cross-sectional area to the sun (Fig.3)[2].

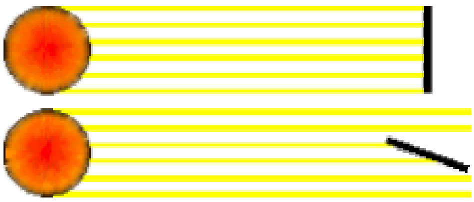

Fig.3

The latitude and the topography shape the accessibility of sun light and radiation intensity. They influence the length of the shape as well. The scheme in Fig.4 indicates that slope in the south direction get the highest amount of solar radiation on the area unit and the house set the least shape. In the northern slope, however, the same amounts of radiation reaches smaller area and at the same time give less light and heat.

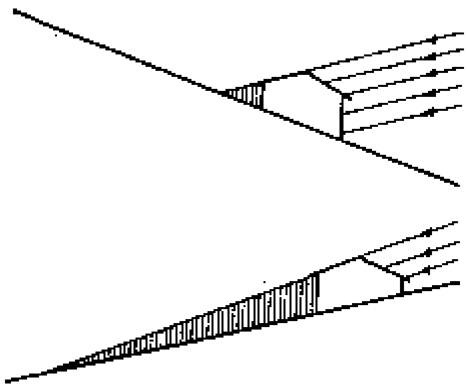

Fig.4: upper -south slope, lower-slope in north direction

During considering the passive usage of solar energy we should also think of the radiation that is reflected from the ground, because albedo – the ratio of reflected radiation to falling one – used in a proper way may considerably increase the amount of radiation received from the surface. From example the snow cap in front of the house increases the quantity of radiation that reaches windows and in the same time the inferior of the building. It has a great meaning especially in winter.

Surface type	Snow	White gravel	Bright soil	Dark soil	Dense grass
Albedo (%)	75-95	85-90	22-32	10-15	29

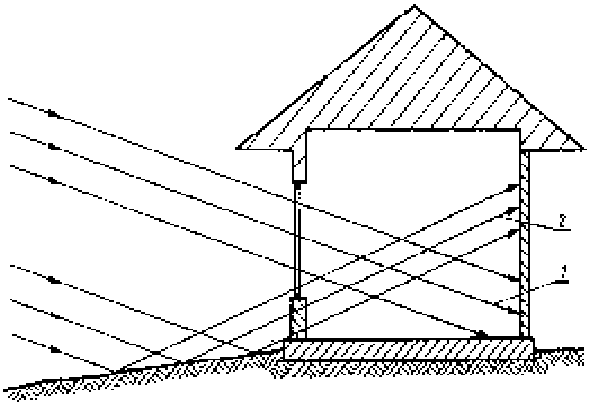

Fig.5: 1-direct radiation, 2-reflected radiation

The other important feature of effective gaining passive solar energy is the situation of houses in a housing estate. The most proper localisation is along the east-west streets. In such arrangement one of the longest walls in the house is directed south. In middle latitudes (including Poland) there is a little deviation from the east-west line possible. The tolerable one is to 25°[4].

One more thing that should be considered is forest and lonely trees. By designing the house just right behind the forest a specific protection against the wind is created. It is because incoming air streams flow over the trees, loose their velocity and fall down far away from the building. In case of planting the lonely trees like a pine or spruce close to a house wall make the protection layer against heat looses (Fig.6).

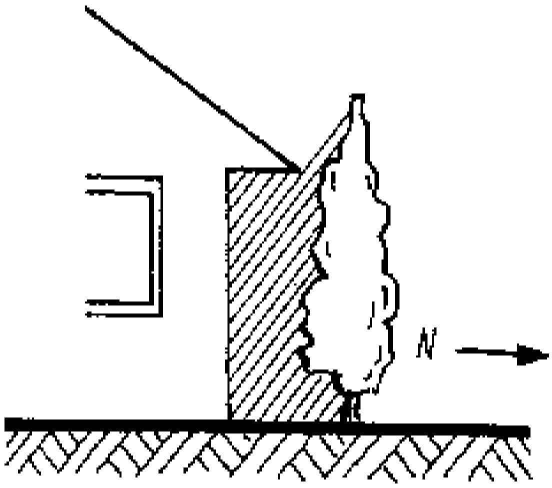

Fig.6

There are three main types of passive solar system: direct gain, indirect gain, and isolated gain (Fig.7). These designs are based upon the different methods used in the collection, storage and distribution of the energy.

Direct solar gain, the main source of passive solar heat, is accomplished by capturing the sun's energy through large areas of south facing windows. The direct gain system will utilise 60 - 75% of the sun's energy striking the windows. Window glass is virtually transparent to incoming solar radiation. When sunlight strikes the inferior of the building, it is converted into heat, which is not as readily transmitted back through the glass, what results in a heat gain inside the house. Window glass, however, is generally not a good insulator, and increased solar heat during the day can be offset by loss of heat through windows at night. New high efficiency, triple glazed windows with special coatings have recently been developed that that have such a high insulation value that they are net producers of heat even when facing north in the winter. Insulated shutters can also be placed over windows at night to reduce heat loss [3]. Reducing the loss of heat in building with passive solar system is one of the most important things to be considered.

Indirect gain utilises a storage system immediately inside the window to collect the sunlight. This system can be either a solid wall, called a Trombe wall, or a system of water vessels. Since the storage mass is immediately absorbing the sunlight, it captures more of the energy, but it also blocks the window from light and external views, so this system must be carefully planned as well. The indirect gain system will utilise 30 - 45% of the sun's energy striking the glass adjoining the thermal mass.

Isolated gain concerns the addition of the sunspace. Sunspaces are simple glassed in enclosures attached to the outside of a building. These greenhouse-like spaces heat up during the day. The heat is stored in the floor and walls and slowly diffused throughout the rest of the house. At night sunspaces cool right down and as such are not often used as living spaces because they are too hot during the day and too cold at night. Since sunspace is not directly a part of the house, the house is more protected from the temperature fluctuations. The isolated gain system will utilize 15 - 30% of the sunlight striking the glazing toward heating the adjoining living areas. This method is often used in conjunction with another method.

Passive application of solar energy consists on letting into the room the maximum amount of light without complicated installation. One of the most popular utilizations of passive solar energy is Sun Tunnel Skylight. It consists of a dome, flexible tube and prismatic dissipater. The mechanism of rather simple.The dome in the roof concentrates the light even in cloudy days. Then the light goes through the flexible tube till it meets the dissipater, which appeases the brightness of light and disperse it in the whole room. Sun Tunnel delivers 6000-10000 of lumens of light (in comparison a traditional 100 W bulb only 1200). It is almost imperishable (a bulb gives light for about 2000 hours) and after the installation there are no more payments for the exploitation. Thanks to Sun Tunnel we can limit or completely resign with the traditional light. What is more it can prevent from so called ‘winter depression’, which is caused by too little amount of natural light during this season. It also favourably influences plants and animals. The difference that Sun Tunnel creates is presented in Fig.8.

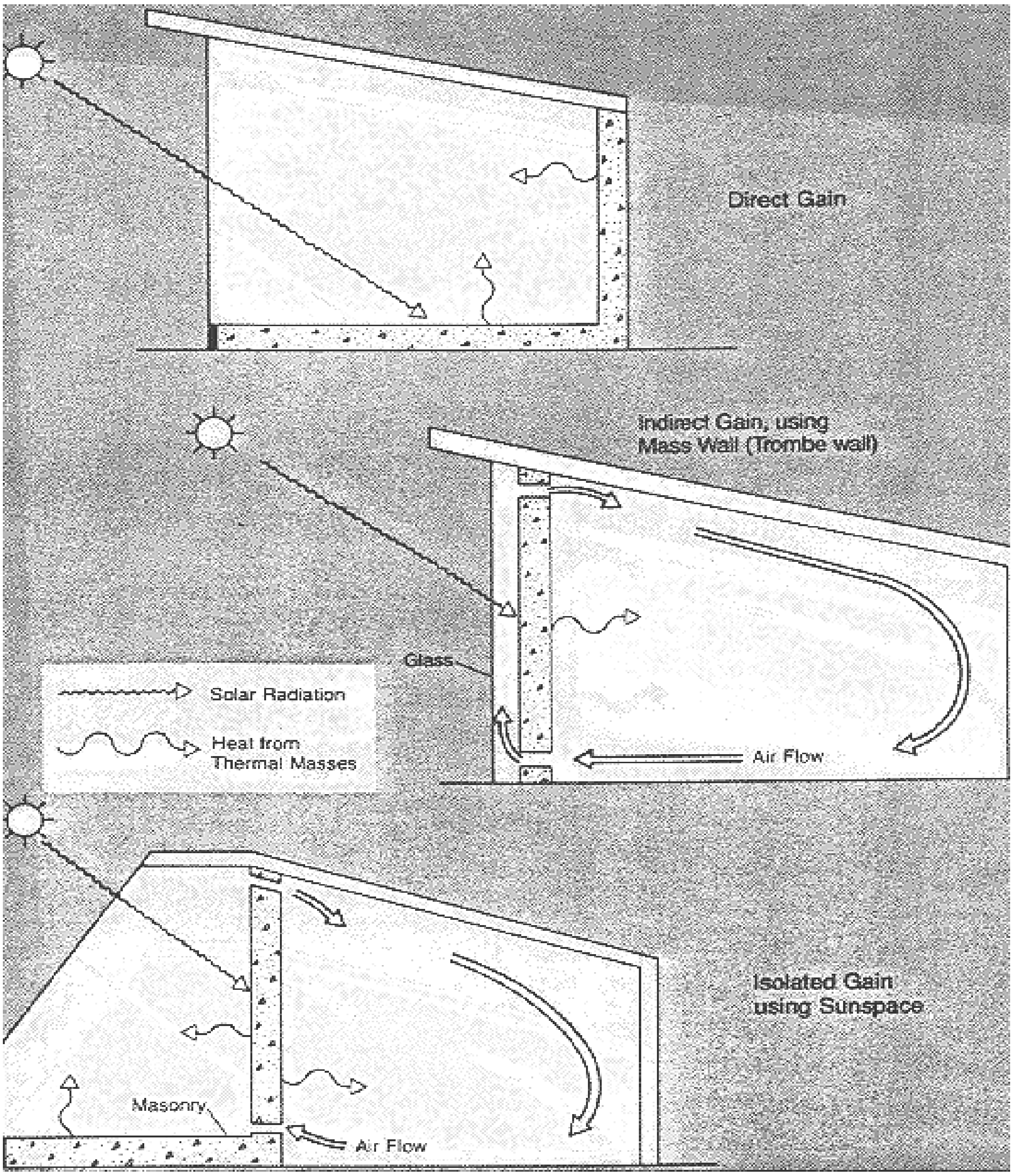
Direct Gain
Indirect Gain, using
Mass Wall (Trombe wall)
Glass
Solar Radiation
Heat from
Thermal Masses
Air Flow
Isolated Gain
using Sunspace
Masonry
Air Flow

Fig.7

Fig.8

5. Active solar energy

Active solar systems consist of collectors that collect solar radiation and electric fans or pumps to distribute heat from the collectors. A liquid or air is used as the heat transfer fluid. Most systems also incorporate storage systems to provide heat when the sun is not shining. Most building codes and mortgage lenders require a back-up heating system for houses heated with solar energy. Back-up systems supply heat when, for example, there are long periods of cloudy weather. Back-up systems range from a wood stove to a conventional heating system. It should be capable of supplying 100% of the home's heating requirements for periods of cloudy weather when little solar heat is available.

Active solar energy systems are usually designed to provide 40% to 80% of the home's heating needs. Systems providing less than 40% of the heat needed for a home are rarely cost-effective except when using air panels for walls, window boxes, and other collectors that heat one room and require no heat storage. Data from systems installed through a government demonstration program, however, indicates that active space heating systems are most economical when they are designed to handle about 50% of a home's heating requirements. A system sized to provide much more than this would not be economical because some of the extra capacity would only be used during the coldest days. The rest of the time the extra equipment would be idle.

There are two basic types of active solar heating systems. These are liquid or air systems, based on the type of fluid heated in the collectors. Liquid systems use water or an antifreeze solution to capture, transfer, and store heat produced by "hydronic" collectors. Air systems use air to capture, transfer, store, and distribute heat from the "air" collectors. Both of these systems collect solar radiation, then distribute and store the heat that the collectors produce. If the system storage cannot provide adequate space heating, an auxiliary or back-up system provides the additional heat. Not all systems store the heat that they collect; they immediately distribute the heat for space heating. Liquid systems are more popular than air systems because they cost less to operate and take up less space. However, depending upon the needs and location the advantages of an air system may outweigh its disadvantages. Air collectors produce heat earlier and later in the day than liquid systems. Air systems produce more usable energy over a heating season than a liquid system of the same size. Also, unlike liquid systems, air systems do not freeze, and minor leaks will not cause problems.

Liquid systems use water, antifreeze, or a phase-change liquid such as methyl alcohol, as the heat transfer or "working" collector fluid. Liquid system components include hydronic collectors, a storage tank, pumps, pipes, a heat exchanger, and controls. The collectors absorb solar radiation and transfer it to the liquid. At the appropriate time, a controller operates a circulating pump, circulating the working fluid through the collector. The liquid returns either to a storage tank or to a heat exchanger for immediate use. Therefore, when the home does not need to be heated and solar radiation is adequate, liquid systems can store solar energy without heating the living space. Ways of storing heat in such system would be described in the following section.

An air system uses air as the working fluid for collecting solar energy. This type of system is composed of collectors, a rock storage bin, fans, ductwork, and controls. It operates in three modes, depending on how much heat is available. In the "simplest mode," heated air moves directly from the collectors to the house. If it collects excess heat, the "second mode" charges the rock bin. Finally, the "third mode" allows the storage bin or a back-up system to heat the home, even when the system is not collecting heat (e.g., at night). Some systems use an air handler to distribute the heated air. An air handler is a sheet metal box containing one or more fans and several motor-driven or spring-loaded dampers. It directs air through the ducts, collectors, and storage bin of the solar system. The air handler opens the appropriate dampers, thereby regulating the modes of operation.

6. Collecting and storing energy

Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone). The storage unit is required because of the non-constant nature of solar energy; at certain times only a very small amount of radiation will be received. At night or during cloudy days, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum productivity, and release it when the productivity drops. In practice, a backup power supply is usually added, too, for the situations when the amount of energy required is greater than both what is being produced and what is stored in the container. Methods of collecting and storing solar energy vary depending on the uses planned for the solar generator.

In general, the optimum collector orientation is true south. True south is the highest apparent point in the sky that the sun reaches during the day. (True south should not be confused with magnetic south as indicated on a compass.) Collector orientation may deviate up to 20° from true south without significantly reducing the performance of the system. Collectors should be tilted at an angle equal to the present latitude plus 15°. A collector receives the most solar radiation between 9:00 am and 3:00 pm. Trees, buildings, hills, or other obstructions that shade collectors reduce their ability to collect solar radiation. Even partial shading will affect performance and increase the payback period of the system.

Collectors can be posited in different locations. They usually receive the most sunlight when placed in rows on the roof. In some cases, however, the roof may be too shady. If the roof does not receive enough sunlight, you may want to mount the collectors on a supporting structure on the ground, or in rows on the south wall of the house, where there is enough sunlight for the collectors to perform satisfactorily. Collectors mounted on the ground or on an exterior wall perform almost as well as those mounted on most roofs.

In general, there are three types of collectors and many forms of storage units.

The three types collectors are: flat – plate collectors, focusing collectors, and passive collectors. The function of the collector is to receive and capture as much of the radiant energy from the sun as is practical.

Flat – plate collector is the most commonly used type of collector today. It has a receiving surface that is flat in shape. Flat – plate collectors are arrays of solar panels arranged in a simple plane

A typical flat-plate collector is an insulated metal box with a glass or plastic cover, called the glazing, and a dark-colored absorber plate. The glazing can be transparent or translucent. Translucent (transmitting light only), low-iron glass is a common glazing material for flat-plate collectors because low-iron glass transmits a high percentage of the total available solar energy. The glazing allows the light to strike the absorber plate but reduces the amount of heat that can escape. The sides and bottom of the collector are usually insulated, further minimizing heat loss. The absorber plate is usually black because dark colors absorb more solar energy than light colors. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar radiation into heat energy. The heat is transferred to the air or liquid passing through the collector. Absorber plates are commonly covered with "selective coatings," which retain the absorbed sunlight better and are more durable than ordinary black paint. Absorber plates are often made of metal, usually copper or aluminum, because they are both good heat conductors. Copper is more expensive, but is a better conductor and is less prone to corrosion than aluminum.

Flat-plate collectors are the most common collector for residential water heating and space-heating installations and therefore they fall into two basic categories: liquid and air. Both types can be either glazed or unglazed.

Glazed liquid collectors are used for heating household water and sometimes for space heating. Unglazed liquid collectors are commonly used to heat water for swimming pools. Because these collectors need not withstand high temperatures, they can use less expensive materials such as plastic or rubber. They also do not require freeze proofing because swimming pools are generally used only in warm weather.

Flat – plate collectors can be of nearly any size and its output is directly related to a few variables including size, facing and cleanliness. These variables all affect the amount of radiation that falls on the collector. The collector is stationary and therefore receives the maximum radiation only when it faces the sun directly. At all other times it "sees" the sun at an angle, and its effective surface area is small, resulting in collection of less energy. However, more and more often these collectors have automated machinery that keeps them facing the sun and therefore loss of energy is reduced.

Focusing collectors are essentially flat-plane collectors with optical devices arranged to maximize the radiation falling on the focus of the collector. They converges the radiation to a relatively small absorbing area. High temperature can be generally achieved. Solar furnaces are examples of this type of collector. Although they can produce far greater amounts of energy at a single point than the flat-plane collectors can, they lose some of the radiation that the flat-plane panels do not. Radiation reflected off the ground will be used by flat-plane panels but usually will be ignored by focusing collectors (in snow covered regions, this reflected radiation can be significant). One other problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at high temperatures, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components [6]. A focusing collector can provide a temperature as high as 4000 ^{o} C.

Although higher temperature of the working fluid can be achieved from the concentrating collector, it is usually involved moving mechanism to track the direct sunshine for the best performance. The movement is in two directions. The collecting surface and aperture must be kept normal to the solar ray, a second motion is also needed to correct for the change in the solar declination. No matter the operation is automatic and manual, it increases the capital, operating and maintenance cost.

Passive collectors are completely different from the other two types of collectors. The passive collectors absorb radiation and convert it to heat naturally, without being designed and built to do so. All objects have this property to some extent, but only some objects (like walls) will be able to produce enough heat to make it worthwhile. Often their natural ability to convert radiation to heat is enhanced in some way, like being painted black, and a system for transferring the heat to a different location is generally added.

These passive collectors can take a few different forms. The most basic type is the incidental heat trap. The idea behind the heat trap is fairly simple. Allow the maximum amount of light possible inside through a window (The window should be facing towards the equator for this to be achieved) and allow it to fall on a floor made of stone or another heat holding material. During the day, the area will stay cool as the floor absorbs most of the heat, and at night, the area will stay warm as the stone re-emits the heat it absorbed during the day.

Another major form of passive collector is thermosyphoning walls and/or roof. With this passive collector the heat normally absorbed and wasted in the walls and roofs is re-routed into the area that needs to be heated.

The last major form of passive collector is the solar pond. The purpose of the pond is to serve as an energy regulator for a building. It is placed either adjacent to or on the building, and it will absorb solar energy and convert it to heat during the day. This heat can be taken into the building, or if the building has more than enough heat already, heat can be dumped from the building into the pond.

As it can be seen in passive system the shell of a building acts as a collector (solid surfaces and glazed surfaces). Insulation on the outside of the building allows the solar radiation to be absorbed by the internal walls after entering through the glazed openings. These glazed openings should be fitted with external shutters to prevent nocturnal heat losses. One current process consist of injecting small balls of polystyrene between the panes of double glazing, which increases the insulation and limits the negative greenhouse effect[7].

The most common method of storing passive solar heat is increasing the thermal mass of a building or sunspace. Heat can be stored in concrete, brick, rock and water by simple increasing the temperature of these materials. Water can store the greatest amount of heat per unit volume (4.2 MJ/m^3 * °C) out of these four. Other materials can store heat by changing their phase, rather than simply increasing in temperature. Calcium chloride hexahydrate is an example of a phase change material that has a heat storing capacity 10 times that of water [3].

Thermal storage can be accomplished by increasing the mass of these heat-storing materials on the inside of the building. Traditional passive solar construction techniques for storing heat include 'trombe' (mass) or water walls, water ponds (mentioned earlier), and increased thickness for tile floors and drywall. Newer technologies include wallboard made out of phase change materials, which can store a great deal of thermal energy without radical changes in building design and construction.

Storage of heat in active solar heating differs in both liquid and air system.

Liquid systems store solar heat in tanks of water or in the masonry mass of a radiant slab system. Most storage tanks require one to two gallons (3.8 to 7.6 Liters) of water for each square foot (0.093 square meter) of collector. The tanks are usually steel, concrete, fiberglass-reinforced plastic (FRP), or wood. Each type of tank has its advantages and disadvantages.

New construction often uses steel tanks because it is easier to attach pipes and fittings. These tanks are easy to construct and usually meet building codes for pressure vessel requirements. Steel tanks, however, corrode from rusting and pitting unless preventative measures are taken. Pitting is a condition where small-diameter holes form in the base metal. Rusting and pitting can be prevented by sealing the tank's surface. Chemicals can be also added to inhibit corrosion if the stored water is not used for drinking. Steel tanks often cannot be used for retrofit projects because they are often too large to fit through entrances.

Tanks made of fiberglass-reinforced plastic (FRP) do not corrode. They can be insulated in the factory or on-site. Like steel tanks, FRP tanks often cannot be used for retrofit projects because they are too large to fit through entrances.

Concrete tanks can be cast-in-place or precast and are suitable for retrofit projects. These tanks usually cost less than others. They must be lined, however, to prevent water seepage. Also, connecting pipes without leakage is often difficult. The weight of these tanks could be a disadvantage, depending on whether a well-anchored tank on a solid floor in a basement is needed, or whether the tank on floor joists in the first or second floor is installed.

Wooden tanks with plastic liners are suitable for retrofit applications. They cost less than other tanks. Water should not exceed the manufacturer's recommended temperature for the liner. These types of tanks can only be installed indoors.

In air system the storing technique is different. To store heat, an air system delivers hot air from the collectors to the storage bin. The air first enters a plenum, which is an empty mixing space at the top of the bin. It passes down through the bin where the rocks absorb most of the heat. The air then returns to the collectors from a lower plenum for reheating.

When the system uses rock bins to heat the home, it draws house air from the lower plenum up through the rocks. Warm air is then drawn from the top of the bin and distributed to the house. Thus, the rock bin serves as storage and as a heat exchanger. When storing heat, the top of the bin is usually about 60°C and the bottom of the bin is about 21.1°C. If the air in the bin is too cool, a back-up system heats the air leaving the top of the bin to the desired temperature before distributing it.

Rock bins can be installed indoors, outdoors, or underground. Most rock bins are installed in crawl spaces and basements because warm air naturally rises to the living space. Because of this, bins in these locations distribute the air more efficiently. Rock bins can be made from cinderblock, concrete, or wood. They should be tightly constructed and sealed to prevent air leaks and moisture intrusion. Air leaks and moisture drastically reduces the efficiency of the system. A rock bin should provide 1/2 to 1 cubic foot (0.014 to 0.028 cubic meters) of storage for every square foot of collector, and should be from 5 to 7 feet (1.5 to 2.1 meters) deep. Rock bins require 2 1/2 to 3 times more space for storage materials than liquid system tanks. Dense rock, such as river rock (which is predominantly quartz), performs best. The rocks should be uniform and about 3/4 inches to 1 1/2 inches (19 to 38 millimeters) in diameter. Before placing rocks in the bin, they should be washed to remove dirt and insect eggs and thoroughly dried. The rocks should also be kept dry inside the bin to prevent problems with mold, mildew, and insects.

7. Photovoltaic cells

Photovoltaics (PV) is the direct conversion of sunlight into electrical current. Although it may seem surprising photovoltaic cells are not a new invention. Their theoretical base appeared in XVIII century. The PV effect was first recorded by French physicist Edmund Becquerel, in 1839, when he noted the appearance of a voltage when illuminating two identical electrodes in a weak-conducting solution. PV technology was originally developed at the Bell laboratories in the mid 1950's. Until the oil crisis of 1973, the primary application of photovoltaics was powering satellites in space. The real step forward was put during the energy crisis. Since that time they are systematically improved.

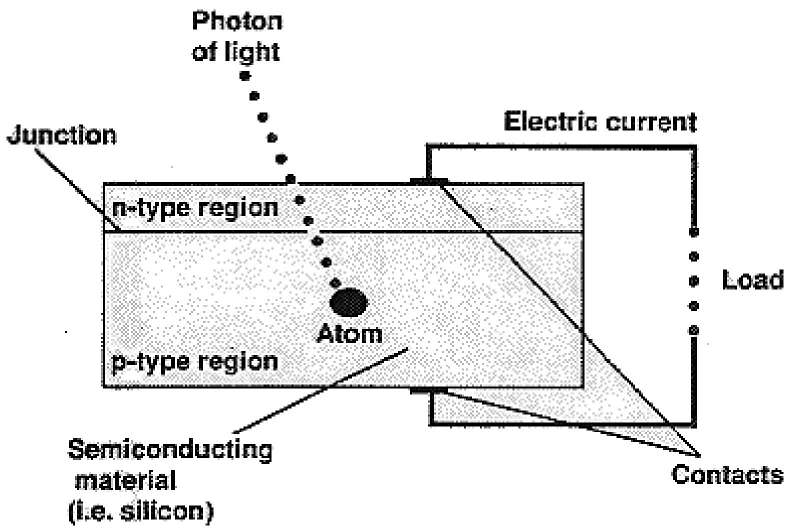

Fig.9

Figure 9 is a diagram of the basic principles behind most types of PV cells. In this case silicon as a semiconducting material is to be considered, although there are several other options. PV cells made of crystalline silicon have electrons knocked out of their crystal structure when exposed to sunlight. Impurities added to the silicon to make it into a semi-conductor prevent the electrons from falling back into place. These liberated, negatively charged electrons will follow the path of least resistance, which is from the p-type (positive) region in which they started to an n-type (negative) region. These electrons build up a negative charge in the n-type region, and can only travel back to the positively charged holes left in the p-type region if an external path is created. A path may be made by a wire connecting the two regions, through which the electrons flow. This flow of electrons creates and electric current in the wire, which may be used directly or "stored" for later use. Electricity storage is important for PV cells because they obviously only generate electricity when the sun is shining.

The original and still the most common semi-conducting material used in PV cells is single crystal silicon. Single crystal silicon cells are generally the most efficient type of PV cells, converting up to 23% of incoming solar energy into electricity. These cells are also very durable and have proved their long life in many space related applications. The main problem with single crystal silicon cells is their production costs. Growing large crystals of silicon and then cutting them into thin (0.1-0.3 mm) wafers is slow and expensive. For this reason, researchers have developed several alternatives to single crystal silicon cells, with hopes of reducing manufacturing costs like poly-crystalline silicon cells, a variety of "thin film" PV cells, and concentrating collectors [3].

The mechanism of PV indicates that the greater the intensity of the light, the more current a solar cell generates. The current moves through a series of cells, called modules, which can provide electricity in any quantity, ranging from a few milliwatts (mW) powering a calculator to several megawatts (MW), the size of a large power plant to a battery where it is stored. Battery storage assures the user of electricity when needed, day or night. A controller is usually installed between the modules and the battery to prevent overcharging. Linked together, this equipment forms a PV system designed to produce 12 or 24 volts of direct current (DC).

Through use of an inverter the direct current is turned into alternating current (AC), the standard home current with which we're all familiar. DC to AC inverters now provide outputs ranging from 100 to 20,000 watts at conversion efficiencies greater than 90 percent and with cleaner power than the utility can provide.

Any number of PV modules can be connected in an array to supply your present load requirements. The array may be expanded easily by adding modules to meet future power needs. Once installed, the modules are maintenance free. An occasional rinsing is all that is necessary.

Most of the photovoltaic cells on the market today operate at an efficiency of less than 15%, that is, of all the radiation that falls upon them, less than 15% of it is converted to electricity. The maximum theoretical efficiency for a photovoltaic cell is only 32.3%, but at this efficiency, solar electricity is very economical. Most of our other forms of electricity generation are at a lower efficiency than this. Unfortunately, reality still lags behind theory and a 15% efficiency is not usually considered economical by most power companies, even if it is fine for toys and pocket calculators. Hope for bulk solar electricity should not be abandoned, however, for recent scientific advances have created a solar cell with an efficiency of 28.2% efficiency in the laboratory. This type of cell has yet to be field tested. If it maintains its efficiency in the uncontrolled environment of the outside world, and if it does not have a tendency to break down, it will be economical for power companies to build solar power facilities after all [6].

A wide range of application of photovoltaics can be noticed nowadays. On a small scale, PV provides electricity for lighting, refrigeration, and other services to households and businesses in many countries. PV is especially appealing in remote areas where extending the utility's electricity grid is expensive or impossible. On a larger scale, utilities have used PV to provide power for centralized grid systems. PV systems are easy to operate, rarely need maintenance and do not pollute the environment.

Homes can use photovoltaic systems to replace or supplement electric power from the utility. A stand-alone residential system consists of solar panels, a battery to store power for use at night, and a device called an "inverter" to allow conventional appliances to be powered by solar electricity. Some systems use appliances specially designed to be powered by solar electricity and do not require an inverter.

Specific remote applications include microwave repeaters, mobile radio systems, remote control systems, radio communications, telephones, and emergency call boxes. They are also used in television cameras, calculators, watches and computers. Systems range in size from a few watts for emergency call systems to several kilowatts for communications repeater stations.

Photovoltaics are also used for extremely important cathodic protection. Each year, metal corrosion causes billions of dollars of damage to structures, pipelines, and other metal objects. Corrosion occurs when metal is exposed to water and soil, and cathodic protection uses an electric charge to prevent it. Most cathodic protection systems require less than 10 kilowatts of power. Typical applications include metals transmission towers, pipelines, underground storage tanks, bridges, and buildings.

Moreover there are photovoltaic-powered remote lighting systems. Typical applications include billboards, highway signs, rural installations, parking lots, and vacation cabins. The military, transportation, utility, and oil industries all use photovoltaic systems to power warning signals such as beacons atop smokestacks or transmission towers, navigational beacons, audible emergency signals, highway warning signs, and railroad signals. If batteries are not used from time to time, their capacity gradually diminishes. To prevent this self-discharge problem, photovoltaic systems can provide a small but constant current to the batteries. PV cells are a cheap and very reliable solution in this case. Remotely operated switches, particularly those on electric power transmission lines, are ideal applications for photovoltaic power.

Monitoring is one of the largest applications for photovoltaics today. Most of the over 20,000 systems in use today use less than 200 watts and are used to monitor the weather, water temperature and flow rates, factory emissions, and pipelines. Photovoltaic cells may be used to power a pump for irrigation, drinking water, or water for industrial purposes [2].

Electricity produced from photovoltaics has a far smaller impact on the environment than traditional methods of electrical generation. During their operation, PV cells use no fuel other than sunlight, give off no atmospheric or water pollutants and require no cooling water. Unlike fossil fuel (coal, oil, natural gas) fired power plants, photovoltaics do not contribute to global warming or acid rain. Similarly photovoltaics present no radioactive risks. The only negative environmental impacts associated with photovoltaics are potentially toxic chemicals used during their manufacture, and the amount of land used to produce electricity.

Manufacturing some types of PV cells, particularly gallium arsenide cells, may involve the production of some potentially toxic substances. These substances are generated in a centralized facility, and proper control of the manufacturing process, and proper disposal of any toxic wastes, should reduce the risks of any environmental contamination. Disposal of PV cells after their useful life is finished, generally 30 years, could present some waste disposal problems, but most of the toxic materials in any cells can probably be recycled.

The amount of land required to produce large amounts of electricity from photovoltaics has been identified as a concern by some people. The fact is, however, that if all the stages in electrical generation are taken into account, PV arrays use the same amount of land per unit of electricity as coal or nuclear power plants. Photovoltaics use land at the point of electrical generation, while coal and nuclear plants use land during mining, processing and electrical generation. When all these items are considered, the land use requirements of the three different options are remarkably similar. In fact, if only one percent of the land in the U.S. was covered with solar cells, all their electrical needs could be met. On top of this, PV arrays can be placed on roofs or on land with little other value such as deserts.

8. Solar thermal energy

Solar thermal power is heat energy obtained by exposing a collection device to the rays of the sun. A solar thermal system makes use of the warmth absorbed by the collector to heat water or another working fluid, or to make steam. Hot water is used in home or commercial buildings and for industrial processes. Steam is used for process heat or for operating a turbine generator to produce electricity or industrial power. Solar thermal applications range from simple residential hot water systems to multi-megawatt electricity generating stations.

Small scale water heating systems use flat plate collectors to capture heat from the sun, while solar thermal electric power plants use various concentrating devices to focus sunlight and achieve the high temperatures necessary to produce steam for power.

Solar thermal heating is the method in which sunlight is reflected from many mirrors onto a central point. At this central point, the heat from sunlight is so intense that it can bring water to a boil, creating steam. This steam can be used to turn motors, which generate electricity

History of solar thermal energy is surprisingly long. The concept of it appeared in 1767 when the Swiss scientist Horace de Saussure invented the world's first solar collector, or "hot box". Renowned astronomer Sir John Herschel used solar hot boxes to cook food during his expedition to Southern Africa in the 1830's. Solar thermal energy became important in parts of Africa for cooking and water distillation. While early American pioneers had used black pots and pans to heat up water as they travelled West during the day, solar water heating really began to heat up when Clarence Kemp patented the first commercial water heater in 1891. Solar water heating thrived during the years of high energy prices in the 1970's and continues to be popular around the world.

In addition to using the warmth of the sun directly, it is possible to use the heat to make steam to drive a turbine and produce electricity. If undertaken on a large scale, solar thermal electricity is very cost-competitive. The first commercial applications of this technology appeared in the early 1980's, and the industry grew very rapidly.

There are several advantages of solar thermal electricity generation. First of all electricity and hot water can be provided at the same time. What is more, plants can be scaled to match the applications and utilities can match power production to daytime electricity demand peaks. Furthermore there are few pollutants associated with solar thermal power production, and permits can be issued and plants built in as little as 18 months, far faster than conventional fossil fuel or nuclear plants.

Solar thermal electric plants use several different methods for concentrating sunlight, and vary significantly in size.

Central receiver systems (Fig.10) are large-scale plants where mirrors focus sunlight on a single collector mounted on a central tower. The mirrors are heliostats, meaning they track the sun in order to maintain focus on the receiver. Water or other heat transfer fluid in the tower is heated and use directly or converted into steam for electricity.

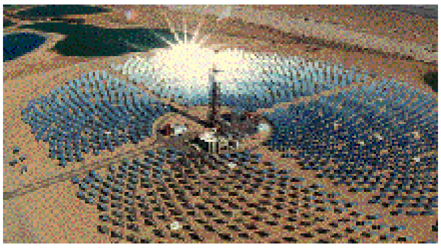
Fig.10

Other system is dish systems (Fig.11), which use a parabolic reflector to focus solar radiation on a receiver mounted at the focal point of the dish. Fluid circulates through the receiver and powers a central turbine generator. Sunlight can be concentrated from 100 to 2000 times using this method.


Fig.11


Fig.12

The last system uses troughs (Fig.12) - long, curved mirrors that focus sunlight onto tubes filled with a circulating heat transfer fluid. The fluid reaches very a high temperature, for instance as high as 400°C in the case of the Solar Electric Generating Systems in Southern California [2]. The thermal energy received by parabolic dishes or troughs can be converted to electricity at each unit or transported to a central point for conversion to electricity.

Solar thermal systems are used mostly in domestic applications but also in commercial and industrial buildings where it provides hot water or space heating. Industries in which these systems are most common include laundry, food service, food processing, metal plating, and textiles.

It is widely used in heating swimming pools as well. Most pool heaters are designed to raise the pool temperature 10-15°C, and to extend the swimming season three or four months. Pool systems differ from residential hot water systems in that the pool serves as a storage tank, and the collector is black plastic tubing with no glazing. The pool pump may serve to circulate water through the system.

Furthermore solar power can be used in transportation. While large, relatively slow vehicles like ships could power themselves with large onboard solar panels, small constantly turning vehicles like cars, unfortunately, could not. The only possible way a car could be completely solar powered would be through the use of battery that was charged by solar power at some stationary point and then later loaded into the car. Electric cars that are partially powered by solar energy are available now, but it is unlikely that solar power will provide the world's transportation costs in the near future.

9. Costs and utilizing of solar energy in the world

There is rather a big possibility of utilizing air and liquid collectors in Poland. They can be applicated in agriculture, architecture, and partly in industry. It is estimated that construction of 23 mln m^2 of such collectors is technically and economically justified. Their power would reach 800-1200 MW, and the year production of energy would be 640 - 960 GWh. In Polish conditions it is possible to get 300-500 kWh from $1m^2$ of the collector per year, which is the equivalent for 70-100 kg of coil. Agriculture have at its own disposal a great buildings area, where solar collectors of 100-500 m^2 could be installed individually. In Poland both types of collectors have the power of 5 MW, where air ones reach 250 kW and liquid-80 kW.

All around the world, especially in USA, Austria, Spain, Japan and France, there are installed working collector with the power of a few hundred MW. One of the example is the solar energy plant with the power of 100 MW in the USA.

Exploitation costs	5,5 mln USD
Investment costs	580 mln USD
Occupied area	400 ha
Production of energy per year	ok. 1.50 GWh

In 1995 there were 6,5 mln m^2 of collectors in European Union, and in the previous years the increase of 15 % per year was observed. Annual increase of 1 mln m^2 is concentrated in 3 countries: Austria, Germany and Greece[8].

The biggest installations of photoelectric conversion in the world are:

- Photovoltaic plant built in 1982 in USA – power of 1MW, occupied area- 8ha
- Photovoltaic plant built in 1989 in Japan – power of 10 MW

The total power of all photovoltaic plants in the world in 1999 is over 20 MW. The efficiency is calculated as 4-8 %, so it is rather small comparing to other renewable energy plants.

In case of common application of cheap photovoltaic cells in Poland there is a possibility for building the installation of a few MW. The cost of producing of 1kWh is about 0.5 USD with a good insolation (data from April 1999)[9].

Unfortunately the solar energy is still too expensive, but the situation will change in the present century. In the last 20 years the prices of photovoltaic cells have diminished over 40 times. Such phenomenon is observed because of the increasing scale of the production as well as the optimalization of the photovoltaic cell production process. The present price are rather stable – 4USD/Wp, however it is expected to fall to 2 USD/Wp in this decade.

Generally, the initial cost is the main disadvantage of solar energy as general. All the methods (except for flat plate collectors) of solar energy mentioned require large space to achieve average efficiency. Therefore, the cost of solar energy increases. The efficiency of generating solar energy also relates to the location of the sun, but it can be improved by installing heliostats like those used in focusing collectors. Air pollution and weather can reduce the productivity of the power plants. Solar electricity by photovoltaic cells is particularly expensive because of the semi-conducting materials. It is estimated that the cost for this kind of solar electricity at least doubles the cost of conventional electricity, which makes it rather an inefficient alternative [10].

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WATER ENERGY

1. Introduction to hydropower

Flowing water creates energy that can be captured and turned into electricity. This is called *hydropower*. The history of hydropower usage goes back to the BC era. Over 2000 years ago Greeks used to turn water wheels for grinding wheat into flour.

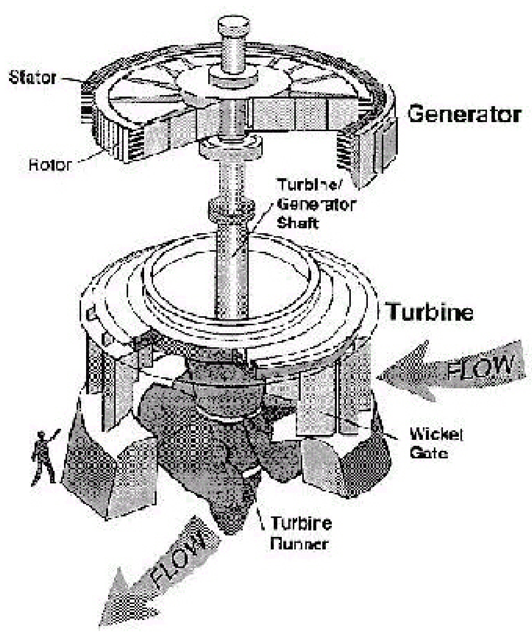
Hydroelectricity, which depends ultimately on the natural evaporation of water by solar energy, is the only renewable resource used on the large scale today for electricity generation. In 1986 it contributed 14.5% of the world's generated electricity. While basic conversion principles are well understood, hydroelectricity faces considerable constraints and challenges, for it is a resource whose exploitation is impossible.

1.1. Converting work to electricity

Electric power is generated in a hydroelectric power plant when water, stored by dams, is released to turn water turbines that are coupled to generators. Transmission facilities then send the electricity to the market terminal and ultimately to the end users.

Dams, which are built across flowing bodies of water, generally have two purposes. One is to raise the water level, thus increasing its potential energy or hydraulic head; the other is to create a water reserve to compensate for fluctuations in river flow or power demand. The importance of both functions varies from site to site. Some dams have virtually no reserve storage capacity. Auxiliary works at a dam may include spillways, gates, or valves to control the discharge of surplus water; an intake structure to carry water into power station; mechanisms to remove silt from the reservoirs; and methods to allow ships or fish through the dam. Dams may also serve other purposes, such as providing water for human consumption, industrial operations, and irrigation; facilitating flood control; increasing the steam's depth for navigation; and creating recreational amenities ([1], [2], [3]). In fact most existing dams do not generate electricity, although many could be retrofitted to do so [4].

Hydraulic turbines convert the energy of an elevated water supply or flowing stream into



mechanical energy on a rotating shaft. Whereas most old-style water wheels used water weight directly, modern hydraulic turbines operate according to the impulse or reaction principle, which converts pressure and kinetic energy to rotational kinetic energy. The most common reaction turbines are known as Francis, Kaplan, Bulb, Tube and Straflo models. The main type of impulse turbine is the Pelton turbine ([2], [5]).

The turbine's rotating shaft drives an electric generator, which transforms mechanical power to electric power. Three types of generators are available for use with hydroelectric plants: for lower-capacity plants, the generator may be either an alternating-current induction type; at higher capacities, a conventional synchronous type is used [5].

Transmission facilities consist of a step-up, or sending, substation at the electric generating plants; a step-down, or receiving, substation at the market terminal; interconnecting transmission lines; and, in some cases, intermediate switching sections [5].

1.2. Global water availability and hydroelectric potential

On a global basis, the total amount of water precipitated over time equals the amount returned to the atmosphere by evaporation. On land, precipitation exceeds evaporation, but the difference is eliminated by the runoff of rivers (and groundwater) to the ocean. In the oceans, an opposite process occurs [6]. Average precipitation, evaporation, and runoff in South America exceeds that of other continents by factor of two; Asia accounts for the largest total runoff.

The energy potential of hydropower is determined by the volume of runoff water by the distance it falls before reaching the ocean. Because runoff is not evenly distributed over continents, average altitudes (which range from 300 m in Europe to 950 m in Asia and 2 040 m in Antarctica) are not adequate for calculating the theoretical potential, even on a gross basis. Seasonal variations in runoff also influence the theoretical potential. Estimates of the theoretical annual potential of world hydroelectricity range from 36 000 to 44 000 terawatt-hours (TWh) ([1], [7], [8]).

This gross theoretical potential is much larger than the technical usable potential (or theoretical exploitable potential), which in turn is substantially larger than the economically exploitable potential. The uncertainty of the economic potential increases when such factors as geological constraints and social and environmental factors are considered. Despite the simplicity of the basic physics, hydropower is surprisingly subtle resource whose evaluation requires a sequence of increasingly detailed studies. This type of medium- and long-term analysis has been a low priority in most developing countries.

2. History of hydroelectric power

2.1. Plants built up to 1930

Use of water power dates back to ancient times: primitive wheels, actuated by river current, once raised water for irrigation purposes, grinding, and myriad other applications. The devices were extremely inefficient, however, and used but a small part of a stream's available power. The development of undershot, breast, and overshot wheels represented great advances: water was confined to a channel, brought to the wheel, and used under a head of waterfall. Such technology was already in use in the Roman Empire, where the largest milling complex discovered so far had a power output equivalent to about 15 kilowatts [9]. Efficiencies grew from perhaps 30% for the undershot to about 80% or more for overshot wheels. About the middle age of the 19th century, the hydraulic turbine superseded the overshot wheel [10].

Hydropower technology is used at dams where flowing water can be regulated and stored. The first hydro facilities, known as run-off-the river plants, are unable to generate power during the dry season when streams and rivers have low flow. Large dam, in contrast, are designed to generate continuos power, but require reservoirs of inundated land, which adds significantly to their construction costs.

Of the many turbines operating today, two were developed during the mid-19th century: the Francis turbine, which was designed in 1849 and powered the first hydroelectric plant in the United States, and the Pelton turbine, which appeared in 1890. In 1913, the Kaplan turbine was developed, followed in 1936 by the bulb turbine. In 1880, the development of hydroelectric power was launched when a small direct current (DC) generating plant was built in the U.S. State of Wisconsin. The first transmission lines, built in 1890, further stimulated the growth of water power. Installed capacity in the United States grew from 2.5 gigawatts in 1890 to 10.4 gigawatts in 1930, with proportional increases in the rest of the industrialised world [10]. This was made possible by an increase in the range of developable head-from 30 meters, around 1900, to 240 meters or more by 1930, when energy conversion efficiencies reached 85% (with the Pelton turbine) and 90% (with the Francis and Kaplan turbines). During the same period, transmission voltages grew from 40 to 300 kilovolts, and plant having capacities in excess of 100 megawatts were installed.

2.2. 1930 to the present

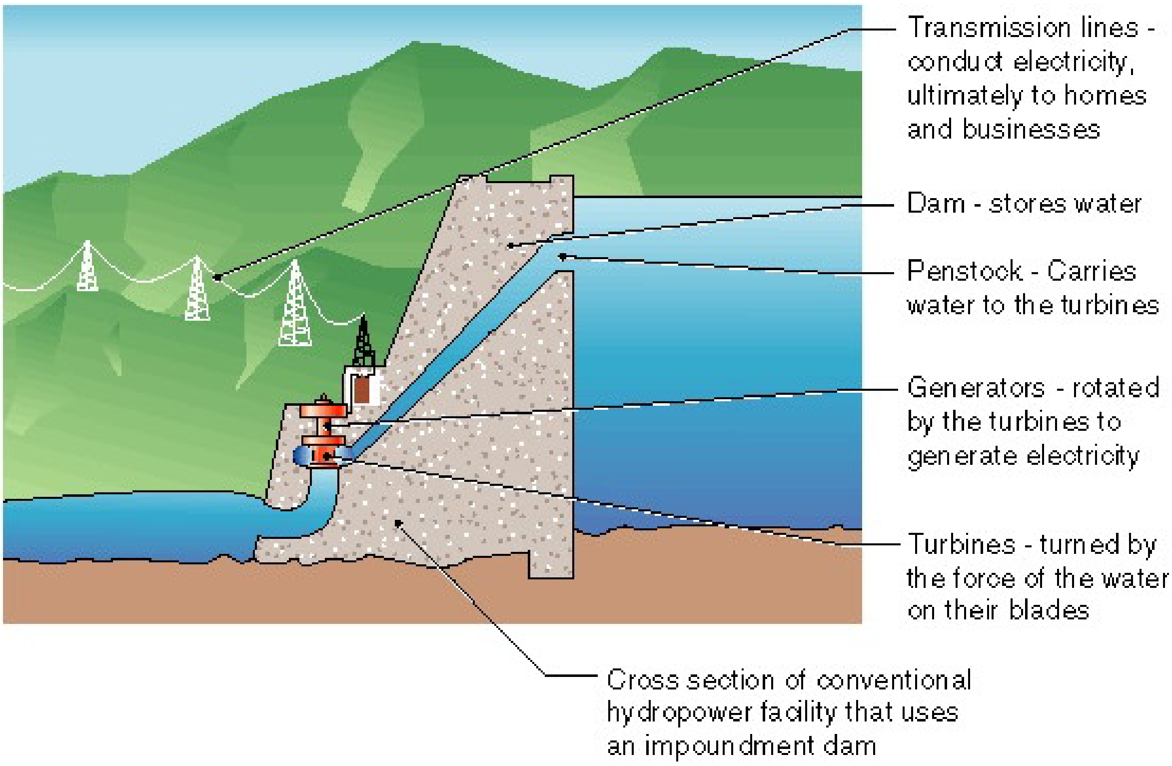
From 1930 until the mid 1960's, a concerted effort was made to increase the scale of hydroelectric generation. The creation of the U.S. Tennessee Valley Authority in the early 1930's with its broad powers for finance, expropriation, and development, represented a critical institutional step [11]. In 1942, the Bonneville Power Authority began operating the Grand Coulee Dam, which (including additions) is still the third largest installed capacity plant in the world.

Today more than 150 dams are classified as "large" and account for 40% of existing world hydroelectric capacity. The largest represent some of the biggest engineering project in the world. The Itaipu dam on the Brasil-Paraguay frontier, for example, is 8 km long and 150 m high. Although it is the largest power complex in the world (equivalent to 10 of the largest nuclear reactors), it is by no means the world's biggest dam. The reservoirs that accompany dams also rank as major bodies of fresh water: Ghana's Lake Volta, for instance covers 8 500 square kilometres, an area almost the size of Lebanon.

Most of the largest dams are now being built in the developing world, where between 1980 and 1986 the absolute increase in hydro generation was almost twice that of the industrialised world (172 versus 96 TWh). One reason why dam construction is on the wane in industrialised countries is that most of the promising sites have either already been developed or are excluded because of their natural beauty or other environmental concerns. In the United States, not a single major dam was approved for federal funding between 1976 and 1990. Interest in hydropower in these countries is now focused more on smaller sites, on the refurbishing and upgrading of existing hydroplants, and on retrofitting dams constructed for other purposes. In the United States, retrofitting non-power dams is estimated to have potential of 26 000 megawatts [4]. Large- and intermediate-scale dams, will continue to be very important in developing countries, in the former Soviet Union and in some industrialised nations, such as Canada.

3. Types hydropower plants

3.1. The impoundment hydropower plant



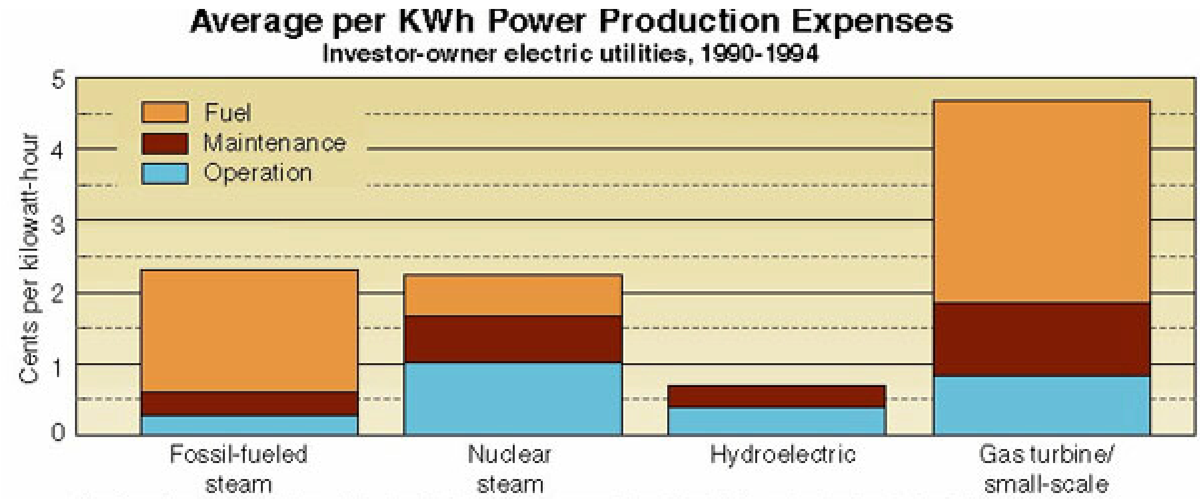
The most common type of hydropower plant called impoundment uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. But hydropower doesn't necessarily require a large dam. Some hydropower plants just use a small canal to channel the river water through a turbine.

3.2. Pumped storage hydroplant

Another type of hydropower plant – called a *pumped storage plant* – allow for large scale storage of electricity energy: they store hydro energy during off-peak hours by pumping water from a lower reservoir to an upper reservoir, and then produce electricity during peak hours, when electricity is the most costly to produce, by turbining water from the upper to the lower reservoir. This spins the turbines forward, activating the generators to produce electricity. In addition, many storage plants also function as conventional hyroplants or as pumps to raise water for irrigation or public use.

4. The costs of hydropower

Costs associated with hydropower are highly variable, depending on the site, conditions of financing, the degree of which environmental and social externalities are included and the efficiency of administration. However, as we can see on the figure below, hydroelectricity is the cheapest one.



5. Ocean energy

The ocean can produce two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves.

Oceans cover more than 70% of Earth's surface, making them the world's largest solar collectors. The sun's heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy. Just a small portion of the heat trapped in the ocean could power the world.

Ocean thermal energy is used for many applications, including electricity generation. There are three types of electricity conversion systems: *closed-cycle, open-cycle,* and *hybrid.* Closed-cycle systems use the ocean's warm surface water to vaporize a *working fluid*, which has a low-boiling point, such as ammonia. The vapor expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator. And hybrid systems combine both closed-cycle and open-cycle systems.

Ocean mechanical energy is quite different from ocean thermal energy. Even though the sun affects all ocean activity, tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. As a result, tides and waves are intermittent sources of energy, while ocean thermal energy is fairly constant. Also, unlike thermal energy, the electricity conversion of both tidal and wave energy usually involves mechanical devices.

Waves, particularly those of large amplitude, contain large amounts of energy. Wave energy is in effect a stored and concentrated form of solar energy, since the winds that produce waves are caused by pressure differences in the atmosphere arising from solar heating. The strong winds blowing across the Atlantic Ocean create large waves, making the west coast of Europe ideally suited to wave energy devices. Wave energy is a relatively new technology and research was at its most intense during the 1970s and 80s under various government and industry sponsored programs. Wave energy research is still carried on and has benefited from funding provided by the European Commission. As a result, a wide variety of wave energy devices have been proposed over the last three decades, comprising many different shapes, sizes and energy extraction methods. Although most of them never passed beyond the outline design stage, many have been the objects of research and development work and several have been deployed in the sea as prototypes or demonstration schemes. Some of these prototypes are shown on the figures below.

Figures 1 and 2 shows the appliances that uses airflow and converts it into electricity. The first one due to the system of traps and the second one use elastic membrane, which due to water weight moves upward and downward.

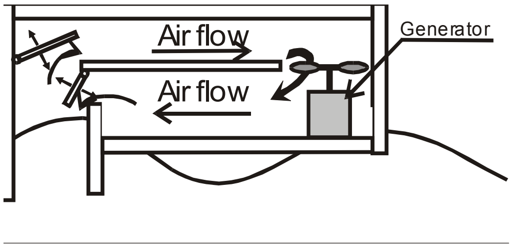


Figure 1

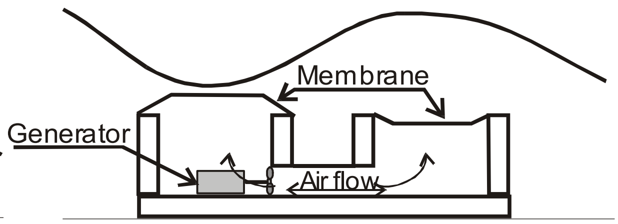


Figure 2

Figure 3 and 4 presents idea of transforming mechanical energy into electricity,

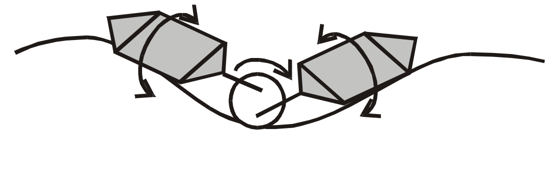


Figure 3

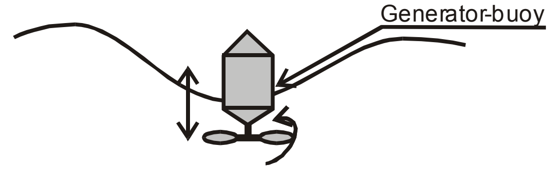


Figure 4

The following figures present shoreline devices, like electrical breakwater (Figure 5).

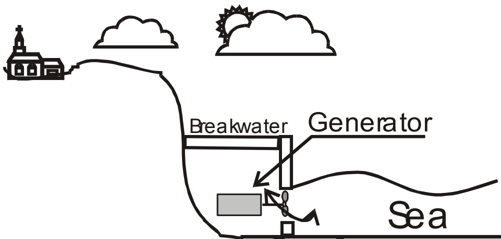


Figure 5

Shoreline devices have the advantage of relatively easier maintenance and installation and do not require deep-water moorings and long underwater electrical cables. The less energetic wave climate at the shoreline can be partly compensated by the concentration of wave energy that occurs naturally at some locations by refraction and/or diffraction.

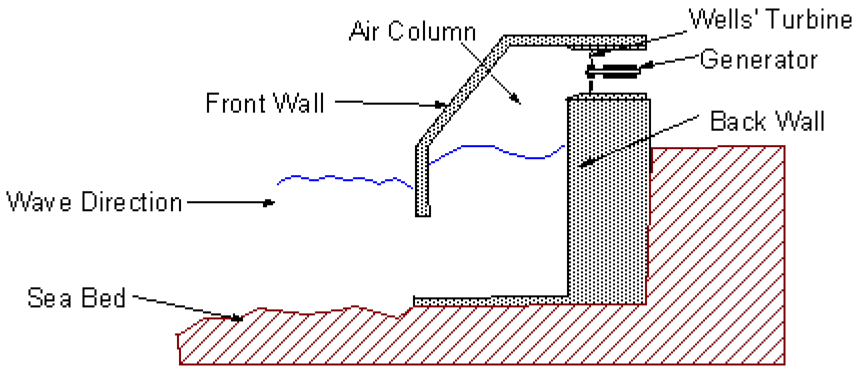
The two pictures below present two major classes of shoreline devices Oscillating Water Column (OWC) and The Convergent Channel (TAPCHAN).

The OWC comprises a partly submerged concrete or steel structure, which has an opening to the sea below the water line, thereby enclosing a column of air above a column of water. As waves impinge on the device, they cause the water column to rise and fall, which alternately compresses and depressurises the air column. This air is allowed to flow to and from the atmosphere through a turbine, which drives an electric generator. Both conventional (i.e. unidirectional) and self- rectifying air turbines have been proposed. The axial-flow Wells turbine, invented in the 1970s, is the best known turbine for this kind of application and has the advantage of not requiring rectifying air valves. A number of OWC devices have been installed world-wide, with several of them being built into a breakwater to lower overall construction costs.

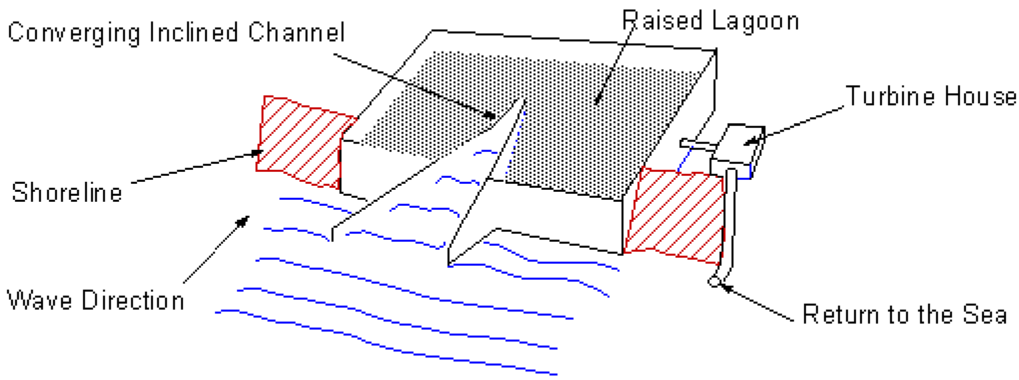
The TAPCHAN comprises a gradually narrowing channel with wall heights typically 3 to 5 m above mean water level. The waves enter the wide end of the channel and, as they propagate down the narrowing channel, the wave height is amplified until the wave crests spill over the walls to a reservoir which provides a stable water supply to a conventional low head turbine. The requirements of low tidal range and suitable shoreline limit the world-wide replicability of this device.

Diagram Shoreline Wave Energy Devices

Oscillating Water Column Device



Tapered Channel Device (TAPCHAN)



6. Conclusions

The principal advantages of using hydropower are its large renewable domestic resource base, the absence of polluting emissions during operation, its capability in some cases to respond quickly to utility load demands, and its very low operating costs. Disadvantages can include high initial capital cost and potential site-specific and cumulative environmental impacts. Potential environmental impacts of hydropower projects include altered flow regimes below storage reservoirs or within diverted stream reaches, water quality degradation, mortality of fish that pass through hydroelectric turbines, blockage of upstream fish migration, and flooding of terrestrial ecosystems by new impoundment. However, in many cases, proper design and operation of hydropower projects can mitigate these impacts. Hydroelectric projects also include beneficial effects such as recreation in reservoirs or in tailwaters below dams.

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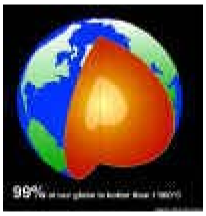
GEOTHERMAL ENERGY

1. Introduction

Miles beneath the Earth's surface lies one of the world's largest energy resources—geothermal energy. Our ancestors have used geothermal energy for cooking and bathing since prehistoric times. Today, we use this enormous energy reservoir to supply millions of people with clean, low-cost electricity.



Geothermal energy is the heat contained below the Earth's crust. It's clean and sustainable. This heat is brought to the surface as steam or hot water created when water flows through heated rock and used directly for space heating in homes and buildings or converted to electricity. Most of the geothermal resources are located in the western U.S.. 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.

Almost everywhere, the shallow ground or upper 30 cm of the Earth's surface maintains a nearly constant temperature between 10° and 16°C. Geothermal heat pumps can tap into this resource to heat and cool buildings. A geothermal heat pump system consists of a heat pump, an air delivery system (ductwork), and a heat exchanger—a system of pipes buried in the shallow ground near the building. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water.

Also wells can be drilled into underground reservoirs for the generation of electricity. Some geothermal power plants use the steam from a reservoir to power a turbine generator, while others use the hot water to boil a working fluid that vaporizes and then turns a turbine. Hot water near the surface of Earth can be used directly for heat. Direct-use applications include heating buildings, growing plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes such as pasteurizing milk.

Hot dry rock resources occur at depths of 5 to 10 meters everywhere beneath the Earth's surface and at lesser depths in certain areas. Access to these resources involves injecting cold water down one well, circulating it through hot fractured rock, and drawing off the heated water from another well. Currently, there are no commercial applications of this technology. Existing technology also does not allow recovery of heat directly from magma, the very deep and most powerful resource of geothermal energy.

2. Earth energy

The heat contained in shallow ground which is used to directly heat or cool homes and commercial buildings through "direct-use" technologies such as geothermal heat pumps (GHP) and district heating systems. Unlike other forms of geothermal energy, earth energy is found throughout the U.S

2.1. Geothermal heat pumps

GHPs use the Earth's relatively constant ground temperature to provide low-cost heating and cooling. In the winter, GHPs transfer heat from the ground into homes and buildings; in the summer, GHPs cool homes and buildings by transferring indoor heat into the ground. GHPs can cut heating costs by 50 percent, and cooling costs by 25 percent. For example more than 200,000 GHPs are operating in U.S. homes, schools and commercial buildings.

2.2. District heating systems

Many communities use district heating systems to heat homes or public buildings by circulating hot water through pipes. Overall, direct-use applications use geothermal energy to supply the energy equivalent of nearly 1 million barrels of oil.

3. Geothermal Power Plants

Geothermal power plants use wells to pipe steam and hot water trapped underground to the surface to make electricity. Currently (in U.S) geothermal power plants have a total generating capacity of 2,700 megawatts, enough electricity to power the homes of more than 3.5 million people. The power plants produce electricity at 5˘ to 7.5˘ per kilowatt-hour.

The Geysers Power Plant in northern California, the world's largest geothermal power plant, generates more than 1700 megawatts of electrical power, 7 percent of the total electricity Pacific Gas and Electric Company (PG&E) supplies to California.

4. Forms of Geothermal Resources

Of the five forms of geothermal energy, only two: hydrothermal reservoirs and earth energy are currently used commercially. To use the other three forms: geopressured brines, hot dry rock and magma need advanced technologies to be developed.

4.1. Hydrothermal Reservoirs

Hydrothermal reservoirs are large pools of steam or hot water trapped in porous rock. To create electricity, the steam or hot water is pumped to the Earth's surface where it drives a turbine that spins an electric generator. Because steam resources are rare, hot water is used in most geothermal power plants. Steam and hot water power plants use different power production technologies.

Dry Steam is routed directly to the turbines, eliminating the need for the boilers used by conventional natural gas and coal plants.

High-temperature hot water with temperatures above 200°C are usually utilized using a flash technology where hot water is sprayed into a low-pressure tank. The water vaporizes to steam, which is routed to the turbine.

Hot water resources below 200°C are utilized using a binary cycle technology where the hot water vaporizes a secondary working fluid, which then drives the turbine.

5. Other Forms of Geothermal Energy

5.1. Hot dry rock

This energy consists of dry, impermeable rock. To use this energy, water must be pumped into the rock at high pressures to widen existing fissures and create an underground reservoir of steam or hot water.

5.2. Magma

Magma is the molten or partially molten rock found below the Earth's crust. Magma reaches temperatures up to 1200°C . While some magma bodies exist at accessible depths, a practical way to extract magma energy has yet to be developed.

5.3. Geopressured brines

These brines are hot, pressurized waters containing dissolved methane. Both the heat and methane can be used for power generation.

6. Benefits of Geothermal Energy

6.1. Environment

Geothermal energy offers an environmentally benign source of electricity. Geothermal power plants meet the most stringent environmental regulations and release little, if any, carbon dioxide, a greenhouse gas suspected of contributing to global warming.

6.2. Reliability

Geothermal power plants are highly reliably and can operate 24 hours a day. Most power plants operate more than 95 percent of the time.

6.3. Domestic resource

Geothermal energy offers a large source of secure, domestic energy. In addition, sales of geothermal technology enhance U.S. trade and stimulate the economy.

Geothermal reservoirs of low to moderate temperature (20°C to 150°C) are often used to provide direct heat for residential, industrial, and commercial uses. The geothermal resource in this low-temperature range occurs as hot or hydrothermal water under pressure in an underground reservoir. This resource is widespread in the United States and is used to Provide heat for homes and offices, commercial greenhouses, fish farming, food-processing, gold mining, and a variety of other applications.

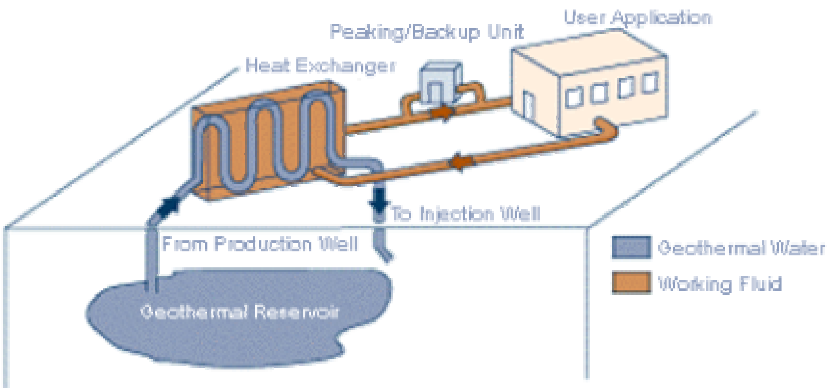
The direct use of geothermal energy in homes and commercial operations yields a net savings in energy costs to the consumer. This savings depends on the application and the industry, but can be as much as an 80% reduction from traditional fuel costs. Geothermal power is not only an economic energy source, it is also very clean, producing only a small percentage (and in many cases none) of the air pollutants emitted by burning fossil fuels.

7. The Direct-Use Resource

Subsurface conditions for low temperature geothermal resources exist throughout the western United States, and there is tremendous potential for new direct-use applications. A recent survey of 10 western states identified more than 9000 thermal wells and springs, more than 900 low to moderate temperature geothermal resource areas, and approximately 416 sites where the direct use of geothermal energy is occurring.

The survey also identified approximately 271 collocated sites cities within 8 kilometers of a resource with a temperature greater than 50°C that have excellent potential for direct-heat use. If these collocated resources were used only to heat buildings, the cities have the potential to displace 18 million barrels of oil equivalent of traditional energy sources with geothermal systems.

Direct-use geothermal systems are typically composed of three components:



A production facility use usually a well to bring the heated water to the surface.

A mechanical system piping, heat exchanger, controls to deliver the heat to the space or process.

A disposal system injection well or storage pond to receive the cooled geothermal fluid.

Many companies provide commercially proven equipment: standard drilling equipment, pumps, valves, piping, and heat exchangers, that may be necessary in developing a direct-use system. Companies that have already developed geothermal resources can provide a wealth of information on system components and equipment.

Many Operations are Using Heat Directly from the Earth

The primary uses of low temperature geothermal resources are in district and space heating, greenhouses and aquaculture facilities, and other industrial and commercial operations.

7.1. District and Space Heating

In the United States, more than 120 locations (with hundreds of individual systems at some locations) are using geothermal energy for district and space heating. District systems distribute hydrothermal water from a central location through a series of pipes to individual houses and buildings, or blocks of buildings. District heating uses one or more geothermal wells to heat several buildings. Space heating uses one well per structure. In both types of heating, the geothermal production well and distribution piping replace the boiler heat source of the traditional heating system.

Geothermal district heating systems typically result in net savings to consumers of 30% to 50% of the cost of natural gas heating. There is tremendous potential for new district heating systems.

7.2. Greenhouses and Aquaculture Facilities

Greenhouses and aquaculture fish farming are the two primary uses of geothermal energy in the agribusiness industry. Most greenhouse growers estimate that using geothermal resources instead of traditional energy sources saves about 5% to 8% of total operating costs or up to 90% of fuel costs. The relatively rural location of most geothermal resources also offers several advantages, including clean air, few disease problems, clean water, a stable workforce, and, often, low taxes.

7.3. Industrial and Commercial

Industrial applications include food dehydration, laundries, gold mining, milk pasteurizing, spas, and others. Dehydration operations, or the drying of vegetable and fruit products, is the most common industrial use of geothermal energy. The earliest commercial use of geothermal energy was for swimming pools and spas, and many continuously are in use today.

The advantage of a geothermal heating system is that it harnesses the constant earth temperature of 60 to 70 degrees to transfer heat from a closed-loop making heat exchange much more efficient than with a conventional air-to-air heat exchange coil. Consider the difference between taking outside air of 32 degrees and heating it to 72 degrees to make your house comfortable, and taking the water in a closed loop installation that is 65 degrees and heating it to 72 degrees. The heating system uses much less input energy to produce an output temperature of 72 degrees. In most residential applications, closed-loop systems can provide heating and cooling and produce as much as 75% off the hot water needed for the average home or business.

8. Geothermal energy in Poland

According to the Department of geology, our geothermal resources are about 100 mld p.u. From these resources we can easily use about 20%. Steam or hot water sources are on the depth of 2500 meters and the temperature of the water is from 40^0 C up to 100^0C. The main problem is of course the cost.

In Poland we have some places where we already use geothermal energy or we will be using it:

- Skierniewice- power : 8MW temp. 69^0C
- Mszczonow- power : 8MW temp. 42^0C
- Zyrardow- power 10 MW temp.70^0C
- Bialy Dunajec- power 12 MW temp.98^0C
- Lodz- power 10 MW temp. 85^0C
- Czarnkow – power 16 MW temp. 40^0C
- Wegrowiec- power 9 MW temp. 40^0C

We are constantly working to use geothermal resources in Kolobrzeg, Koszalin, Pyrzyce, Szczecin, Torun.

Geothermal reservoirs of low to moderate temperature (20°C to 150°C) will be used to provide direct heat for residential, industrial, and commercial uses. Especially as a heating system of water and homes accept from old engine-rooms.

We already use warm heating pumps in many houses and other places. As an example we can name a few of them:

- Tennis Club in Sopot- to warm the tennis hall they apply a heating 50 kW pomp.
- Euromax in Straszyn uses such pomps to heat the warehouses, work-shops, offices. The collector which is 3,2 km long is dug in the ground on the depth of 1,5m.
- Sowinski National Park- to heat the administration building. The pomp works with the power of 116,5 kW and uses the heat of 9,5^0C from the depth of 22,5m.
- Energetic Institute in Slupsk
- Energetic Institute Walcz
- Energetic Institute in Lublin
- City Hall in Pleszew

As we see the geothermal energy is used even in Poland. It is very environmentally friendly and is a renewable resource. So it will be cheaper than our central heating and more popular soon. Also as in the case of wind energy and other renewable resources the law is almost the same.

The lower house of the Polish parliament decided that the usage of the renewable energy is good from the ecological, social and economic point of view and also profitable and should become a part of sustainable development of the country. The Seym should help to destroy the barrier which stop the development of the sources of the renewable energy. And it is also becoming responsible for creating good financial and laws opportunities for such development. It will create some acts which make firms invest in the renewable sources of energy and provide the best opportunities for them.

9. Conclusions

Geothermal energy is produced from the vast amounts of heat within the earth. Today 20 countries produce power with natural geothermal steam rising from deep wells drilled into hot permeable aquifers. The capacity of all the geothermal power plants amounts to 7,300 MW electric. With nearly 2,300 megawatts of installed geothermal power, geothermal energy is the United State's second largest grid-connected renewable electricity source (after hydropower). Geothermal energy is essentially non-polluting.

While present geothermal plants rely on naturally occurring hot water/steam fields, a much greater energy potential can be recovered by drilling into hot rock and circulating liquid in a closed loop. This is variously called Hot Dry Rock, Deep Heat Mining, or Enhanced Geothermal Systems. (Cold water is pumped into the reservoir, is heated as it flows through fractures in the rock, returns to the surface, and the heat energy is extracted. So to develop a geothermal energy should be the priority and is very important for a future energy usage.

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WIND ENERGY

1. The source of wind energy

All renewable energy, and the energy in fossil fuels, ultimately comes from the sun. The sun radiates 100,000,000,000,000-kilowatt hours of energy to the earth per hour. That means the Earth receives 10 to the 18th power of watts of power.

About 1 to 2 per cent of the energy coming from the sun is converted into wind energy. That is about 50 to 100 times more than the energy converted into biomass by all plants on earth.

1.1. Temperature differences drive air circulation

The regions around equator, at 0° latitude are heated more by the sun than the rest of the globe. Hot air is lighter than cold air and will rise into the sky until it reaches approximately 10km altitude and will spread to the North and the South. If the globe did not rotate, the air would simply arrive at the North Pole and the South Pole, sink down, and return to the equator.

The atmosphere is only 10 km thick. Troposphere, which extends to about 11 km. is the place where all of our weather (and the greenhouse effect) occurs.

The prevailing wind directions are important when sitting wind turbines, because we want to place them in the areas where the wind energy can be the best used.

We distinguish three kinds of wind:

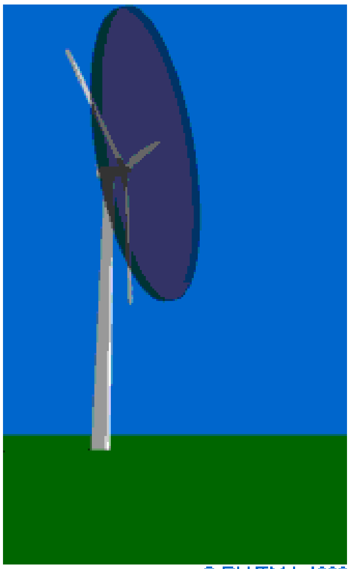
- The geostrophic wind
- The surface wind
- The local winds (sea breeze)

The geostrophic winds are largely driven by temperature and pressure differences, and are not very much influenced by the surface of the earth. The geostrophic wind is found at altitudes above 100m above the ground level. They are not used when talking about wind energy. The wind, which is used as a source of wind energy, is the surface wind. It is influenced by the ground surface (up to 100m). The ground slows the wind. Also a wind direction near the ground is much different then the direction of the geostrophic wind.

Although as I said the two above winds are important in determining the prevailing winds in a given area, local climatic conditions may have an influence on the most common wind directions. Local winds are mostly used in a wind system. Especially sea breeze and land breeze by the sea.

A wind turbine obtains its power input by converting the force of the wind into a turning force acting on the rotator blades. The amount of energy, which the wind transfers to the rotator, depends on the density of the air, the rotator area, and the wind speed.

The picture shows how air 1m thick moves through the 1,500m^2 rotator of a typical 600kW-wind turbine. (Each cylinder actually weighs 1.9t):



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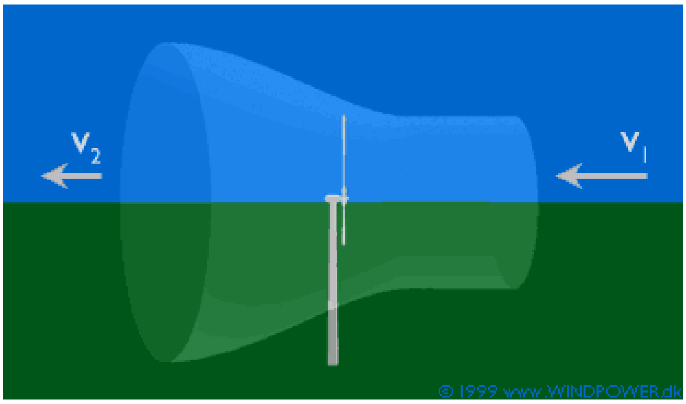
A typical 600 kW wind turbine has a rotator diameter of 43-44m. (A rotor area of some 1,500 square meters). The rotor area determines how much energy a wind turbine is able to harvest from the wind.

2. Wind turbine

The process of accumulation of the energy by the turbine is not very easy. A wind turbine will deflect the wind, before the wind reaches the rotor plane. This means that we will never be able to capture all of the energy in the wind using a wind turbine.

The wind turbine rotor must slow down the wind when it captures the energy of the wind and converts it into rotational energy.

The amount of air entering through the swept rotor area from the right (every second) must be the same as the amount of air leaving the rotor area to the left.



In the picture above we have the wind coming from the right, and we use a device to capture part of the energy of the wind. (In this case we use a three bladed rotor, but it could be some other mechanical device).

This is an illustration of an imaginary tube, a so-called stream tube around the wind turbine rotor. The stream tube shows how the slow moving wind will occupy a space around the rotator. The wind will not be slowed down to its final speed immediately behind the rotor plane. It will be slowing down little by little until the speed becomes almost constant. Then the turbulence in the wind will cause the slow wind behind the rotator to mix with the faster moving wind from the surrounding area. And the wind behind the rotor gradually diminishes as we move away from the turbine.

So as we can see the speed of the wind is extremely important for the amount of energy a wind turbine can convert to electricity.

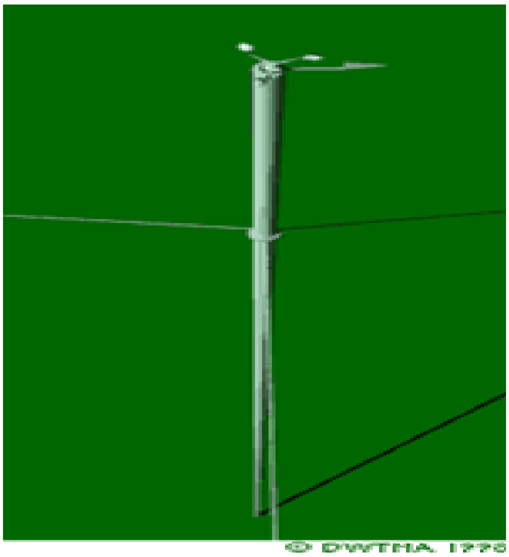
3. Wind speed measurements

The best way of measuring wind speeds at a prospective wind turbine site is to fit an anemometer to the top of a mast which has the same height as the height of the wind turbine to be used. If anemometers are placed on the side of the mast it is essential to place them in the prevailing wind direction in order to minimize the wind shade from the tower.

The data on both winds speeds and wind directions from the anemometer are collected on electronic chips on a small computer, a data logger, which may be battery operated for a long period.

Anemometer:

- On the left the anemometer on the top of the mast.
- On the right the enlargement of the anemometer.



4. Localization of turbines

The aerial photograph shows a good location for wind turbines along a shoreline with the turbines standing on a cliff which is about 10 m tall. It is a common mistake to believe that in this case we can add the height of the cliff to the height of the wind turbine tower to obtain the effective height of the wind turbine, while doing wind speed calculations, at least when the wind is coming from the sea. This is an extremely wrong way of thinking. The cliff in the front of the picture will create turbulence, and brake the wind even before it reaches the cliff. It is not a good idea to move the turbines closer to the cliff. That would lower energy output, and cause a lower lifetime for the turbines, due to more tears and wear from the turbulence.

It is better to put the turbine in a rounded hill in the direction facing the sea, rather than the escarpment like in the picture. In case of a rounded hill, we might even experience a speed up effect. Also we cannot put the turbines on the territory where we have a lot of hailstorms or thunderstorms because the turbulence decreases the possibility of using the energy in the wind effectively for a wind turbine.

The wind speed is always fluctuating, and the energy content of the wind is always changing. The extent of the variation is depended upon weather and local surface conditions. Energy output from a wind turbine would vary as the wind varies. In most locations around the globe it is windier during the daytime than at night.

This difference in wind power is quiet big due to the fact that temperature differences between the sea surface and the land surface tend to be larger during the day than at night. The wind is also more turbulent and tends to change direction more frequently during the day than at night. It is an advantage that most of the wind energy is produced during the daytime, because electricity consumption is higher than at night. Many power companies pay more for the electricity produced during the peak hours of the day.

4.1. Wind obstacles

This picture shows an interesting phenomenon:

We expect that the turbine on the right will start working first when the wind starts blowing because it is facing the wind directly. But actually the turbine on the right will not start working at the low wind speed which are sufficient to drive the other two wind turbines. The reason is the small wood in front of the wind turbines which shelters the right turbine. In this case, the annual production of these wind turbines is probably reduced by 15 per cent on average, and even more in case of the rightmost turbine.

Obstacles to the wind such as buildings, trees, rock formations etc. can decrease wind speeds significantly, and they often create turbulence in their neighborhood. The turbulence is bigger behind the obstacle than in front of it.

So it is best to avoid major obstacles close to wind turbines, particularly if they are upwind in front of the turbine.

Obstacles will decrease the wind speed downstream from the obstacle. The decrease in wind speed depends on the porosity of the obstacle and how "open" the obstacle is.

A building is obviously solid, and has no porosity, whereas an open tree in winter (with no leaves) may let more than half of the wind through. In summer, however, the leafs on the trees decrease the porosity even about one third. The slowdown effect on the wind because of the obstacle increases with the height and length of the obstacle.

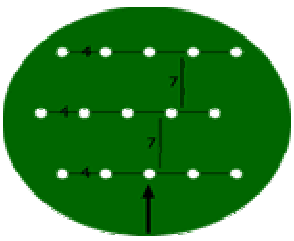
When developers calculate the energy production for wind turbines, they always take obstacles into account if they are close to the turbine - less than 1 km.

Since a wind turbine generates electricity from the energy in the wind, the wind leaving the turbine must have a lower energy content than the wind arriving in front of the turbine. This follows from the fact that energy can neither be created nor consumed.

Wind turbines in parks are usually spaced at least three rotor diameters from one another in order to avoid too much turbulence around the turbines downstream. In the prevailing wind direction turbines are usually spaced even farther apart.

We would therefore like to space turbines as far apart as possible in the prevailing wind direction. On the other hand, land use and the cost of connecting wind turbines to the electrical grid would tell us to space them closer together.

The turbines in wind parks are usually spaced somewhere between 5 and 9 rotor diameters apart in the prevailing wind direction, and between 3 and 5 diameters apart in the direction perpendicular to the prevailing winds.



In this picture three rows of five turbines are placed .The turbines (the white dots) are placed 7 diameters apart in the prevailing wind direction, and 4 diameters apart in the direction perpendicular to the prevailing winds.

Knowing the best places to settle the turbines and also all obstacles developers and scientists can calculate the energy loss due to wind turbines shading one another. Typically, the energy loss will be somewhere around 5 per cent.

If we take under consideration tall buildings, or a narrow mountain pass, we will notice that the air becomes compressed on the windy side of the buildings or mountains, and its speed increases considerably between the obstacles to the wind. This is known as a "tunnel effect".

So, even if the general wind speed in open terrain may be, say, 6 meters per second, it can easily reach 9 meters per second in a natural "tunnel".

Placing a wind turbine in such a tunnel is one clever way of obtaining higher wind speeds than in the surrounding areas.

To obtain a good tunnel effect the tunnel should be embed in the landscape. In case the hills are very rough , there may be lots of turbulence in the area, the wind will be blowing in a lot of different directions.

If there is much turbulence it may decrease the wind speed advantage completely, and the changing winds may impose a lot of useless tear on the wind turbine.

Another way of sitting wind turbines is to place them on hills or ridges overlooking the surrounding landscape. It is always an advantage to have as wide view as possible in the prevailing wind direction in the area. On hills, we may also see that wind speeds are higher than in the surrounding area. This is also due to the fact that the wind becomes compressed on the windy side of the hill, and once the air reaches the ridge it can expand again.

4.2. How to select a good wind turbine site?

Looking at nature itself is usually a good guide to find a suitable wind turbine site.

If there are trees and other plants in the area, we may see how the trees are twisted to a what way and this could be an information for us about the prevailing wind direction.

If we move along a coastline, we may also notice that centuries of erosion have worked in one particular direction. This is also an information about the wind direction. Meteorology data is probably the best guide, but these data are rarely collected directly at the site where we want to place our turbines.

If there are already wind turbines in the area, their production results are an excellent guide to local wind conditions. In countries like Denmark and Germany where we can often find a large number of turbines scattered around the countryside, manufacturers can offer guaranteed production results on the basis of wind calculations made on the site.

So as I previously said we would like to have as wide and open view as possible in the prevailing wind direction, and we would like to have as few obstacles as possible in that same direction. If we find a rounded hill to place the turbines, we may even get a speed up effect for free, just like that.

Talking about turbines we have to be aware that large wind turbines have to be connected to the electrical grid. The generators in large, modern wind turbines generally produce electricity at 690 volts. A transformer located next to the turbine, or inside the turbine tower, converts the electricity to high voltage (usually 10-30 kilovolts).

The electrical grid near the wind turbine should be able to receive the electricity coming from the turbine. If there are already many turbines connected to the grid, the grid may need reinforcement.

The reason why we care about wind speeds is their energy content. The wind power varies with the cube of the wind speed.

The more kinetic energy a wind turbine pulls out of the wind, the more the wind will be slowed down as it leaves the turbine. If we tried to extract all the energy from the wind, the air would move away from the turbine with the zero speed. In the other extreme case, the wind could pass though our tube above without being interrupted at all. In this case we would not have extracted any energy from the wind.

We can therefore assume that there must be some way of braking the wind which is in between these two extremes, and is more efficient in converting the energy in the wind to useful mechanical energy. An ideal wind turbine would slow down the wind by 2/3 of its original speed.

As we know the energy potential per second (the power) varies in proportion to the cube of the wind speed, and in proportion to the density of the air. Usually, wind turbines are designed to start running at wind speeds somewhere around 3 to 5 meters per second. This is called the cut in wind speed. The wind turbine will be programmed to stop at high wind speeds above, say 25 meters per second, in order to avoid damaging the turbine or its surroundings. The stop wind speed is called the cut out wind speed.

The energy content of the wind varies very strongly with the wind speed. The most of the wind energy is available at wind speeds which are twice the most common wind speed at the site.

Finally, we need to account for the fact that the turbine may not be running at standard air pressure and temperature, and consequently make corrections for changes in the density of air.

5. Annual Energy Output from a Wind Turbine

Output varies almost with the cube of the wind speed.

With an average wind speed of 4.5 m/s at hub height the machine will generate about 0.5 GWh per year, i.e. 500,000 kWh per year. With an average wind speed of 9 meters per second it will generate 2.4 GWh/year = 2,400,000 kWh per year. Which is as we can observe that doubling the average wind speed has increased energy output 4.8 times.

If we had compared 5 and 10 meters per second instead, we would have obtained almost exactly 4 times as much energy output.

The reason why we do not obtain exactly the same results in the two cases, is that the efficiency of the wind turbine varies with the wind speeds.

Another way of stating the annual energy output from a wind turbine is to look at the capacity factor for the turbine in its particular location.

In a very windy location, it may be an advantage to use a larger generator with the same rotor diameter (or a smaller rotor diameter for a given generator size). This would tend to lower the capacity factor (using less of the capacity of a relatively larger generator).

6. The mechanism of turbines

6.1. The rotor and rotor blades

The rotor consisting of the rotor blades and the hub which are placed upwind of the tower and the nacelle (gondola) on most modern wind turbines. This is done because the air current behind the tower is very turbulent.

6.1.1. What makes the rotor turn?

It is of course obvious that the wind but not only. It is a bit more complicated than just the air molecules hitting the front of the rotor blades. Modern wind turbines borrow technologies known from airplanes and helicopters, plus a few advanced tricks of their own, because wind turbines actually work in a very different environment with changing wind speeds and changing wind directions.

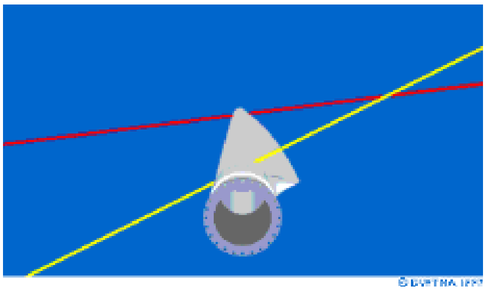
The wind which hits the rotor blades of a wind turbine will not come from the direction in which the wind is blowing in the landscape, (lets say from the front of the turbine). This is because the rotor blades themselves are moving.

Since most wind turbines have constant rotational speed, the speed with which the tip of the rotor blade moves through the air (the tip speed) is typically some 64 m/s, while at the center of the hub it is zero. 1/4 out the length of the blade, the speed will then be about 16 m/s.

Rotor blades for large wind turbines are always twisted.

Seen from the rotor blade, the wind will be coming from a much steeper angle (more from the general wind direction in the landscape), as we move towards the root of the blade, and the center of the rotor. A rotor blade will stop giving lift, if the blade is hit at an angle of attack which is too steep.

Therefore, the rotor blade has to be twisted, so as to achieve an optimal angle of attack throughout the length of the blade.



The wind in the landscape blows between, 8 m/s and 16 m/s. In the picture we can see how the angle of attack of the wind changes much more dramatically at the root of the blade (yellow line) than at the tip of the blade (red line), as the wind changes. If the wind becomes powerful enough to make the blade stall, it will start stalling at the root of the blade.

Wind turbine rotor blades look a lot like the wings of an aircraft. In fact, rotor blade designers often use classical aircraft wing profiles as cross sections in the most out part of the blade. The thick profiles in the most inside part of the blade, are usually designed specifically for wind turbines. Choosing profiles for rotor blades involves a number of compromises including reliable lift and stall characteristics, and the profile's ability to perform well even if there is some dirt on the surface which may be a problem especially in areas where there is little rain.

6.1.2. Rotor Blade Materials

Most modern rotor blades on large wind turbines are made of glass fibre reinforced plastics, like glass fibre reinforced polyester or epoxy.

Using carbon fibre or aramid as reinforcing material is another possibility, but usually such blades are uneconomic for large turbines.

Wood, wood-epoxy, or wood-fibre-epoxy composites have not reached the market for rotor blades, although there is still development going on in this area. Steel and aluminum alloys have problems of weight and metal fatigue . They are currently only used for very small wind turbines.

Wind turbines are designed to produce electrical energy as cheaply as possible. Wind turbines are therefore generally designed so that they yield maximum output at wind speeds around 15 meters per second. It is not worthy to design turbines that maximize their output at stronger winds, because such strong winds are rare.

In case of stronger winds it is necessary to waste part of the excess energy of the wind in order to avoid damaging the wind turbine. All wind turbines are therefore designed with some sort of power control. There are two different ways of doing this safely on modern wind turbines.

The turbine's electronic controller checks the power output of the turbine several times per second. When the power output becomes too high, it sends an order to the blade pitch mechanism which immediately turns the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again. Designing a pitch controlled wind turbine requires some good engineering to make sure that the rotor blades pitch exactly the amount required. On a pitch controlled wind turbine, the computer will generally turn the blades a few degrees every time the wind changes in order to keep the rotor blades at the optimum angle in order to maximize output for all wind speeds.

The pitch mechanism is usually operated using hydraulics.

(Passive) stall controlled wind turbines have the rotor blades closing onto the hub at a fixed angle. The geometry of the rotor blade profile, has been aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade which is not facing the wind. This stall prevents the lifting force of the rotor blade from acting on the rotor. As the actual wind speed in the area increases, the angle of attack of the rotor blade will increase, until at some point it starts to stall.

If you look closely at a rotor blade for a stall controlled wind turbine you will notice that the blade is twisted slightly as you move along its longitudinal axis. This is partly done in order to ensure that the rotor blade stalls gradually rather than abruptly when the wind speed reaches its critical value.

The basic advantage of stall control is that we avoid moving parts in the rotor itself, and a complex control system. Around two thirds of the wind turbines currently being installed in the world are stall controlled machines.

7. Active Stall Controlled Wind Turbines

An increasing number of larger wind turbines (1 MW and up) are being developed with an active stall power control mechanism.

When the machine reaches its rated power, we can observe that if the generator is about to be overloaded, the machine will pitch its blades in the opposite direction from what a pitch controlled machine does.

One of the advantages of active stall is that we can control the power output more accurately than with passive stall. Another advantage is that the machine can be run almost exactly at rated power at all high wind speeds. A normal passive stall controlled wind turbine will usually have a drop in the electrical power output for higher wind speeds, as the rotor blades go into deeper stall. The pitch mechanism is usually operated using hydraulics or electric stepper motors.

Another power control method is to yaw the rotor partly out of the wind to decrease power. This technique of yaw control is in practice used only for tiny wind turbines (1 kW or less). The wind turbine yaw mechanism is used to turn the wind turbine rotor against the wind.

8. The wind turbine generator

The wind turbine generator converts mechanical energy to electrical energy.

Wind turbine generators are very unusual, in comparison to other generating units which are attached to the electrical grid. One reason is that the generator has to work with a power source (the wind turbine rotor) which supplies very fluctuating mechanical power .

8.1. Generating Voltage (tension)

On large wind turbines (above 100-150 kW) the voltage generated by the turbine is usually 690 V three-phase alternating current (AC). The current is sent through a transformer next to the wind turbine or inside the tower to raise the voltage to between 10,000 and 30,000 volts, depending on the standard in the local electrical grid.

Large manufacturers usually supply both 50 Hz wind turbine models (for the electrical grids in most of the world) and 60 Hz models (for the electrical grid in America).

8.2. Cooling System

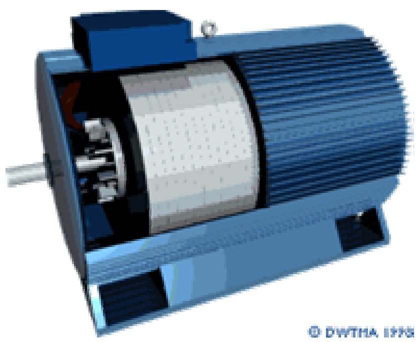
Generators need cooling while they work. Some manufacturers use generator placed in the duct and some of them use large fan for air cooling, and some use water cooled generators. Water cooled generators may be built more compactly, which also gives some electrical efficiency advantages, but they require a radiator to get rid of the heat from the liquid cooling system.

We should be very aware when connecting or disconnecting a large wind turbine generator to the grid by flicking an ordinary switch, that we can easily damage both the generator, the gearbox and the current in the grid.

Wind turbines may be designed with either synchronous or asynchronous generators, and with various forms of direct or indirect grid connection of the generator. Direct grid connection mean that the generator is connected directly to the (usually 3-phase) alternating current grid.

Indirect grid connection means that the current from the turbine passes through a series of electric devices which adjust the current to match that of the grid. With an asynchronous generator this occurs automatically.

The wind turbine generator:



The speed of a generator (or motor) which is directly connected to a three-phase grid is constant, and dictated by the frequency of the grid.

This generator (or motor) has four poles at all times, two South and two North.

We can also add 3 more electromagnets to the stator. With 9 magnets we get a 6 pole machine, which will run at 1000 rpm on a 50 Hz grid. And then we obtain such results:

8.3. Synchronous Generator Speeds (rpm)

Pole number	50 Hz	60 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

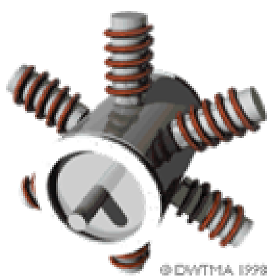
The name synchronous generator is applied to almost all sorts of generators without of course asynchronous generators.

Most wind turbines use generators with four or six poles. The reasons for using these relatively high-speed generators are savings on size and cost. Talking about maximum speed generator for a given power output we can distinguish a slow-moving, large and expensive generator or about high speed ,cheaper and smaller generator. The maximum force generator can handle depends on the rotor volume.

Most wind turbines in the world use a so-called three phase asynchronous generator, also called an induction generator to generate alternating current. This type of generator is not widely used outside the wind turbine industry, and in small hydropower units. The interesting thing about this type of generator is that it was really originally designed as an electric motor. In fact, one third of the world's electricity consumption is used for running induction motors driving machinery in factories, pumps, fans, compressors, elevators, and other things where we need to convert electrical energy to mechanical energy.

One reason for choosing this type of generator is that it is very reliable and also very inexpensive.

8.4. Asynchronous (Induction) Generators



8.4.1. Gearbox

The power from the rotation of the wind turbine rotor is transferred to the generator through the power train. If we used an ordinary generator, directly connected to a 50 Hz alternating current three phase grid with two, four, or six poles, we would have to have an extremely high speed turbine with between 1000 and 3000 revolutions per minute (rpm),with a 43 meter rotor diameter that would give speed of the rotor of far more than twice the speed of sound, so it sounds for us rather impossible. Another possibility is to build a slow-moving AC generator with many poles. But if we wanted to connect the generator directly to the grid, we would end up with a 200 pole generator and speed of 30 rpm.

Another problem is, that the mass of the rotor of the generator has to be extremely big. So a directly driven generator will be very heavy and expensive.

The practical solution, which is used in lots of industrial machinery, and also in car engines is a gearbox. With a gearbox you convert between slowly rotating, high power which turbines get from the wind turbine rotor - and high speed, low power, which turbines use for the generator.

8.5. The electronic wind turbine controller

The wind turbine controller consists of a number of computers which continuously monitor the condition of the wind turbine and collect statistics on its operation. The controller also controls a large number of switches, hydraulic pumps, valves, and motors and the wind turbine.

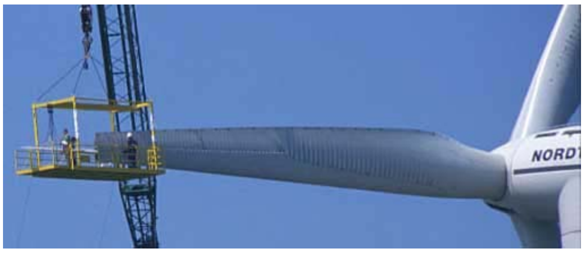
As wind turbine sizes increase to megawatt machines, it becomes even more important that that they function very good all the time.

The controller communicates with the owner or operator of the wind turbine via a communications link for example it can send alarms or requests for service over the telephone or a radio link. It is also possible to call the wind turbine to collect statistics, and check its present status. In wind parks one of the turbines is usually equipped with a PC from which it is possible to control and collect data from the rest of the wind turbines in the park. This PC can be called over a telephone line or a radio link. There is usually a controller both at the bottom of the tower and in the turbine. On recent wind turbine models, the communication between the controllers is usually done using fibre optics. On some recent models, there is a third controller placed in the hub of the rotor. That unit usually communicates with the other units using serial communications through a cable .Computers and sensors are usually duplicated in all safety areas of large machines. The controller continuously compares the readings from measurements from the wind turbine to ensure that both the sensors and the computers themselves are OK. It is possible to monitor or set about between 100 and 500 parameter values in a modern wind turbine. The controller may check the rotational speed of the rotor, the generator, its voltage and current. Further measurements may be made of outside air temperature, temperature in the electronic cabinets, oil temperature in the gearbox, the temperature of the generator windings, the temperature in the gearbox bearings, hydraulic pressure, the pitch angle of each rotor blade, the number of power cable twists, wind direction, wind speed from the anemometer, the size and frequency of vibrations in the nacelle and the rotor blades, or whether the tower door is open or closed- alarm system.

The controller looks also after the power quality of the current generated by the wind turbine.

Voltage and current are typically measured 128 times per alternating current cycle. On this basis, a processor calculates the stability of the grid frequency and the active and reactive power of the turbine. In order to ensure the proper power quality, the controller may switch on or switch off a large number of electrical capacitors which adjust the reactive power. There are very powerful electromagnetic fields around power cables and generators in a wind turbine. This means that the electronics in the controller system has to be insensitive to electromagnetic fields. And also the electronics should not emit electromagnetic radiation which can stop somehow the function of other electronic equipment. How the controller interacts with the wind turbine components is extremely important. Improved control strategies are responsible for an important part of the increase in wind turbine productivity in recent years.

8.6. Size of the wind turbines



The area of the disc covered by the rotor, (and wind speeds), determines how much energy we can harvest in a year.

The picture gives you an idea of the normal rotor sizes of wind turbines: A typical turbine with a 600 kW electrical generator will have a rotor diameter of 44 meters . Rotor diameters may vary because many manufacturers make their machines adjusted to local wind conditions: A larger generator, requires more power (in example: strong winds) to turn at all. So if we install a wind turbine in a low wind area we will maximize annual output by using a small generator for a given rotor size (or a large rotor size for a given generator). For a 600 kW machine rotor diameters may vary from 39 to 48 m. The reason why we may get more output from a relatively smaller generator in a low wind area is that the turbine will be running more hours during the year.

There are certain reasons for choosing larger and smaller turbines.

Here are some reasons for choosing larger ones:

- Larger machines are usually able to deliver electricity at a lower cost than smaller machines. The reason is that the cost of foundations, road building, electrical grid connection, plus a number of components in the turbine -the electronic control system - are independent of the size of the machine.
- Larger machines are more suitable for the offshore wind . The cost of foundations does not rise in proportion to the size of the machine, and maintenance costs are independent of the size of the machine.
- In areas where it is difficult to find sites for more than a single turbine, a large turbine with a tall tower uses the existing wind resource more efficiently.

Here are some reasons for choosing smaller turbines:

- The local electrical grid may be too weak to handle the electricity output from a large machine.
- There is less fluctuation in the electricity output from a wind park consisting of a number of smaller machines. Again, smaller machines may be an advantage in a weak electrical grid.
- The cost of using large cranes, and building a road strong enough to carry the turbine components may make smaller machines more economic in some areas.
- Several smaller machines spread the risk in case of temporary machine failure.
- Aesthetical landscape considerations may sometimes dictate the use of smaller machines. Large machines, however, will usually have a much lower rotational speed,

which means that one large machine really does not attract as much attention as many small, fast moving rotors.

8.7. Wind turbine safety

The components of a wind turbine are designed to last 20 years. This means that they will have to endure more than 120,000 operating hours, often under stormy weather conditions. Large wind turbines are equipped with a number of safety devices to ensure safe operation during their lifetime.

One of the classical, and most simple safety devices in a wind turbine is the vibration sensor , which was first installed in the Gedser wind turbine. It consists of a ball resting on a ring. The ball is connected to a switch through a chain. If the turbine starts shaking, the ball will fall off the ring and switch the turbine off.

There are many other sensors in the nacelle ,electronic thermometers which check the oil temperature in the gearbox and the temperature of the generator.

Safety regulations for wind turbines vary between countries. Denmark is the only country in which the law requires that all new rotor blades be tested both statically-(applying weights to bend the blade), and dynamically,(testing the blade's ability to stand fatigue from repeated bending more than five million times).

It is essential that wind turbines stop automatically in case of dysfunction of a critical component. (if the generator overheats or is disconnected from the electrical grid it will stop braking the rotation of the rotor, and the rotor will start accelerating rapidly in a second.

In such a case it is essential to have an overspeed protection system. Danish wind turbines are requited by law to have two independent fail safe brake mechanisms to stop the turbine

The primary braking system for most modern wind turbines is the aerodynamic braking systems. These systems are usually spring operated, in order to work even in case of electrical power failure, and they are automatically activated if the hydraulic system in the turbine loses pressure. The hydraulic system in the turbine is used to turn the blades or blade tips back in place once the dangerous situation is over.

Experience has proved that aerodynamic braking systems are extremely safe.

They will stop the turbine in a matter of a couple of rotations. And also they offer a very gentle way of braking the turbine without any major stress, tear and wear on the tower and the machinery. The normal way of stopping a modern turbine is to use the aerodynamic braking system.

Another type of breaking system is the MECHANICAL one.

The mechanical brake is used as a backup system for the aerodynamic braking system, and as a parking brake, when the turbine is stopped.

Large, modern wind turbines normally use tubular steel towers. The primary advantage of this tower is that it makes it safer and far more comfortable for service personnel to access the wind turbine for repair and maintenance. The disadvantage is cost.

The primary danger in working with wind turbines is the height above ground during installation work and when doing maintenance work.

New Danish wind turbines are required to have fall protection devices, (the person climbing the turbine has to wear a parachutist-like set of straps).

The straps are connected with a steel wire to an anchoring system that follows the person while climbing or going down in the turbine.

The wire system has to include a shock absorber, so that persons are reasonably safe in case of a fall. A Danish tradition (which has later been taken up by other manufacturers), is to place the access ladders at a certain distance from the wall. This enables service personnel to climb the tower.

Protection from the machinery, fire protection and electrical insulation protection is governed by a number of national and international standards.

During servicing it is essential that the machinery can be stopped completely. In addition to a mechanical brake, the rotor can be locked in place with a pin, to prevent any movement of the mechanical parts.

8.8. Turbines can be upward or downward machines

Upwind machines have the rotor facing the wind. The basic advantage of upwind designs is that one avoids the wind shade behind the tower.

On the other hand, there is also some wind shade in front of the tower, (the wind starts bending away from the tower before it reaches the tower itself, even if the tower is round and smooth. Each time the rotor passes the tower, the power from the wind turbine drops slightly. The basic thing about upwind designs is that the rotor needs to be made rather inflexible, and placed at some distance from the tower . In addition an upwind machine needs a yaw mechanism to keep the rotor facing the wind.

Downwind machines have the rotor placed on the windy side of the tower. They have the theoretical advantage, that they may be built without a yaw mechanism.

A more important advantage is that the rotor may be made more flexible. This is an advantage both in regard to weight, and the power dynamics of the machine, -(the blades will bend at high wind speeds). The basic advantage of the downwind machine is , that it may be built lighter than an upwind machine.

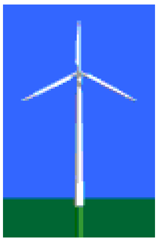
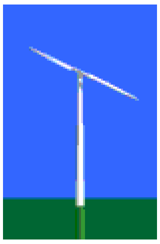
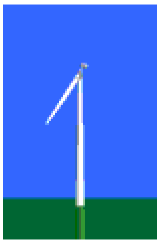
8.9. Number of blades

Most modern wind turbines are three-bladed designs with the rotor position maintained upwind (on the windy side of the tower) using electrical motors . This design is usually called the classical Danish concept, and tends to be a standard against which other concepts are evaluated. The vast majority of the turbines sold in world markets have this design. The basic design was first introduced with the renowned Gedser wind turbine. Another characteristic is the use of an asynchronous generator.

Two-bladed wind turbine designs have the advantage of saving the cost of one rotor blade and its weight. However, they tend to have difficulty in penetrating the market, partly because they require higher rotational speed to yield the same energy output. This is a disadvantage both in regard to noise and visual intrusion. Lately, several traditional manufacturers of two-bladed machines have switched to three-bladed designs. Two- and one-bladed machines require a more complex design: the rotor has to be able to tilt in order to avoid too heavy shocks to the turbine when a rotor blades passes the tower. This arrangement may require additional shock absorbers to prevent the rotor blade from hitting the tower.

And the strangest thing: one-bladed wind turbines do exist, and indeed, they save the cost of another rotor blade! One-bladed wind turbines are not very widespread , because the same problems that are mentioned under the two-bladed design apply to an even larger extent to one-bladed machines. In addition to higher rotational speed, and the noise and visual intrusion problems, they require a counterweight to be placed on the other side of the hub from the rotor blade in order to balance the rotor. This obviously negates the savings on weight compared to a two-bladed design.

On these pictures below we can see the three types of wind turbines with different number of blades:

8.10. Sound emission from the wind turbines

Sound emissions from wind turbines may have two different origins: Mechanical noise and aerodynamic noise.

Mechanical noise: metal components moving or knocking against each other may originate in the gearbox and in the generator of a wind turbine.

Machines from the early 1980s or before do emit some mechanical noise, which may be heard in the surroundings of the turbine, in the worst cases even up to a distance of 200 m.

In last three years noise emissions had dropped to half their previous level due to better engineering practices.

Gearboxes for wind turbines are no longer standard industrial gearboxes, but they have been adapted specifically for quiet operation of wind turbines. Also the rotor blades may act as membranes that may retransmit noise vibrations from the nacelle and tower.

The turbine manufacturers nowadays make computer models of their machines before building them, to ensure that the vibrations of different components do not interact to amplify noise.

Sound insulation plays a minor role in most wind modern turbines on the market today, although it can be useful to minimize some medium- and high-frequency noise.

8.10.1. Aerodynamic sources of sound emission

When the wind hits different objects at a certain speed, it will start making a sound. If it hits the leaves of trees and bushes, or a water surface it will create a mixture of high frequencies, often called white noise.

The wind may also set surfaces in vibration, as sometimes happens with parts of a building, or car . These surfaces in turn emit their own sound. If the wind hits a sharp edge, it may produce a pure tone.

Rotor blades make a slight sound which we may hear if we are close to a wind turbine working at low wind speeds.

Rotor blades must brake the wind to transfer energy to the rotor. In the process they cause some emission of noise. If the surfaces of the rotor blades are very smooth the surfaces will emit a minor part of the noise.

The tip of the blade moves faster than the root of the blade, great care is taken about the design of the rotor tip.

Also research on quieter rotor blades continues, but most of the benefits of that research will be turned into increased rotational speed and increased energy output, since noise is generally not a problem if we take under consideration certain distance given to neighboring houses.

The sound emission levels for all new Danish turbine designs tend to be around the same values. This seems to indicate that the gains due to new designs of for example quieter rotor blade tips are spent in slightly increasing the tip speed (the wind speed measured at the tip of the rotor blade), and then increasing the energy output from the machines.

It appears that noise is not a major problem for the industry, given the distance to the closest neighbors (usually a minimum distance of about 7 rotor diameters or 300 m is observed). Another thing is the surrounding. No landscape is ever completely quiet. Birds and human activities emit sound, and at winds speeds around 4-7 m/s and up the noise from the wind in leaves, shrubs, trees, masts will gradually mask any potential sound from wind turbines.

This makes it extremely difficult to measure sound from wind turbines accurately. At wind speeds around 8 m/s and above, it generally becomes a quite issue to discuss sound emissions from modern wind turbines, since background noise will generally mask any turbine noise completely.

Sound reflection or absorption from terrain and building surfaces may make the sound picture different in different locations. Generally, very little sound is heard upwind of wind turbines.

In accordance with international standards manufacturers generally specify a theoretical dB(A) level for sound emissions . Sound pressure calculated is typically around 96-101 dB(A) for modern wind turbines. Pure tones have generally be eradicated completely for modern wind turbines, at least.

At distances above 300 m the maximum theoretical noise level from high quality wind turbines will generally be significantly below 45 dB(A) outdoors, corresponding to the legislation in Denmark. (For built-up areas with several houses, a noise limit of 40 dB(A) is the legal limit in Denmark).

Noise regulations vary from country to country. In practice the same machine designs can be used everywhere.

Calculating potential sound emission from wind turbines is generally important in order to obtain planning permission (from the public authorities) for installing wind turbines in densely populated areas. It is easier to calculate the potential sound emissions than to measure them in practice.

8.11. Seasonal Variation in Wind Energy

In temperate zones summer winds are generally weak compared to winter winds. Electricity consumption is generally higher in winter than in summer in these regions.

In the cooler areas of the globe, electrical heating is therefore ideal in combination with wind energy, because the cooling of houses varies with the wind speed like the electricity production of wind turbines vary with wind speeds. Wind patters may vary from year to year. In the case of Denmark, you will see that output from wind turbines typically have a standard deviation of some 9 to 10 per cent.

Power quality issue:

The buyer of a wind turbine does not need to concern himself with local technical regulations for wind turbines and other equipment connected to the electrical grid. This responsibility is generally left to the turbine manufacturer and the local power company.

The term "power quality" refers to the voltage stability, frequency stability, and the absence of various forms of electrical noise on the electrical grid.

Most electronic wind turbine controllers are programmed to let the turbine run idle without grid connection at low wind speeds. Once the wind becomes powerful enough to turn the rotor and generator at their rated speed, it is important that the turbine generator becomes connected to the electrical grid at the right moment.

Otherwise there will be only the mechanical resistance in the gearbox and generator to prevent the rotor from accelerating, and eventually over speeding. There are several safety devices, including fail-safe brakes, in case the correct start procedure fails.

To prevent this situation, modern wind turbines are soft starting- they connect and disconnect gradually to the grid. Modern wind turbines are normally equipped with a bypass switch- a mechanical switch which is activated after the turbine has been soft started. In this way the amount of energy wasted will be minimized.

If a turbine is connected to a weak electrical grid, there may be some power surge problems . In such cases it may be necessary to reinforce the grid, in order to carry the fluctuating current from the wind turbine.

9. Offshore wind power research

Megawatt sized wind turbines, cheaper foundations and new knowledge about offshore wind conditions is improving the economics of offshore wind power. Wind energy is already economic in good onshore locations .But nowadays offshore wind energy is rapidly becoming competitive with other power generating technologies.

9.1. The Danish plan 21

According to *The Danish Governments' Action Plan for Energy, Energy 21* 4,000 MW of offshore wind power should be installed before year 2030. With another 1,500 MW installed onshore Denmark will then be able to cover more than 50 per cent of total electricity consumption by wind energy. In comparison, the current wind power capacity in Denmark is 1,100 MW (mid 1998).

A total of 5,500 MW of wind power in the Danish electricity system means that the wind turbines periodically will cover more than 100 per cent of Danish electricity demand. Therefore, the future Danish offshore power plants should be an integrated part of the Scandinavian electricity system, which is based on huge amounts on hydro power. With a total investment of some 48 billion DKK (= 7 billion USD) for the 4,000 MW offshore capacity the Danish action plan will be the world's largest investment in wind power ever.

Danish power companies have already applied for planning permission for 750 MW of offshore wind parks. According to their timetable more than 4,000 megawatts of wind power will be installed offshore in Denmark before 2027. The first stage is likely to be a smaller 40 MW offshore park just of the coast of Copenhagen in year 2000.

A report drafted by the Danish power companies for the Minister of Environment and Energy identifies four main areas in Danish sea territory suitable for wind power with a potential of 8,000 MW. For environmental reasons the Committee has concentrated the capacity in few and remote areas with water depths between 5 and 11 meters. The areas have been selected to avoid national park areas, shipping routes, microwave links, military areas, etc. The distance from coastal areas varies from 7 to 40 km. This also minimizes the visual impact onshore. The most recent research into foundations indicates that it may be economic to install offshore turbines even at 15 meters water depth. This mean that the offshore potential is some 16,000 MW in the selected areas in the Danish Waters.

The major challenge for offshore wind energy is cutting costs: Undersea cabling and foundations have recently made offshore wind energy an expensive option.

New studies of foundation technology, plus megawatt-sized wind turbines are now on the point of making offshore wind energy competitive with onshore sites, at least for shallow water depths up to 15 meters .

Since offshore wind turbines generally yield 50 per cent higher output than turbines on nearby onshore sites (on flat land), offshore sitting may be quite attractive.

Two Danish power company groups and three engineering firms made a pioneering study on the design and costing of offshore wind turbine foundations in 1996-1997. The report concluded that steel is the best for larger offshore wind farms.

It appears that all of the new technologies will be economic until at least 15 meters water depth, and possibly beyond such depths. In any case, the marginal cost of moving into deeper waters is far smaller than what was previously estimated.

With these concepts foundation and grid connection costs for large 1.5 megawatt turbines are only 10 to 20 per cent higher than the corresponding costs for the 450-500 kW turbines used in offshore wind parks in Denmark.

Contrary to popular belief, corrosion is not a major concern with offshore steel structures. Experience from offshore oil rigs has shown that they can be protected using cathodic corrosion protection.

Surface protection (paint) on offshore wind turbines will be delivered with a higher protection class than for onshore turbines.

The steel used for the wind turbines will have to last for 50 years.

So it can be a new design for the next century and later maybe, it can replace our wind turbines onshore at all.

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HYDROGEN

1. Introduction

1.1. How the hydrogen was formed – 'The big bang theory'

It is believed that hydrogen atoms were created as one of the first atoms in the universe. The big bang theory assumes that the universe was extremely compact, dense and hot. About 10 to 20 billion years ago an explosion, called big bang, occurred and the universe has started to expand and cool. This explosion produced a single force, which was further separated into gravity, electromagnetism and nuclear force. After one second, protons were formed and then in so called 'first three minutes' a combination of protons and neutrons formed the isotope of hydrogen deuterium and some other light elements like helium, lithium, boron and beryllium. From about 300'000 to 1 million after the big bang, the universe cooled to about 3000^{o}C and protons and electrons combined to form hydrogen atoms. [1]

The overall framework of the big bang theory came out of the Einstein's general relativity field equations, which was modified myriad times later on.

1.2. The places of hydrogen occurrence

Hydrogen is the most abundant element and it makes up over 90% of universe's matter. It can be found in the Sun and most of the stars, some planets, like for instance Jupiter, are formed mostly of hydrogen. Collection of hydrogen by gravitational forces of stars, and further conversion into helium by nuclear fusion is a process that supplies stars, including the Sun, with the energy. This process gives off radiant energy, which sustains life on earth.

The amount of hydrogen on Earth is estimated as 0.9% of the whole mass of the planet, and is mostly provided by water. This can be found in numerous substances like natural gas, methanol, coal and is present also in all animals and vegetables. Hydrogen is present in almost every compound in the human body, for instance in keratin that forms our hair and skin or in DNA. [1]

1.3. Physical and chemical properties of hydrogen

Hydrogen is a colourless, odourless and extremely flammable substance, and is the smallest and simplest member of the family of chemical elements. The hydrogen is formed of a nucleus consisting of a proton, bearing one unit of positive electrical charge, and an electron, bearing one unit of negative electrical charge, which is travelling around this nucleus. Pure hydrogen exists as a hydrogen gas, in which pairs of hydrogen atoms bonds together and forms a molecule. It is much more lighter than air, because of that it can fly off to the space against Earth's gravitational force.

Hydrogen gas does not usually reacts with other elements at room temperature, but when heated it combines explosively with oxygen at temperature of 450^{o}C and produces a huge amount of energy. The explosive mixture is between 6% of H_2 in O_2 to 5% of O_2 in H_2. [2]

1.4. The history of researches on the hydrogen

The history of hydrogen goes back to the XVI century, when T. Paracelsus managed to gain it by acting acetic acid on iron. Because of the burning properties of this gas, it was called a 'burning air'. In 1660, R. Boyle obtained hydrogen by acting H_2SO_4 on Fe, and discovered that it is not burning in the rarefied air. In 1776, Henry Cavendish designated hydrogen as a simple substance, lighter than air, and in 1781 he proved that the product of combustion is water. The very interesting thing is that, he was not aware that hydrogen is a part of molecule of water, it was stated 20 years later by A. L. Lavoisier, and he called it 'hydrogen' (lat. Hydrogenium – forming water). The first practical usage of hydrogen dates on august 1783, when in Paris J. A. C. Charles released a balloon filled with hydrogen. However, after series of dirigibles catastrophes, which the best known was the catastrophe of Hindenburg dirigible and took place in may 1937 in the New York, people had returned to the idea of brothers Montgolfier's based on filling the dirigibles with hot air. [2]

Two energetic crises and catastrophic condition of the environment caused anew interest in hydrogen as the most pro-ecological source of energy. Combustion of hydrogen does not cause an emission of SO_2, CO_2, CO, dust, furans and doxins, and what is more the technologies of fuel cells gives us possibility to eliminate nitric oxides (NO_x), which are always present during combustion.

2. Known methods of hydrogen production

2.1. Industrial methods of hydrogen production

Unfortunately, all known industrial methods of hydrogen production are unprofitable. That means, we have to provide more energy to produce it than we are able to gain from hydrogen combustion.

2.1.1. The Bosh method

This method is based on decomposition of water vapour, using coke, in the temperature of 1200 ^oC to hydrous gas, and then converse the mixture of this gas with water vapour on Fe_2O_3 and Cr_2O_3 catalyst in the temperature of 300-450^oC. Emitted CO_2 is absorbed by water under increased pressure (10-30 Mpa) and NaOH absorbs residues. [3]

$C + H_2O \rightarrow CO + H_2$

$C + H_2 + H_2O \rightarrow CO_2 + 2H_2$ [2]

The biggest shortcoming of this method is the necessity of achieving so high temperature, what causes an immense loss of the energy.

2.1.2. Natural gas steam reforming

This method is composed of two steps. The first step is to expose natural gas to high-temperature steam to separate hydrogen from carbon atoms in natural gas (CH_4), additionally carbon monoxide (CO) and carbon dioxide (CO_2) are produced. The second step is to convert the carbon monoxide with steam to produce supplementary hydrogen and carbon dioxide.

$CH_4 + H_2O \rightarrow CO + 3H_2$

$CO + H_2O \rightarrow CO_2 + H_2$ [2]

Hydrogen produced by this method is not used as a fuel, but in manufacture of fertilisers and chemicals, and to upgrade the quality of petroleum products. Nowadays, this is the most effective way of gaining hydrogen, but it uses fossil fuels both in manufacturing process and as the heat source, what is a great disadvantage of this method.

2.1.3. Gasoline reforming

Hydrogen is produced by this method due to increase the octane number of gasoline in the process of dehydrogenation of hydrocarbons.

$C_6H_{12} \rightarrow C_6H_6 + 3H_2$ $C_6H_{14} \rightarrow C_6H_6 + 4H_2$ [2]

2.1.4. Electrolytic decomposition of water

This method is using the electric energy to split water into hydrogen and oxygen gas.

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (on the cathode)

$2OH^- \rightarrow H_2O + 1/2\ O_2 + 2e^-$ (on the anode)

H_2O + electricity $\rightarrow H_2 + 1/2\ O_2$ (globally) [4]

To gain hydrogen by means of this method, we have to provide more energy in form of electricity (4.3 to 5.7 kW·h/m3) than we are able to achieve from combustion of hydrogen (3 kW·h/m^3). There are some proposals of using other sources of energy like nuclear energy, or the energy of sun and wind, to perform electrolysis, but also these opportunities faces some problems.

2.1.5. Thermochemical decomposition of water

Thermal decomposition of water is occurring only in the temperature above 5177^{o}C (practically imposible), which is practically impossible to achieve nowadays. However, execution of decomposition in two cycles allows decreasing this temperature to 3067^{o}C.

$CO + H_2O \rightarrow H_2 + CO_2$ (477^{o}C)

$CO_2 \rightarrow CO + ½\ O_2$ (3067^{o}C) [4]

Profitability of this method is strictly connected with possessing the cheap source of carbon monoxide (for instance gasification or incomplete combustion of coal), because the full cycle is too expensive in realisation, caused by the cost of achieving the temperature needed to decompose CO_2.

2.1.6. The Schulten method

The Shulten method is based on decomposition of water composed of four steps of closed cycle. The highest temperature needed to perform this method is 927^{o}C, which can be obtained without any trouble. During this method, a cycle of reactions between methane (CH_4), water (H_2O), carbon monoxide (CO) and some others substances occurs. The efficiency of whole cycle is 40-45%, which is quite satisfying. [4]

2.2. Future methods of hydrogen production

Due to literature, the researches over new methods of hydrogen production are performed in the following directions:

- Transforming solar energy in the photocells into electrical power, which used for the water electrolysis,
- Transforming solar energy in the solar cells into electricity, which flew through the cover made of rhodium, molybdenum, wolfram and presently porphyrynium compounds (nearing in structure to chlorophyll) decompose water, not electrolytic, but catalytic,
- Transforming solar energy in the solar kiln of 1000 [kW] power, with parabolic mirrors into heat (to 4000 [K]) and using obtained heat to thermal decomposition of water (water thermolysis 2500 [^{o}C]),
- The Hotelly method, based on hot electrolysis of water vapour at the temperature 900 [^{o}C],
- Bacteria usage for the anaerobic decomposition of biomass,
- Photoreduction of water by means of microorganisms.

To the last method, as the one that promises the biggest hopes, is assigned the whole chapter.

3. Photobiological methods of hydrogen production

In the first period of creation life on Earth, when unicellular plants occurs only in water, the composition of Earth atmosphere did not resemble the present one. With the lack of ground oxygen generators, in other words plants, fluctuation of the concentration of this gas had to be great. In that situation, only those unicellular plants could survive, which as the result of evolution, had formed protective mechanisms, which enables them to survive thanks to switching themselves from photosynthesis, which allows reproduction, development and energy accumulation, to photoreduction (using accumulated energy resources). Using photoreduction, algae were breathing with oxygen taken from water, and a waste product was hydrogen. The next evolution stage was transforming those unicellular plants into more developed and more complex forms. Those plants, after a certain period of time, also settled on lands, and contributed to setting the composition of the Earth atmosphere. That caused, the plants, which did not have to use photoreduction, after a certain period of time, 'forgot' about it. It appears, that some green unicellular algae are still able to use this, worked out millions years ago, method which is letting survival in the extreme anaerobic conditions. Over 60 years ago, scientists knew that some types of algae are able to produce trace amounts of hydrogen [5]. However, finding the answer for the question why it happens and when the process occurs, took scientists about 20 years [6]. Through the next several tens years it was tried to go deeply into the mechanism ([7], [8], [9], [10]) and conditions of hydrogen formation during the process of photoreduction ([11], [12]) as well as specifying factors which has influence on the yield of its formation [13], [14].

The perspective of exploitation, in the nearest future, traditional energy carriers, as well as the necessity of rescuing devastated by the products of combustion of these carriers natural environment, was an impulse to intensified studies of the mechanism of photoreduction production of hydrogen [15]. The aim of these studies was increasing the yield and decreasing costs of generation of that the most pro-ecological energy carrier with unlimited resources in the form of seas and oceans.

That grouped and intensified efforts, resulted in discovering by the scientists from the Universities of Berkeley and Colorado, molecular switch, which permits to control switching cells of one type of algae (*Chlamydomonas reinhardtii*) from photosynthesis accumulation of energy, development of the algae, to process of photosynthesis which result is damage use of accumulated energy accompanied by hydrogen emission. The switch appears to be sulphate ions [16], [17].

This research, according to scientists, is a great turn, because it will allow during the nearest 10 years elaborating profitable for the industrial scale, biotechnological hydrogen production. The driving force of the process will be solar energy, the raw material will be water and the catalysts enzymes (in the case of algae, ferredoxin, hydrogenase and nitrogenase [18]) with the presence of mineral salts.

3.1. Factors present in the photobiological reactions

3.1.1. Solar energy

Resources of the solar energy are, in our Earth time scale, unlimited. The intensity of solar radiation reaches the maximum value of about 1300 [W/m^2] and depends on the wavelength, which differentiate from about 0.3 to about 2.6 [μm]. Unfortunately, only a half of solar energy (the range of wavelength from 0.38 to 0.68 [mm]) can be used by plants in the processes of photosynthesis. From that amount of the energy stream about one fifth can not penetrate into plant cells because is reflected from leafs. In case of water plants besides the reflection, also are added loses of energy caused by water absorption depended on the depth. Theoretical bounded efficiency of photosynthesis is estimated at 12-13 [%] [19], however practically it is not higher than 2 [%] [20]. From that amount about 40 [%] is connected to loses of plants breathing, which contrary to photosynthesis, last for 24 hours. It is assumed, that the real energy profit absorbed by land plants is equal to 0.25 [%], and water plants together with plankton 0.5 [%]. The rest of the energy is transformed, in case of land plants, to heat during the process of transpiration [21].

During assimilation of carbon dioxide in the process of photosynthesis, sugar (glucose) is formed, according to following reaction:

$$6CO_2\ (264\ [g]) + 12H_2O\ (216\ [g]) + h\nu = \\ = C_6H_{12}O_6\ (180\ [g]) + 6\ O_2\ (192\ [g]) + 6\ H_2O\ (108\ [g]),$$

Because from combustion of 1 [mole] (180 [g]) of glucose we get 2.826 [MJ] of heat, thus that value is designates the bottom amount of provided, during the photosynthesis, energy of solar radiation. In the reality to store in one molecule of glucose solar energy in amount of 5 [eV], in the process of photosynthesis 8 photons, about 14 [eV], must be provided [22].

Under optimum conditions, from 1 [m^2] of leaf surface, it is gained 0.5-1.5 [g] of glucose per hour, after its combustion it is possible to gain energy stream of density equal 2.18-6.54 (mean 4.36) [W/m^2] [21]. Assuming the mean value of the density of solar energy radiation 1000 [W/m^2], it is gained the conversion efficiency 0.436 [%].

Thanks to the process of photosynthesis, life on Earth is possible, because transformed in this way the energy of solar radiation into chemical energy (glucose, starch, hydrocarbons etc.), it becomes nutrition for other plants, animals and people. It is estimated that every year only land plants binds $1.046 \cdot 10^{24}$ [J] of solar energy [21]. In paper [53] that amount was evaluated as $4 \cdot 10^{20}$ [J] per year only.

Reactions of photosynthesis, which are accompanied by oxygen emission, are called photoreduction. An example of such reaction is emission by sulphur bacteria sulphate against oxygen. Such reaction goes in the water environment reach in sulphuretted hydrogen (an effect of decaying processes), and it is written by:

$$H_2S + CO_2 + h\nu = 2S + H_2O + -(CH_2O)-$$

Also reactions, which results in hydrogen emission under anaerobic conditions and lacking with sulphur, but with the presence of light, must be included to reactions of photoreduction.

In the article [22] was said, quoted on ecological sources (70 [g/m^2], as the experimental amount of daily produced biomass from the squared meter) as well as, on the Nobel prize winner in the field of chemistry (1961), that for satisfying energetic needs of American economy, it is needed biomass with acreage equal of hundreds of Arizona state. In the article [20], on the basis of G. Calzafer calculations (1985) it was given, that for satisfying energetic needs of 10 milliards of people, estimated using about 4 [kW] of energy individually, it would be sufficient to transform solar energy with an efficiency 10 [%] from an area of 18 [%] of Sahara desert.

3.1.2. Water

Oceans with seas are taking up about $3.61 \cdot 10^8$ [km^2] which is 71 [%] of area of Earth. Thus water resources – similarly to solar energy – in the Earth time scale, are practically unlimited. However, the water quality is aggravating all the time and this fact should also be taken under consideration during analysing possibility of biophotolytic hydrogen production. Plants, for its proper development, demands not only light, carbon dioxide and mineral salts, but firstly of all water with a proper purity. In water with high concentration of mineral salts, at the beginning algae are thriving, which after exploitation of mineral contents, atrophies and decays what is accompanied by oxygen exploitation. Then anaerobic bacteria decays algae proteins to sulphuretted hydrogen or separated sulphur. In such a acidified with sulphuretted hydrogen water environment, all life is atrophying.

Usage of $^{18}O_2$ isotope have proved that oxygen is formed as a result of photolysis of water contrary to what was formerly considered from carbon dioxide.

3.1.3. Inorganic compounds

In photobiological reactions, following cations are essential K^+, Ca^{++}, Mg^{++} and Fe^{++}, as well as elements N, S and P, which are commonly absorbed in a form of NO_3^-, SO_4^{-2} and PO_4^{-3}. Apart from those compounds, for plant living some trace amounts of other elements (microelements) such as Mn, Cu, Zn, Mo, B and others, are also essential. The role of particular cations and anions is very differentiated. Some are regulating colloidal properties of plasma, what activates enzymes that are producing proteins (potassium), other forms complexes which are a part of chlorophyll (iron, magnesium) and another are keeping proper pH of the cell.

Nitrates are released materials in the protein transformations. Through nitrate ion reduction to $-NH_2$, it leads to amino acids synthesis, raw materials to protein formation.

To synthesis of some amino acids, sulphates are also essential, during which sulphate ion is reduced to sulphur or thiol (sulfhydryl) group.

Phosphates are building up to chloroplasts forming high energetic compounds, which under influence of solar radiation energy, are transformed and in this way are storing solar energy in form of chemical energy.

3.1.4. Enzymes

Except factors in photosynthesis of glucose given above and then formation of assimilative starch, enzymes take part in it as well. Below are given the most important one and best known.

Chloroplasts (Chl) are a part of plant cells with diameter of 3-8 μm [23]. It was calculated that in 1 [cm^2] of a leaf, there may be 50 millions of it. An effect of its contribution to photosynthesis is emission of oxygen. That does not have to be chloroplasts in living cells. It appeared that photolysis of water (oxygen emission without glucose formation) is performed by chloroplasts or theirs fragments isolated from living cells. However, to obtain it the presence of hydrogen acceptor is essential, for instance quinones ferricyanide of or NADP (nicotinamide-adenine dinucleotide phosphate). Seeing that reaction occurs as well in the absence of CO_2, it is another prove for the fact that assimilative oxygen is formed thanks to photolysis of water, and not from CO_2 reduction.

NADP in the process of photosynthesis, as result of interactions with chloroplasts, in the presence of solar radiation, cause water photolysis given by the reaction:

$$2\ H_2O + 2\ NADP^+ + h\nu = O_2 + 2\ NADPH + 2\ H^+$$

Hydrogen ions, in the presence of manganese, reduce CO_2 to glycerophosphate acid and then to glucose.

ADP and ATP. Illuminated chloroplasts absorb also from water inorganic phosphates and build it in the high energetic organic compound, and reaction of transforming ADP (adenosine diphosphate) into ATP (adenosine triphosphate) is written as:

$$ADP + PO_4^{-3} + h\nu = ATP + 3e^-$$

Detachment of phosphoric acid (H_3PO_4) from ATP, emits a part of stored energy, which may be used for CO_2 reduction to coal in the coal chain of carbohydrate and oxygen emission.

Chlorophyll and carotene. The role of light absorber in chloroplasts is played by 2 groups of compound: organic magnesium compounds, so-called chlorophyll of different types (a, b, c, d) and bacteriochlorophylls and carotenoids. Chlorophyll (a) is present in algae, (a and b) in higher plants, (a and c) in brow algae and (d) in red algae). The first of them absorbs light in the red range and infrared range, and the second one in the blue range.

Light absorption is causing in these compounds electron excitement, which is moved to a higher energetic level. Then it goes through several intermediate redox substances and arrives to chlorophyll, and emitted by light energy is kept stored in ATP. In this process does not occur yet, assimilation connected with CO_2 reduction and O_2 emission.

Ferredoxin, cytochrome-f, benzoquinone (plastobenzoquinone). The mechanism of enzyme activity is not known exactly, because very often, they are able to perform a lot of functions. When factors which are influencing in what function the enzyme is performing at the certain stage, are commonly so subtle in the living organisms, what causes them difficult to designate. One of such a function is transport of electric charges. Enzymes, which are responsible for that action, absorbs reversibly an electron (they are reducing themselves) or emits it (are oxidised). Such enzymes are oxidoreductases, for instance ferredoxin, which is a protein with iron built in. This iron can reversibly change from Fe^{+3} to Fe^{+2}. The next electron transporting cell is cytochrome-f, the compound which is containing the iron as well, benzoquinone which emits electrons as easy as iron, and a lot of other compounds [21].

Hydrogenase posses the ability of photolytic decomposition of water to oxygen or after switching of the metabolism, to hydrogen. To this enzyme, for the reason of its specific ability of performing reversible metabolism, as a result of which, hydrogen is produced, is assigned the whole chapter.

3.1.5. Thermodynamic aspect of photosynthesis

To achieve one molecule of hexose (glucose or fructose) six cycles have to occur. During those cycles carbon from CO_2 undergoes reduction by NADPH and is added to chain.

Global balance of closed cycle reaction can be described as:

$$6\ CO_2 + 18\ ATP + 12\ NADPH + 12\ H2O\ +\ h\nu \longrightarrow$$

$$\longrightarrow \quad C_6H_{12}O_6 + 18\ ADP + 18\ phosphate + 6e + 12\ NADP^+ + 6\ H^+$$

Thermodynamic yield of photosynthesis reaction can be described as the ratio of free energy of CO_2 reduction to hexose $\Delta G^o = +\ 477$ [kJ/mole], to energy of 8 moles of photons of light with wavelength $\lambda = 600$ [nm], which are needed to reduce one molecule $NADP^+$ to NADPH. One mole of photons of light with that wavelength possesses energy equal to 199 kJ, thus efficiency of photosynthesis under standard conditions is:

$$\eta = \frac{477}{8 \cdot 199} = 30\ [\%]$$

The energy of solar radiation, after transformation during photosynthesis into chemical energy, is accumulated in plants in the form of store sugars: starch and saccharose. Assimilative starch is synthesised in chloroplasts and accumulated in the form of store starch in leucoplasts. Saccharose is synthesised in cytosol and stored in the cells of many plants, for instance: sugar cane, sugar beet, fruits etc.

3.1.6. The mechanism of photoreduction

Hydrogenase while S ions lacks, is activated to hydrogen production in anaerobic conditions, when the pressure of O_2 is smaller than 2 [%]. Then it oxidises reversibly hydrogen ions, taken from water, providing them electrons and reduces the Fe element in the ferredoxin (Fd). The reaction occurs under light exposure, in a following way [18], [45]:

$$2H^+ + 2Fd(Fe^{+2}) + h\nu \xleftrightarrow{Hydrogenaza} H_2 + 2Fd(Fe^{+3})$$

Such activation of hydrogenase allows alga *Chlamydomonas reinhardtii* to survive in the medium that lacks in S ions, without which photosynthesis and oxygen production is stopped. Thanks to such metabolism switch, the cells are able to produce in a damage way, sufficient amounts of ATP, which are essential to survive.

It is performed in such a way that initiated with electron, gained from organic donor, cyclic electron transport, after that it is driven by solar energy, at last contributes to ATP formation. In this process are used proteins and sugars, which are stored in the cells during typical photosynthesis. These compounds are materials needed to ATP formation as well as the source of bioorganic sulphur.

In this situation, from a cell point of view, hydrogen is a waste product, which has to be disposed, to avoid bursting of cell membrane.

Some tests are performed, which aim is to research behaviour of hydrogenase after its separation from the cell [43]. In this article are given results of electrochemical studies about behaviour of hydrogenase isolated from *Thiocapsa roseoperscina* and put in the form of singular layer on the polarised electrode type Langmur-Bladgetta. It appeared that thermostability of hydrogenase reaches 70 [^oC] with ability of producing oxygen as well as hydrogen in the presence of methyl viologen mediator.

In articles [46] and [47] were provided results of structural studies and differences in electron activity of hydrogenase concentration as well as studies of catalytic mechanism of hydrogenase photolysis in the presence of vapours of elements NiFe and NiFeSe also Ni-B, Ni-SI, Ni-C and Ni-R, on which hydrogen bridges are formed. In the experiments it was used a method of quantum chemical studies.

3.2. Hydrogen production in the process of photoreduction

3.2.1. Hydrogen production by photosynthetic bacteria.

Bacterial production of hydrogen depends on the activity of highly oxygen sensitive nitrogenase enzyme ([24], [25]). There are some members of the diazotrophic bacteria group, including *Azotobacter vinelandii* ([24], [26], [27]), *Rhizobium leguminosarum* ([24], [28]), *Rhizobium japonicum* ([24], [29]), *Rhizobium meliloti* ([24], [30]), *Azospirillum brasilense* ([24], [31]), and *Arthrobacter* sp.([24], [32]), which are able to produce hydrogen under aerobic conditions. These micro organisms generate adenosine triphosphate (ATP) by respiration, which increases its concentration in cell, and promotes nitrogenase activity [24]. Photosynthetic bacteria do not utilise water as the starting compound for hydrogen production but use organic acids. An equation below shows the production of hydrogen from lactate by photosynthetic bacteria. [33].

$$C_3H_6O_3 + 3H_2O \xrightarrow{light} 6H_2 + 3CO_2$$

Materials and methods

The marine nonsulphur photosynthetic bacterium, Rhodovulum sp. NKPB160471R ([24], [34]), was culture in marine RCVB medium ([24], [35]) supplemented with L-malate at room temperature for 48 h under continuous illumination. A rectangular photobioreactor (3 cm width, 2 cm length, 2 cm height) was constructed to measure the correlation between light intensity and hydrogen production.

Results

At a light intensity equal to 1800 W/m^2, hydrogen production reached 9.4 μmol/mg dry weight/h (29.1 μmol/mL/h). Continuous hydrogen production was performed under microaerbic conditions at a light intensity of 34.5 W/m^2. Every 6h, 20 μmol of O_2 were added to double-phase and conventional photobioreactor. The amount of hydrogen was equal to 0.38 ± 0.03 and 0.26 ± 0.05 μmol/mg dry weight/h, respectively. In anaerobic conditions these values were equal to 0.12 ± 0.01 in the double-phase photobioreactor and 0.09 ± 0.02 μmol/mg dry weight/h in the conventional photobioreactor. [24]

Discussion

Hydrogen production by marine photosynthetic bacteria was studied for more than 15 years. From over 500 strains of marine photosynthetic bacteria isolated from Micronesia, Okinawa islands and coastal areas of Japan, the best hydrogen productivity showed Rhodovulum sp. NKPB160471R ([24], [36], [37], [38], [39], [40]).

Double-phase bioreactor appeared to enhance hydrogen production under microaerobic conditions, comparing to results taken from conventional reactor.

3.2.2. Hydrogen production by cyanobacteria.

The possibility of hydrogen production by cyanobacteria is the subject of theoretical and practical considerations ([41], [42], [43]). Photosynthetic electron transport has the energetic function of producing reduced ferredoxin for hydrogenase or nitrogenase to maximize hydrogen production ([44], [45]), when the cells are adapted to anaerobic conditions ([44],

[46]). This action is said to be the cause of activation of hydrogenase or the synthesis of an enzyme(s), which may start hydrogen production. Cyanobacteria possess three enzymes directly or indirectly responsible for hydrogen production i.e. reversible hydrogenase or soluble hydrogenase (called also bidirectional hydrogenase), uptake hydrogenase and nitrogenase localized, in filamentous cyanobacteria like *Nostoc* and *Anabaena* ([44], [47], [48]). Hydrogenase enzymes were described very detailed in ([49], [50], [51]). *Anabaena variabilis* PK84 has essential advantages over the native strains in hydrogen production ([41], [52], [53], [54]) and that it can continuously evolve H_2 during cultivation in CO_2-enriched air in photobioreactors under batch-growth conditions and continuous illumination ([41], [55], [56]).

Materials and methods

The cyanobacteria *Anabaena variabilis* PK84, was used for hydrogen production.

It was grown in inorganic Allen and Arnon (1955) medium in the absence of fixed nitrogen. Na_2MoO_4 in the medium was replaced by 2μM Na_3VO_4 with the aim of synthesis of the V-containing nitrogenase, which is considered as the better H_2 producer comparing to Mo nitrogenase ([41], [53], [57]).

The cyanobacterium was cultivated in an automated helical photobioreactor (PhBR) equiped with an air-lift system ([41], [58]). The cyanobacterium was illuminated by four white fluorescent lamps of 55 W each (Osram Dulux); two circular lamps of 32 W each (Osram L), and two lamps of 23 W each (Philips). *Anabaena variabilis* PK84 was grown autotrophically in the PhBR under sterile air containing 2% CO_2 (500 mL $\cdot$ min^{-1}) and in alternating 12-h light and 12-h darkness. The temperature of the culture was 36^{o}C/14^o to 30^o (light/dark periods). During the light periods the pH was set at the level of 8.0 by adding NaOH. All growth conditions were controlled by a computer system. [41]

Results

H_2 production was not constant during the light period. It was higher during the first 3-6 h of illumination and then remained constant or in most cases slightly decreases. The greatest H_2 productivity when the cell mass of the culture reached the value 3.6 to 4.6 μg Chl a $\cdot$ mL^{-1} (1.2 to 1.6 mg dry weight $\cdot$ mL^{-1}). Further increase of the mass culture had a negative effect on H_2 production. The studies has shown that *Anabaena variabilis* PK84 continuously bubbled with CO_2-enriched air emitted H_2 during cultivation under alternating artificial light and darkness for 2.5 months. The table below shows the amounts of hydrogen produced under different conditions.

H_2 evolution by *A. Variabilis* PK 84 under gas phases of various compositions [41]

H_2 evolution (μmol h^{-1}mg^{-1}Chl a)				
Time after onset of light period	Air	Air + 2% CO_2	80% Argon + 20% oxygen	100% Argon
2 h	68.0 ± 12.0	81.0 ± 10.0	148 ± 4.0	149 ± 11.0
9 h	106.0 ± 7.0	-	190.0 ± 8.0	191.0 ± 11.0

Discussion

The results have sown that *Anabaena variabilis* PK84 has a great ability of hydrogen production. One of the greatest advantages seems to be H_2 production for a long period of time (2.5 moths). The shortcoming of this method is the necessity of continuous illumination, what seriously increases the cost of hydrogen production.

3.3. Hydrogen production by photosynthetic algae.

The possibility of gaining hydrogen due to alga activity was already described in 1942 [59]. However, the amounts of produced hydrogen were trace. The mechanism of its emission was a mystery for a very long time. Nowadays, we know that this emission could be observed, only when there was a lack of oxygen in the growth medium. Under these conditions the activation of hydrogenase enzyme occurred.

The H_2 emission was able to sustain for about 160 h, thanks to bubbling the medium with neutral gas, what provided anaerobic conditions [60]. The major disadvantage of this method appeared to be the cost of further separation of this inert gas from hydrogen. The other idea was to control the metabolism of hydrogenase through to additions of some chemical compounds like $Na_2S_2O_6$ (sodium hyposulfite) or herbicide to stop photovoltaic production of O_2. However, this caused some irreversible changes, what very often resulted in extinction of the culture of algae.

Nowadays, new method was developed. This method is not based on any mechanical or chemical interference, but on 'switching' the algae between photosynthesis and photoreduction. What is more, it seems that it is the most profitable way of hydrogen production.

Materials, methods and results

The process of hydrogen production by green algae *Chlamydomonas reinhardtii* can be divided into 3 stages [18].

Stage I. Development of the culture. Strain C137 (mt^+) of algae *Chlamydomonas reinhardtii* in the solution of triacetatephosphate with pH 7.0 was grown in flat bottles at 25 [^oC], bubbled with 3 [%] CO_2 in air, and were all the time illuminated with white fluorescent light ($200 \cdot 10^{-6}$ [μ mole of photons $m^{-2}s^{-1}$]). During the development of the culture, the concentration of cells were measured, up to concentration of about 3-$6 \cdot 10^6$ [cells/litre], after reaching it, sulphur ions were separated from the medium and culture was still incubating, with continuous illumination for about 150 [h].

Stage IIa. Alternative of oxygen exploitation. After removing S ions it was observed at the beginning $\tau = 0$ [h] to $\tau = 24$ [h] a rapid increase, and then slower decrease of the emitted amount of oxygen, as a result of stopping photosynthesis in the cells. At the beginning of Stage II the amount of emitted oxygen was equal to 48 [µmoles O_2/(mole Chl $\cdot$ s)], after 24 [h] about 18 [µmoles O_2/mole Chl $\cdot$ s)] and at the end of the experiment $\tau = 120$ [h] about 3 [µmoles O_2/(mole Chl $\cdot$ s)].

Besides anaerobic conditions the cells were still living, as evidence CO_2 measurements were taken every 22 [h]. Before those measurements, illumination was turned off, to force cell to perform respiration. The amounts of CO_2 emitted were: about 12 [µmoles CO_2/(mole Chl $\cdot$ s)] ($\tau = 0$ [h]), 14 [µmoles CO_2/(mole Chl $\cdot$ s)] ($\tau = 22$ [h]), 10 [µmoles CO_2/(mole Chl $\cdot$ s)] ($\tau = 44$ [h]) and about 6 [µmoles CO_2/(mole Chl $\cdot$ s)] at the end of the experiment ($\tau =120$ [h]).

Stage IIb. Alternative of hydrogen production. It was not possible to measure the amount of emitted hydrogen and study living processes of the cell, connected with turning off the illumination, thus these two experiments were separated (IIa and IIb). Result which, in recalculation on 1 litre of algae colony with concentration $6 \cdot 10^6$ [cells Chl/ml], were obtained during photoreduction hydrogen production in this experiment $\tau = 0$ [h] to $\tau = 150$ [h] were as given below.

To about 50 [h] since the moment of S ions removal from the colony hydrogen was not emitted, and then it was produced practically with a stable speed about 2 [ml H_2/h] or 1.2 [µmole H_2/(mole Chl $\cdot$ s)]. Globally amount of emitted gas, till the experiment was finished (150 [h]), was about 155 [ml]. Chromatography analysis has shown that volumetrically composition of this gas was 87 [%] H_2, 1 [%] CO_2 and the rest N_2.

Stage III. Regeneration of the cells. To continuously illuminated cells, which were weakened by processes of reversed metabolism, sulphur ions were again provided as well as mineral salts and porous sparger (bubbler) the mixture of air and CO_2. After about 2-3 days of regeneration and resources storage in the form of photosynthesis products, the colony was switched again to hydrogen production. S ions were removed and after about 50 [h] hydrogen was gained again. In this way three whole cycles were performed.

Discussion

The hydrogen production by unicellular green algae seems to be best way of hydrogen production due to the process of photoreduction. One of the greatest advantages is the simplicity of culturing the algae. It grows and multiplies easily in Sager & Granick medium, but I have noticed increased living features in the TAP medium, which I strongly recommend.

4. Hydrogen fuel

4.1. Hydrogen storage methods

One of the greatest problems connected with hydrogen was the method of its storage. The very high explosiveness of this gas, forced scientists to work intensively on developing new safe way of its lying in. We can distinguish the following ways of hydrogen storage:

- Compressed in the gas vessel. This method may be applied only in stationary usage, because of the danger of explosion and high weight of the vessel.
- In the liquid form, kept in the highly armoured and thermostatic vessels. The temperature has to be maintained at the level of –253°C or 20 K. This method was investigated by the BMW Company to apply it in cars.
- In the form of metal hydrides. One volumetric unit of lithium during the reaction with hydrogen is able to absorb about 1600 units of this gas.
- In the form of intermetalic compounds. A powder of an alloy of lanthanum with cobalt and samarium with nickel is able to absorb under the pressure of 0.4 MPa (4 atm) such amount of hydrogen, which was able to store in the same vessel but under the pressure of 100 Mpa (1000 atm).

Storage system	Volumetric Storage Capacity [g H_2/l]	Mass Specific Storage Capacity [g H_2/kg]
Compressed gas vessel 25 MPa	17,5	64
Liquid hydrogen (-253°C or 20 K)	35	105
Metal hydride - today (room temperature)	80	10
Metal hydride - future (room temperature)	> 160	20 - 25

4.2. Characteristic features of hydrogen fuel

According to experts, hydrogen fuel will be the only fuel, which will be allowed to use in the new century. This is caused by increasing environmental restrictions, hydrogen fuel is so far the only one known, during which combustion no fumes are produced and the only one formed compound is water. What is more the hydrogen fuel has the best energetic properties. The comparison of these properties is put in the table below.

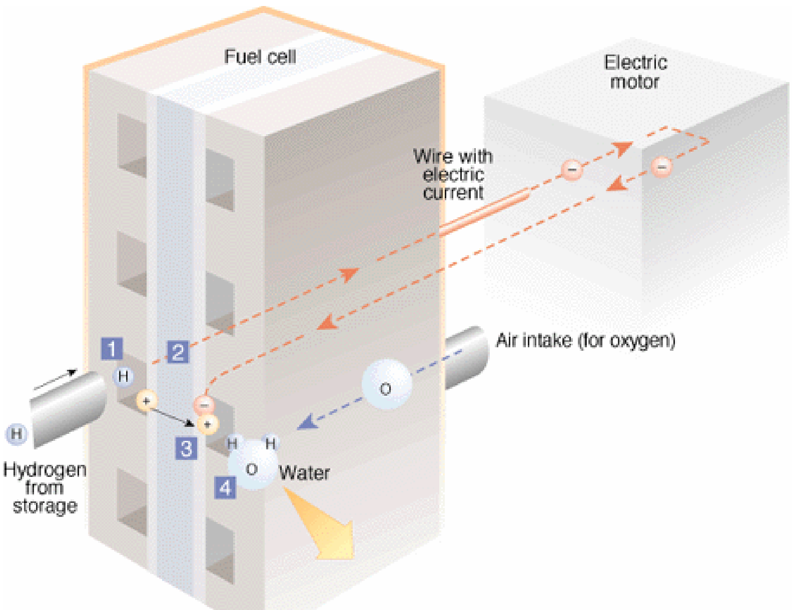
Fuel energy density comparison	
Fuel	**Energy density (MJ/kg, 25^{o}C)**
Hydrogen	120
Gasoline	47.27
Natural gas	47.21
Methane	55.55
Kerosene	46.00
Crude oil	45.55
Coal	31.38
Ethanol	29.70
Methanol	22.69
Wood	17.12

As we can see, hydrogen fuel releases during the combustion almost three times more energy that high-octane gasoline. What is more, if fuel cell is applied, the efficiency increases to almost 90%, which is in much greater than in the case of gasoline engine (about 38%).

4.3. Fuel cells

A fuel cell produces electricity by converting the chemical energy of fuel directly to power in a controlled chemical reaction - without combustion and without moving parts. Fuel cells are therefore inherently ultra clean, highly efficient and reliable.

The performance and structure of the fuel cell is explained below:



1. Hydrogen molecules, which consist of single proton circled by a single electron, enter the fuel cell and come in contact with platinum. This catalyst helps to split the hydrogen into positively charged ions and negatively charged electrons.

2. An 'electrolyte', a special membrane or a substance screens out the electrons. These electrons, which create an electric current, are sent through the wire to power the vehicle's electric motor. Then they return to the fuel cell.

3. The ions are able to pass through the electrolyte.

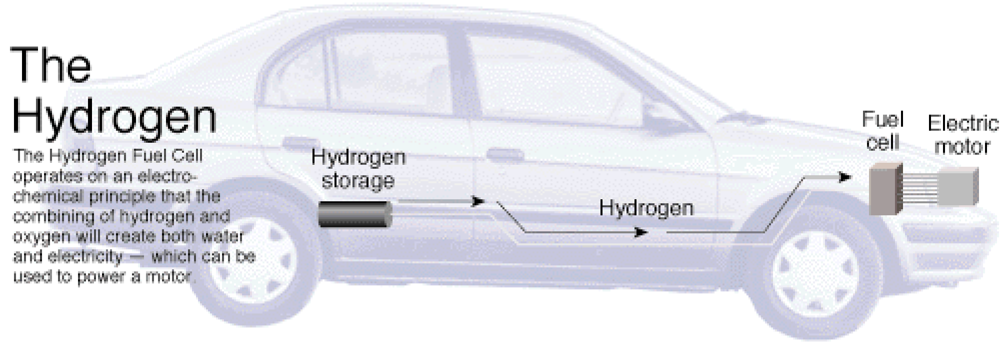
4. In the third portion of the fuel cell, the hydrogen ions, the electrons and oxygen combine to make water. Water is continuously removed from the fuel cell as the ions and electrons keep flowing through the cell. It is the cell's only waste product.

The process works like this:
Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
Cathode: $4e^- + 4H^+ + O_2 \rightarrow 2H_2O$
Overall: $2H_2 + O_2 \rightarrow 2H_2O$

4.4. Hydrogen-powered cars

As you may already know, we have thought of many alternative fuel cars. We have thought of electric cars. They don't cause pollution, and they go reasonably fast. On the other hand, they can't go the speed limit on highways, they take a lot of batteries, they are heavy, they take hours and hours to recharge, and can only go 100 or 200 miles without being recharged. That could be expensive and would be a pain. So, we also thought of solar powered cars. Solar powered cars are a great idea, but has many drawbacks. They are very slow. They can't go at night where there is no sun to power them. They will resort to electric energy if there is not enough sun to power them. They are expensive and heavy. They are not in production yet, but some people probably do have them. They are not perfected, so are not reliable. If it breaks down, how would you get any parts? After considering those thoughts, we decided that solar powered cars would not be our most popular and common non-polluting car. I am sure that some people will still buy them, though.

In the next decade, around year 2010, hydrogen powered cars will be very common. They will exist before then, but there won't be very many. There will be hydrogen stations. It will take a little longer to refuel your car, fifteen minutes, but that is better than eight hours to recharge your electric car. The only pollution with hydrogen powered cars is warm water vapour.



The hydrogen-powered cars equipped with fuel cell are very silent, because they work like electric cars. Within the next fifteen years your car may be hydrogen powered and instead of pulling into a gas station you may be pulling into a hydrogen station. Although several companies are working on hydrogen powered cars.

The example of application of fuel cell in the car

Mazda has made a car that is running better then any of the other hydrogen-powered cars. Mazda's cars (Miatas) may be the best alliterative to gasoline cars, but unfortunately it is not using fuel cell. Gasoline powered cars create too much pollution and sluggish battery powered cars use a lot of electricity and have a lot weight in batteries. A trail of warm water vapour for exhaust the only problem is that there are lubricants that burn up along with the hydrogen fuel so it may not meet California's zero emissions requirement. No carbon dioxide is admitted and admits less than 1/10 as much carbon monoxide as gasoline engines exhaust. The hydrogen burns when it is combined with oxygen so the engines exhaust is mainly water except for some burned lubricants. The hydrogen engine is like Mazda's rotary gasoline engine the fuel is drawn into the combustion chamber where it is ignite by a spark plug. Turning a triangular rotor and powering the wheels. Earlier hydrogen powered cars with conventional gasoline engines converted to hydrogen power constantly back fired. Rotary engines eliminate backfiring because in the conventional engines the piston comes up and the hydrogen and oxygen are ignited to early. The hydrogen Miata handles and accelerates just like a gasoline powered Miata.

At the beginning hydrogen cars are estimated to cost 50% more than gasoline powered cars. One of the biggest barriers is getting hydrogen stations to fill the hydrogen cars. Mazda expects hydrogen cars to be wide spread by the next decade, but it probably won't be until the 2010 before there are enough hydrogen stations to be useful to the hydrogen cars.

There are many car companies making hydrogen-powered cars for future production. These companies are the Japanese manufacturers Mazda and Toyota, and all three American manufacturers Ford, GMC, and Chrysler. There are also German manufactures like BMW and Mercedes-Benz working on hydrogen cars. Chrysler is making a hydrogen car called the

NECAR 4. The NECAR means New Electric Car. It is based on the Mercedes-Benz A-class compact car. It reaches a top speed of 90 mph, but it can still go the speed limits. It can go almost 280 miles on a tank of hydrogen. It can hold five passengers and has a lot of cargo space. All of the fuel cell is in the floor, so that helps explain all of the cargo room. Diamler Chrysler hopes to have these hydrogen cars in limited production by the year 2004. The company will have spent over 1.4 billion dollars on this technology when the first fuel cell vehicles are for sale. These fuel cell cars have the range of gasoline powered cars. They don't pollute, or they have the fuel emissions of electric cars.

4.4.1. Passenger Cars and Mini Vans

- LH_2-BMW

Sedan BMW 735;
2.5 l engine with 6 cylinders derived from BMW gasoline engine;
Power output approx. 80 kW in hydrogen operation;
Power output approx. 140 kW with gasoline operation;
Operating range with LH_2 from 130 l hydrogen cryotank between 300 km and 400 km;
Passenger capacity 5 persons;
Maximum velocity approx. 170 km/h;
Prototype demonstration by BMW since approx. 1979;
[the most recent prototype has three fuel supply and control systems: gasoline, LNG, LH_2];

- Mazda Rotary Engine Cars

HR-X hydrogen-powered 2-rotor rotary engine with 998 ccm displacement and some 70 kW [1991];
Four speed automatic transmission;
Vehicle weight: approx. 1260 kg;
Metal hydride storage of 280 kg weight for 37 Nm^3 providing some 200 km;
HR-X2 hydrogen-powered rotary engine car [1992/1993];
Operating range of approx. 230 km;
Maximum speed of approx. 145 km/h;
Miata hydrogen-powered 2-rotor rotary engine with almost 90 kW power output [1993];

- Energy Partners, Inc., „Green Car"

Sports car prototype (weight: 1360 kg) based on chassis by Consulier;
PEM-fuel cell/ battery hybrid drive system with a PEMFC gross power output of 15 kW_e from three fuel cell stacks;
Brushless electric drive motor of 25.5 kW_e;
Compressed hydrogen storage of 11.7 Nmł at 20 Mpa;
Operating range approx. 96 km, refueling time 15 minutes;
Passenger capacity of 2 persons;
Maximum speed of approx. 96 km/h;
Prototype was presented in 1993;

- Daimler-Benz Necar II

Mini-Van with an operating weight of approx. 2.5 t (Length 4659 mm, width 1870, height 2380 mm);
PEM-fuel cell drive system composed of 2 high performance stacks with in total 50 kW_e;
gross power output at an air pressure of approx. 0.3 MPa and a specific system weight of 6 kg/ kW_e (at a voltage of 180-280 V);
Electric three phase A.C. motor of 33 kW_e via two stage automatic transmission;
Compressed gaseous hydrogen (CGH_2) storage at 25 MPa level in 2 carbon fiber composite materials tanks of 140 l geom. volume each (Length 1895 mm, diameter 351 mm) ;

Operating range > 250 km;
Passenger capacity of 6-7 persons;
Maximum speed of 110 km/h;
Prototype was presented in Berlin in May of 1996;

- Toyota RAV4L V

Fun Vehicle (Length 3975, width 1695 m, height 1635 mm);
PEM-fuel cell drive system of 20 kW_e gross power output, 120 kg weight and 60% stack efficiency;
Front wheel drive via synchronous permanent magnet electric motor of 45 kW_e and max. torque of 165 Nm ;
Hydrogen storage for 2 kg of hydrogen in a metal hydride storage of 100 kg weight;
Operating range approx. 250 km;
Passenger capacity of 5 persons;
Maximum speed of approx. 100 km/h;
Prototype was presented by fall of 1996, improved prototypes will be presented every coming year;

- Renault Laguna Break

Medium sized station wagon;
PEM-fuel cell drive system with 3 De Nora stacks of in total 30 kW_e gross power output at an air pressure of 0.35 Mpa;
Battery for coverage of acceleration peak and hill climbing demand;
Electric propulsion system by Ansaldo Ricerche;
LH_2 storage by Air Liquide for an operating range of 500 km at a speed of 100 km/h;
Passenger capacity 2 + persons;
Maximum speed of 120 km/h;
Presentation of prototype in summer of 1997, Series production possible by 2010;

- A-Model

Micro compact car;
PEM-fuel cell drive system with 2 high performance stacks of in total 50 kW_e gross power output at an air pressure of approx. 0.3 MPa and a specific system weight of 6 kg/ kW_e (at a voltage of 180-280 V);
Operating range of 500 km;
Hydrogen onboard storage in form of liquid methanol and compact methanol reformer for onboard hydrogen production;
Passenger capacity of 4-5 persons;
Maximum speed of > 110 km/h;
Prototype presentation in fall of 1997;
Series production in second generation A-model possible shortly after the turn of the century if cost goals can be achieved;
Mass production volumes (100,000 units per year) shall be achieved by 2005;

- Peugeot Van

Peugeot 806 van of approx. 2 t operating weight;
PEM-fuel cell drive system with 2 or 3 De Nora stacks with in total 30 kW_e gross power output at an air pressure of 0.12-0.14 Mpa;
Small battery for peak demand coverage;
Fuel cell propulsion system by De Nora;
Ultra high compressed gaseous hydrogen storage at 70 MPa in composite materials tank with a metallic inner liner by CEA, France, providing a hydrogen storage capacity of 5 kg for an

operating range of approx. 300 km;
Passenger capacity of 5+ persons;
Maximum speed of > 100 km/h;
Presentation of prototype by 1998/99;

- Ford Fuel Cell Passenger Car Prototypes

PEM-Fuel Cell power output of 60-65 kW_e (Partners: International Fuel Cells Corp., Mechanical Technology, Ballard Power Systems, Inc.);
Advanced lightweight vehicle concept with approx. 900 kg weight (Partner: Alcan Aluminum);
Compressed hydrogen storage at 34.5 MPa pressure level in carbon composite materials tanks of liquid hydrogen storage assuring hydrogen storage of 3.58 kg;
Operating range at a fuel economy of 2.9 l/100 km (80 mpg) as required by the PNGV program approx. 600 km (380 mi); at least 465 km (290 mi); probably if drag coefficient can be reduced to 0.2, then even 700 km (440mi) may be achieved;
Assembly of three prototypes in 1997 and 1998; presentation to the public end of 1998/ beginning of 1999;

4.4.2. Hydrogen in Urban Transportation

In large metropolitan agglomerations worldwide, road traffic represents one of the most important and fastest growing emission sources for both, pollutants and noise.

All efforts during the last 10 to 15 years in order to get hold of this situation was outpaced by the growth in numbers of the emission sources, i.e. vehicle units. In the cities in countries undergoing a rapid industrialisation process (e.g. Mexico City, Sao Paulo, Bangkok, Jakarta) this situation is particularly dramatic. In the already industrialised countries, on the other hand, the sensitiveness of the population with respect to the emission of noise and pollutants as unavoidable side effect of mobility is ever growing.

Hydrogen as a new vehicle fuel provides the opportunity for both, the reduction or avoidance of polluting emissions and the drastic reduction of the noise level produced. Already hydrogen operated internal combustion engines have a low noise potential and significantly reduced pollutant levels but especially the fuel cell electric drive opens the chance for very low noise levels at zero emission capability.

The disadvantage of hydrogen in principal, not representing a primary but only a secondary energy carrier, at long term can be transformed into its advantage. Hydrogen can be generated from various renewable energy sources and in contrary to electricity can be stored over longer periods of time. As seen presently, this advantage of hydrogen will remain, since superconductive electricity storage systems may not allow daily, weekly or even seasonal storage at reasonable expenditures. Due to these advantageous characteristics hydrogen provides the unique opportunity to introduce renewable energy flexibly into the energy and especially transportation system. The necessity for such an introduction of renewable energies into the existing system arises in principal from to requisites: reduction of CO_2 emissions and long term substitution of mineral oil products.

A further advantage of hydrogen use in fuel cell propulsion drives operated in urban driving cycles is the possibility to increase fuel economy significantly in comparison to its use in internal combustion engines. Thus hydrogen obtained from natural gas via steam reforming and consumed in urban fuel cell vehicles can achieve a superior energy efficiency and emission balance over the entire fuel supply chain than if natural gas would be burned directly in internal combustion engine vehicles. Therefore, hydrogen in combination with fuel cell drives already in a transitory phase may a meaningful and clean alternative to existing vehicle fuels and drive systems.

Compared with Diesel, gasoline and natural gas drive systems, fuel cell electric drives offer a much lower noise level and therefore is of advantage in noise polluted metropolitan areas.

An example of hydrogen-powered bus.

Daimler-Benz -NEBUS

Low floor city bus with a length of 12 m.

PEM-fuel cell drive with 10 Ballard/ Daimler-Benz stacks of 25 kW_e gross power output providing 190 kW_e net power output.

Compressed gaseous hydrogen (CGH_2) storage at 30 MPa level in 7 aramid fiber tanks of 147 l geometric volume each containing in total some 45,000 l of hydrogen providing 250 km operating range.

Passenger capacity of 58 persons (34 seated, 24 standing).

Wheel hub motor by ZF.

Maximum speed, depending on drive axle gear ratio, approx. 85 km/h.

Presented on May 26, 1997 in Stuttgart/ Demonstration operation at UIPT conference/ Further demonstration still to be decided on.

5. Conclusions

The hydrogen as an energy carrier, seems to be great answer for human problems, it is very clean, new technologies of production are rather cheap, its high energetic properties and infinite resources makes it a perfect source of energy.

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