Wind Power

The wind turbine, also called a windmill, is a means of harnessing the kinetic energy of the wind and converting it into electrical energy. This is accomplished by turning blades called aerofoils, which drive a shaft, which drive a motor (turbine) and ar e connected to a generator. "It is estimated that the total power capacity of winds surrounding the earth is 1 x 1011 Gigawatts" (Cheremisinoff 6). The total energy of the winds fluctuates from year to year. Windmill expert Richard Hills said that the wind really is a fickle source of power, with wind speeds to low or inconsistent for the windmill to be of practical use. However, that hasn't stopped windmill engineers from trying. Today, there are many kinds of windmills, some of which serve differen t functions. They are a complex alternative energy source.

What to consider when building a windmill In choosing where to build a windmill, there are many important factors to consider. First is the location: 1) Available wind energy is usually higher near the seacoast or coasts of very large lakes and offshore islands. 2) Available wind energy is gene rally high in the central plains region of the U.S. because of the wide expanses of level (low surface roughness) terrain. 3) Available wind energy is generally low throughout the Southeastern U.S. except for certain hills in the Appalachian and Blue Rid ge Mountains, the North Carolina coast, and the Southern tip of Florida. This is because of the influence of the "Bermuda high" pressure system, which is a factor especially during the summer. Also important to consider is the wind where you are going to build: 1) the mean wind speed (calculated my cubing the averages and taking the mean of the cubes) and its seasonal variations. 2) The probability distribution of wind speed and of extreme wi nds. The mean wind speed must be high enough, and the distribution must be so that all the data points are very similar. 3) The height variation of wind speed and wind direction. Wind cannot be too high or too low in relation to the ground or it is too difficult to harness. 4) The gustiness of the wind field in both speed and direction. Gusty winds greatly affect the power output of the windmills and are usually harmful. 5) The wind direction distribution and probability of sudden large shifts in di rection. The wind must be unlikely to suddenly shift direction. It must blow in the same general direction. 6) the seasonal density of the air, and variations of density of the air with height. The denser the air, the worse it will be for windmills. 7) Hazard conditions such as sandstorms, humidity, and salt-spray, which are bad for windmills. The physics behind these will be discussed later. 8) Trade winds in the subtropics, and the channeled wind through mountain passes are especially beneficial to windmills. Once a suitable location is found, the wind is analyzed extensively, and the criteria is met, there are still more requisites. 1) The terrain upon which the windmills are built must be relatively flat. The elevation difference between the turbine site and the terrain is no larger than 60 meters over a 12-km radius. You may have seen windmills such as those in California on little hills, but this is because the requirement is met. The hill may be the only one around for miles. 2) All hills must have small height to width ratios: h:l must be < 0.016. 3) The elevation difference between the highest and lowest point must be 1/3 or less of the height difference between the bottom of the rotor disk and the lowest point in the terrain strip. The surface roughness of the terrain upon which the windmill is to be built must be low. If it varies by more than 10%, this is no good. The terrain must be smooth, and consistently so. A rough surface has more of a negative effect on the wind than a s mooth surface. There is a value n, called, which is assigned to the terrain in terms of its roughness. This value is used to calculate the height of the windmill. For instance, over the sea, the index location, n is 0.14. Over rough inland country, n is 0.34.

Turbines

Windmills are turbines. The two names can be used synonymously. Turbines are a means of harnessing the a fluid's power (the wind) by converting the kinetic energy of the fluid (the wind) into mechanical power (the rotating shaft) When the shaft of a w indmill is hooked up to a generator, electrical energy can be formed. The generator can be used to produce either DC or AC current. Generators that produce DC can be connected to batteries, an inverter to produce AC, or to power DC loads. Some generato rs are connected to heating coils. Generators that produce AC can be hooked up to AC motors such as water pumps. Windmills are NOT efficient. At the very most, a windmill can extract only 16/27ths of the kinetic energy from the wind. This is called the Betz Limit and it can be mathematically proven through calculus. Most of today's windmills extract about 30 perc ent of the wind's energy. The American farm windmill can only extract 10%. An important equation used to find the wind power density, how much power is available per square meter is the equation $P = .5\ pu^3$, where P is the wind power density in W/m2, p is the density of the

air, and u^3 is the cube of the wind velocity. An equation for the power available is (kinetic energy flux) = .5 p V3 A, where p is the kinetic energy density J/m^3, V is the velocity of the wind, A is the cross sectional area of the wind on the turbine.
The equation for determining the power of the shaft, (which is less than the final power output, since gear trains and generators cause power to be lost) is as follows: Cp = P(((((((
(0.5 p V^3 (D2)
4

Where Cp is the power coefficient (Power of shaft), p is the air density,
D is the rotor diameter, V is the velocity of the wind and P is the net power output.

Also Cp = P available
P turbine

The power available is a function of elevation. At ground level, 100% of the power is available. At 100 feet, 97% is available. At 5000 feet, 86% is available. Some turbines are shrouded like jet engines. The shroud is a way to channel the wind. An equation for the power harnessed by a shrouded wind turbine is: P(Pe) = (QT ((p + (k) where P is the power, Pe is the power extracted, (is the turbine efficiency, QT is the volumetric flow rate of air on the turbine, (V/A), ((p + (k) is the change in pressure energy between the inlet and the exit of the wind turbine, and k is the cane in kinetic energy of a unit volume of air that passes through the machine.

Shrouds concentrate and diffuse the wind as it passes through a horizontal access wind-turbine. They reduce the turbulence of the wind and "direct it". The advantages of shrouds, as told by Cheremisinoff (pg. 61 of Fundamentals of Wind Energy), are: a) the axial velocity of the turbine increases, meaning that smaller rotors can operate at higher revolutions, b) the shroud can greatly reduce tip-losses, and c) the aerofoils would not have to be rotated in a direction parallel to the wind if the wind-di rection changed. The cut in speed is the lowest wind speed below which no usable power can be produced by a wind turbine. This means that the wind must be fast enough to move the aerofoils to drive the shaft to create enough power, after much is lost, so that the end amo unt of power is greater than zero. Rated power is the maximum power output of a turbine, which is dependent on a number of factors, especially the generator. In calculating the height of the windmill, it is important to keep in mind that the windmill must be high enough to be above

obstructions. The wind velocity decreases as one approaches the surface.
That means that the higher you build, the better chance there will be that the wind speed is higher, however, you must find the perfect medium--there are often more variables as you increase in altitude. In calculating how high a windmill should be the following equation is used: $V1/V2 = (H1/H2)n$, Where V1 is the wind speed at the highest point of the highest blade, V2 is the wind speed at the lowest point of the lowest blade, H1 is the height of the highest point, and H2 is the height of the lowest point. n is the index location of the site, a va lue that measures the roughness of the terrain.

The structures, aerofoils (see also vector diagrams, attached)
The support of the windmill is generally made out of steel. The windshaft is the shaft which carries the windwheel or aerofoils. It is turned as the aerofoils turn. It is made of steel or wood.
Aerofoils are the blades on a windmill. They can be made out of any material. They were first made of wood or wood composites. Steel was used after that. Aluminum is used in the Darrieus windmills because it is much stronger. Unfortunately, Aluminum fatigues quicker. Some windmills use fiberglass blades. New materials such as strong alloys are being used in today's windmills experimentally. It is important that the blades have a large lift force and a small drag force. The lift force is the force needed to bend the flow of the (fluid) air. It is the force perpendicular to the stream of the air. The drag force is the force parallel to the stream. The aerofoil must be able to develop a lift force at least 50 times greater than the drag. Torque acts on the aerofoil with a vector from the center of rotation away. Other forces that act on the blades of windmills are wind shears, wind gusts, which push on the aerofoils, gravity, a pull towards the earth, and shifts in the direction of the wind. Shifts in the direction of the wind are often accounted for by having a small blade, called a tailvane, on the backside of a windmill. The wind blows on a flat side of the tail, which is oriented differently from the aerofoils. Then, the aerofoils can be rotated to face into the wind. If the wind is blowing in the directi on of this tail instead of the direction of the aerofoils, the tail rotates a shaft, which rotates the whole windmill in the proper direction so as to orient it towards the wind. As Paul Gipe explained in his book Wind Energy comes of age, (page 27), Wind gusts can greatly affect a windmill. A turbulent gust is a gust greater than two minutes with a certain mean wind speed. Gusts are analyzed extensively, with magnitudes, one fo r the lull speed, which is the wind speed of a negative gust amplitude, and the peak speed, which is the wind speed for a positive gust amplitude. The gust amplitude is the

difference between the largest speed in the gust and the mean speed. The
gust du ration is the time from the beginning to the end of a gust. The gust frequency is the number of positive gusts, which occur per unit time.
The gust formation time is the time it takes from the beginning of a gust
to the time it attains the peak gust spe ed. The gust decay time is the time it takes for the gust the end after it reaches its highest amplitude.
There is quite a bit of terminology with aerofoils. The angle of the surface to the fluid flow is the angle of attack, alpha. The angle of attack must be just right. If it is too great, the lift will dramatically
decrease and the drag will increase, st alling the windmill. At rest, (when the windmill is not in operation), the angle of attack is 85°. When
in motion, the angle of attack is anywhere from 2-10 degrees. Newer and more advanced windmills have an angle of attack in the upper end of this
ran ge. The pitch angle, ß is the angle between the chord of the aerofoil
and its plane of rotation. The pitch angle can be adjusted. Solidity is the ratio of the blade width (at widest point) to the distance between the
centers of the blades. A typical "pinwh eel American windmill" might have
a ratio of about 1:1, because the blades are very narrow and very close together, whereas a new two-bladed aerofoil would have a ratio of about 0.03. There is a transfer of work between the wind stream and the moving
blade. In order for this transfer to be efficient, a typical blade is usually 1/4 the width of its length. (If the blade is 10 feet long, it will be 2.5 feet wide at its widest point). A erofoils come in many shapes. Some blades are made a little wider than this ratio, because it is easier to start such a windmill. However, blades like this aren't as efficient. No matter what the shape, "most have a blunt nose and a finely
tapering tab le" (Calvert). A flow must be able to follow the curved surfaces of the aerofoil without being separated. The mass flow rate is given by the equation: m = p Vb A, where p is the air density, Vb is the
air speed at the blades and A is the area. The number of blades on a windmill varies. There are many different types of windmills. The following equation helps figure out how fast the a certain-bladed windmill
will rotate in relation to windmills with different numbers of blades: Speed of windmill = 1 / sq. root of number of blades The aerofoils of a four bladed machine rotate 71% as fast as that of a 2 bladed machine. A six bladed machine rotates at 58% and an 8 bladed machine rotates at 56%
as fast as a 2 bladed machine.

Electricity and Storage of Energy

As mentioned previously, the generators in a wind turbine can convert the mechanical energy produced by the rotation of the shaft into electrical energy, DC. From there, some windmills have synchronous inverters, complex electronic devices which convert the DC generated by the turbines into AC. This is an expensive option. There is a loss of power as well through its processes. Others have induction generators, which produce AC current without a synchronous inverter and less power loss. The energy extracted from the wind and converted into mechanical energy then electrical energy by the generator must be stored, since it is not used generally used all at once. It is important to keep a surplus of energy for usage when the wind is not bl owing fast enough, despite the corrections that can be made in the pitch of the aerofoil blades and when the windmill is out of service or the demand is especially high.

Storing the wind's energy effectively is the key to its long-term use. Windmills used as water pumpers or air-compressors can pump excess water, hydrogen or air into reserve tanks. Today, there are a number of ways to store the wind's energy. Windmills are used to charge Electrolyte batteries. Lead-acid or Lead-cobalt car batteries are commonly used as well. However, batteries may be expensive and inefficient--they may lose 10-25% of the energy stored in them. Nickel-Iron, Nickel-cadmium, and zinc-a ir cells are often used as well. These tend to be more efficient. Some windmills are now using organic electrolyte batteries such as $CuCl_2$, Ni Cl_2, and NiF_2 batteries as well as sodium-sulfur batteries, which operate at high temperature, are used. Although uncommon and still in experimental phases, some energy is stored not by being converted directly into electrical energy, but rather by being stored as thermal or electromagnetic energy,

Sound Fluids are elastic. Pressure waves are constantly being created and propagated by the aerofoils and the turbine as a whole (entire components excepting the support). We can hear them in the sound given off. The sound intensity is directly proportional with the speed of the windmill. The frequency of the waves is directly proportional to the angular speed of the blades on the rotor. The flutter you hear has aerodynamic and elastic properties. The higher speed the aerofoils are, the louder the sound a nd the louder the flutter they will make, as more pressure waves are being created and propagated. The generators are noisy. They often confuse birds and cause them to fly towards the turbine. Windmills can be very noisy. A 300 kW turbine at 1 mile away has a dB level equal to a traffic light 100 feet away (Gipe). Windmill sound levels are regulate d. The sound level must be kept under 46 dB in a residential area. Wind turbines can cause interference, disturbances with TV and radio reception (ghost images on TVs), affect microwaves and disrupt satellite communication. These problems are currently being resolved. Many have

already been fixed. There is also a .009
probability of a bird or insect being struck by the blades. Windmill makers must use artificial sound or florescent paint or scents to scare away flying creatures.

Brakes

Mechanical brakes are used to hold windmills at rest when they are not needed, are not functioning, or are under repair. Greek windmills used sticks or logs jammed into the ground to keep the windmill stopped,
but modern brakes are more sophisticated. Many windmills today use airbrakes like those used in planes. Other windmills have rope brakes. Ropes connected to the aerofoils are simply pulled and tethered to a post
to keep the aerofoils from turning. The torque on a rope brake can be calculated b y the equation (M-m)(R2 + r)g.

The Types of Windmills
There are a number of types of windmills. They are divided into Horizontal-Axis and Vertical-Axis types. Low speed horizontal-axis windmills are used for water pumping and air compressing. American windmills (of the Midwest) are an example. Earlier wi ndmills such as the
ones in England and Holland build a couple hundred years ago are another
example. The horizontal-axis was invented in Egypt and Greece in 300 BCE.
"It had 8 to 10 wooden beams rigged with sails, and a rotor which turned
perpendicular
to the wind direction" (Naar 5). This specific type of windmill became popular in Portugal and Greece. In the 1200's, the crusaders built and developed the post-mill, which where used to mill grain. It was first used
to produce electricity in Denmark i n the late 1800's and spread soon after to the U.S. In America, windmills made the great plains. They were
used to pump water and irrigate crops. During World War I, farmers rigged
windmills to generate 1 kW of DC current. They mounted their devices o n
the tops of buildings and towers. On western farms and railroad stations,
the pumping windmill was 20-50 feet high with a 6-16 foot wheel diameter"
(45)]. With 10-mph wind speed, a 6 foot-diameter wheel, a 2-foot diameter
pump cylinder, a windmill-pump could lift 52 gallons per hour to a height of 38 feet. A 12-foot in diameter wheel could lift 80 gallons per
hour to a height of 120 feet. (Naar, p. 46).

The growth of wind-electricity in America was greatly stunned in 1937 with
the Rural Electrification Act, which made low-cost electricity more available. However, in the 1970's, due to oil shortages, earlier

prototypes of high-speed horizontal-axis windm ills were developed. High-speed horizontal-axis types are used for many purposes, come in many sizes. These include the typical windmills on a California windmill farm and other windmill farms, and any other wind turbines in which the shaft turned by th e aerofoils is horizontal. High-speed horizontal types may have 1, 2, 3, 4, or many aerofoils. Low-speed types such as European ones have much larger aerofoils in relation to their height above the ground. Low speed types such as American Midwest ones are usually a pinwheel, with many small blades encircled with an outer frame like a wheel. Vertical-axis windmills were first developed in the Persians in 1500 BCE to mill corn. Sails were mounted on a boom, which was attached to a shaft that turned vertically. By 500 BCE, the technology had spread to Northern Africa and Spain. Low-speed ve rtical-axis windmills are popular in Finland. They are about 150 years old. They consist of a 55-gallon oil drum split in half. They are used to pump water and aerate land. They are inefficient. High-speed vertical-axis windmills include the Darrieus models. These have long, thin, curved outer blades, which rotate at 3 to 4 times the wind speed. They have a low starting torque and a high tip-speed ratio. They are inexpensive and are used for electricity generation and irrigation. There are three types, the delta, chi, and gamma models. All models are built on a tripod. The advantages to a Darrieus-windmill are that it can deliver mechanical power at ground level. The generator, gearbox, and turbine components are on the ground, instead of at t he top of a tower as in horizontal-axis windmills. They cost much less to construct, because there is less material, and the pitch of the blades does not have to be adjusted. Another type of HSVAW's are the Madaras and Flettner types, revolving cylinder s which sit on a tracked carriage. "The motion of a spinning cylinder causes the carriage to move over a circular track and the carriage wheels to drive an electric generator" (Justus). The Savonius model, which originated in Finland in the 1920's, is a n S-shaped blade, which rotates and turns a vertical shaft. Today, these types of windmills are very popular with scientists and their technology is being developed.

Windmills Today Many windmills are used today: some estimates say 150,000 (Cheremisinoff 31), in the Midwest. They are used to heat water, refrigerate storage buildings or rooms, refrigerate produce, dry crops, irrigate crops, heat buildings, and charge batteries for tr actors on farms (33). Ever since the energy shortages of the 70's, the growing concern of pollution due to the burning of fossil fuels and the depletion

of natural resources, windmills have been greatly studied and developed.
Today, Sandia National Laboratories, Alcoa, GE, Boe ing, Grumman, UTC, Westinghouse, and other scientists are researching and developing Darrieuses and new types of windmills. Today, windmills are used to operate sawmills and oil mills in Europe. They are used in mining to extract minerals, to pump water , to generate electricity, and to charge batteries. "Windmills have been used on buoys moored far out in the ocean, the power being used for the collection and transmission of oceanographic and weather data. They also work in deserted places as an aid t o radio and telephone communications and they are used to work navigation lights on isolated hazards" (Calvert 77).

My Windmill

I built a windmill of my own. The goal of the windmill was to get as much electrical energy as possible. This immediately ruled out any new-wave type windmill. Instead, I went to Home Depot and got a returned ceiling fan. I took off the white box wit h the motor and switches and left the spinning black box on. I mounted the blades on the black box. I put this on a post and a support. Then I got a Maxon DC motor and, after fashioning a clamp-like device to hold the motor on to the support, I put a r ubber tire on the spinning shaft of the motor and adjusted it so that this rubber tire would be rotated by the spinning black box upon which the blades spun. Next, I attached two large wires to the motor. I then made a circuit. This circuit was a littl e difficult to make. It had a place for the wires from the motor, ran through resistors and a variable resistor, and then an Ammeter and then the place where I was to plug in the light. In parallel was a place for a battery and/or a voltmeter. After a few minor adjustments, I was ready to test my product. At first, when the circuit was completed, the current flow was very low. There were a number of adjustments I had to make in order to make the windmill work better. First, I moved the fan that was blowing air on the blades, farther away. I added a seco nd fan and adjusted the angle of these two so that they were blowing at the center of the windmill. I turned the windmill around so that it faced away from the fans. I loosened the screws that held the blades on. I inserted a piece of cardboard 1/3" th ick into this space. This was to adjust the pitch angle of the blades so that they would "cut through" the air better. The adjustments I made were excellent. They worked. When I connected everything, I began to notice an immediate change in the Ammete r. I was seeing as much as 20 milliamps and 6.1Volts. Before, there were 5 milliamps and 3.5 Volts. I began to experiment more with the angles of the fans, distances, and stuff like that. For my light source, I used a green light. It had an internal resistance of 450 ohms. This bulb was 1/2 W. It lit up easily and was bright. The Future

The Future will likely bring bigger and better things for the wind turbine. Many new wind turbine models are being built. The wind turbine holds much promise for energy production in the years to come.