EXPLORING WIND ENERGY

Student Guide

NEED 2007

Putting Energy into Education

NEED Project PO Box 10101 Manassas, VA 20108 1-800-875-5029 www.NEED.org

Evolution of the Windmill


Tower Windmill

The earliest European windmills, built in the 1200s, were called ***postmills***. Their purpose was to grind grain between millstones. This is how windmills got their name. Millwrights built postmills out of wood. The entire windmill could be rotated when the wind changed directions. It was the miller's job to rotate the postmill.

In the 1300s, ***smockmills*** were invented. The sails are attached to the cap, the top of the windmill, and that is the only part that rotates. The miller still had to physically rotate the cap into the wind when it changed directions. These mills were bigger, heavier, and stronger, since the building didn't move. In the 1500s, ***tower windmills*** were built in Spain, Greece, and the Mediterranean Islands. Tower windmills were small and made out of stone. They had many small, lightweight sails, which worked well in the lighter winds of southern Europe. They were used to pump water and grind grain.

The Dutch began to use ***drainage windmills*** in the 1600s to pump water that flooded the land below sea level. Using windmills to dry out the land, they doubled the size of their country. Windmills made work easier and faster. In addition to grinding grain, windmills in the 1700s were used to grind cocoa, gunpowder, and mustard. ***Hulling mills*** removed the outer layer of rice and barley kernels. ***Oil mills*** pressed oil from seeds. ***Glue mills*** processed cowhides and animal bones. ***Fulling mills*** pounded wool into felt. ***Paint mills*** ground pigments for paint as well as herbs and chemicals for medicines and poisons.

Windmills were used for other work, too. Miners used windmills to blow fresh air into deep mine shafts. Windmills provided power to run sawmills and paper mills. Sawmills cut logs and paper mills made paper. Wind power created the first Industrial Revolution in Europe.

American windmills

As Europeans came to America in the mid 1600s, they brought with them their windmill designs. Windmills were a common sight in the colonies. In the 1800s, settlers began to explore the west. But the land was too dry for farming. A new style of windmill was invented, one that pumped water.

In 1854, a mechanic from Connecticut named Daniel Halladay, built the first windmill designed specifically for life in the West. The ***Halladay Windmill***, which is still in use today, sits on a tall wooden tower. It has a dozen or more thin wooden blades and turns itself into the wind. This American style windmill is less powerful than the old European models, but is built to pump water, not grind grain.

As the West was settled, railroads were built across the Great Plains. Steam locomotives burned coal for fuel. They needed thousands of gallons of water to produce steam to run the engines. Windmills were vital in the railroad industry to provide water at railroad stations. A large windmill could lift water 150 feet. It worked in wind speeds as low as six miles per hour. Farmers built homemade windmills, or purchased them from traveling salesmen. These windmills provided enough water for homes and small vegetable gardens. Ranchers used windmills to pump water for their livestock to drink. In addition to pumping water, windmills in the American West performed many tasks and made life easier. Windmills were used to saw lumber, run the cotton gin, hoist grain into silos, grind cattle feed, shell corn, crush ore, and even run a printing press.

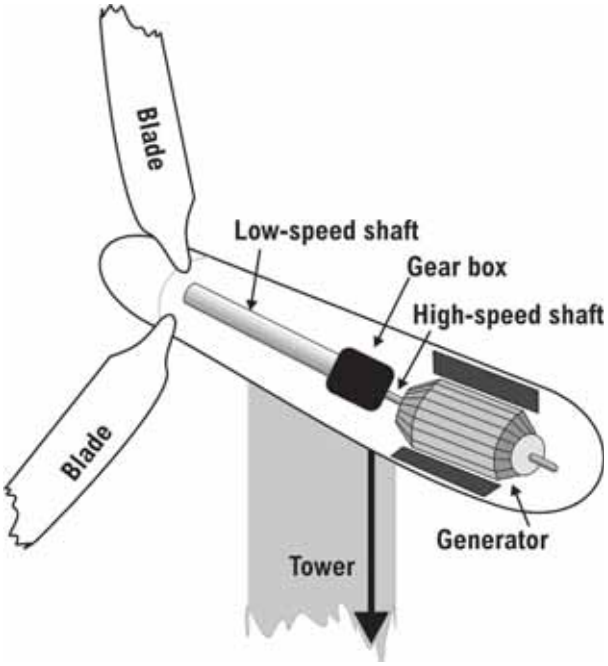
In the 1890s, Poul LaCour, an inventor in Denmark, invented a wind turbine generator with large wooden sails that could generate electricity. At this time, lights and small appliances were available in America, but there were no power lines in the West to transmit electricity. Small-scale windmills became popular in rural areas as people connected their windmills to generators to produce small amounts of electricity. They could power lights, listen to the radio, and charge batteries.

Wind power became less popular as power plants and transmission lines were built across America. By the 1940s, fossil fuels became an inexpensive source of power generation. Using wind power to generate electricity was almost abandoned. After the oil crisis of the 1970s, however, the use of wind power began to increase. Scientists and engineers designed new wind machines that could harness the energy in the wind more efficiently and economically than early models. Today, wind is the fastest growing source of electricity in the world.

Modern Wind Machines

Today, wind is harnessed and converted into electricity using machines called ***wind turbines***. The amount of electricity that a turbine produces depends on its size and speed of the wind. Most large wind turbines have the same basic parts: blades, a tower, and a gearbox. These parts work together to convert the wind's kinetic energy into mechanical energy that generates electricity.

1. The moving air spins the turbine blades.
2. The blades are connected to a low-speed shaft. When the blades spin, the shaft turns.
3. The low-speed shaft is connected to a gearbox. Inside the gearbox, a large slow-moving gear turns a small gear quickly.
4. The small gear turns another shaft at high speed.
5. The high-speed shaft is connected to a generator. As the high-speed shaft turns the generator, it produces electricity.
6. The electric current is sent through cables down the turbine tower to a transformer that changes the voltage of the current before it is sent out on transmission lines.



Wind turbines are most efficient when they are built where winds blow consistently at least 5.8 m/s (meters per second) (13 miles per hour). Faster winds generate more electricity. High above ground, winds are stronger and steadier. So wind turbines should be placed on top of towers that are at least 30 meters (100 ft) tall.

There are many different types of wind turbines with different blade shapes. Wind turbines can be designed to optimize output for specific ranges of wind speed. While one turbine might operate efficiently in winds as low as 2.5 m/s (5.6 mph), another may need winds up to 20 m/s (44.8 mph).

Wind turbines also come in different sizes, based on the amount of electrical power they can generate. Small turbines may produce only enough electricity to power a few appliances in one home. Large turbines are often called utility-scale because they generate enough power for utilities, or electric companies, to sell. The largest turbines in the U.S. produce 2.5–3.5 MW, enough electricity to power 750 to 1,750 homes. Large turbines are grouped together into wind farms, which provide bulk power to the electrical grid.

What a Drag—Aerodynamics

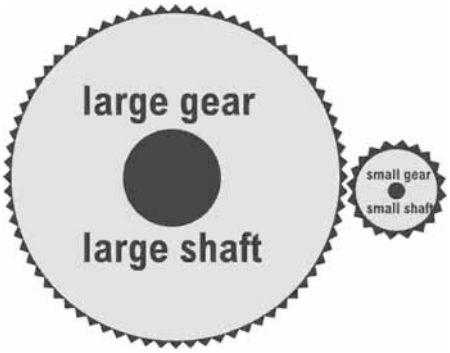
Efficient blades are a key part of generating power from a wind turbine. The blades are turned by the wind and spin the motor drive shaft while, at the same time, they experience drag. This mechanical force slows down the whole system, reducing the amount of power that is generated.

Drag is defined as the force on an object that resists its motion through a fluid. When the fluid is a gas such as air, the force is called ***aerodynamic drag***, or air resistance. Aerodynamic drag is important when objects move rapidly through the air, such as the spinning blades on a wind turbine. Wind turbine engineers who design rotor blades are concerned with aerodynamic drag. Blades need fast tip speeds to work efficiently. Therefore, it is critical that the rotor blades have low aerodynamic drag.

There are many ways to reduce drag on wind turbine blades:

- Change the pitch: the angle of the blades dramatically affects the amount of drag.
- Use fewer blades: reduce drag by using fewer blades; each blade is affected by drag.
- Use light-weight materials: reduce the mass of the blades by using less material or lighter material.
- Use smooth surfaces: rough surfaces, especially on the edges, can increase drag.
- Optimize blade shape: the tip of a blade moves faster than the base; wide, heavy tips increase drag.

Gearing up for more power



Another key part of generating power in a large wind turbine is the gears. Power output is directly related to the speed of the spinning drive shaft (revolutions per minute or rpm's) and how forcefully it turns (torque).

A large wind turbine has a rotor with blades, a gearbox, and a generator. As the blades spin, the rotor rotates slowly with heavy torque. The generator has to spin much faster to generate power, but it cannot use all the turning force, or torque that is on the main shaft. This is why a large wind turbine has a gearbox.

Inside the gearbox, there is at least one pair of gears, one large and one small. The large gear, attached to the main shaft, rotates at about 20 rpm with a lot of torque. This large gear spins a smaller gear, with less torque, at about 1500 rpm. The small gear is attached to a small shaft that spins the generator at high speed, generating power. The relationship between the large and small gears is called the ***gear ratio***. The gear ratio between a 1500-rpm gear and a 20-rpm gear is 75:1. Some small residential wind turbines spin much faster and do not have gears.

Wind Turbine Efficiency—Betz Limit

Wind turbines must convert as much of the available wind energy into electricity as possible to be efficient and economical. As turbines capture energy from the wind, the resultant wind has less energy and moves more slowly. If the blades were 100 percent efficient, they would extract all of the wind's energy and the wind would be stopped. The maximum theoretical percentage of wind that can be captured has been calculated to be about 59 percent. This value is called the **Betz Limit** and modern turbines are designed to approach that efficiency. Most turbines today reach efficiencies of 35-45 percent. The total efficiency of a typical wind turbine system is 10-30 percent of the available wind energy, since there are conversion losses at every step in the system.

Wind Farms

Wind power plants, or wind farms, are clusters of wind turbines grouped together to produce large amounts of electricity. These power plants are usually not owned by a public utility like other kinds of power plants are. Private companies own most wind farms and sell the electricity to electric utility companies.

Choosing the location of a wind farm is known as **siting a wind farm**. To build a wind farm, wind speed and direction must be studied to determine where to put the turbines. As a rule, wind speed increases with height and over open areas with no windbreaks. The site must have strong, steady winds. Scientists measure the wind in an area for one to three years before choosing a site.

The best sites for wind farms are on hilltops, the open plains, through mountain passes, and near the coasts of oceans or large lakes. Turbines are usually built in rows facing into the prevailing wind. Placing turbines too far apart wastes space. If turbines are too close together, they block each other's wind.

There are other things to consider when siting a wind farm, such as:

What is the weather like? Do tornadoes, hurricanes, or ice storms affect the area? Any of these may cause expensive damage to the wind turbines and associated equipment.

Is the area accessible for workers? Will new roads need to be built? New roads are expensive.

Can the site be connected to the power grid? It is expensive to lay long-distance transmission lines to get electricity to where people live, so wind farms should be located near transmission lines with available capacity.

Will the wind farm impact wildlife in the area? Developers building a wind farm need to get permission from the local community and government before building. There are strict building regulations to follow.

Energy on Public Lands

Finding open lands for wind farms is important for the future of wind energy. The Bureau of Land Management (BLM) controls many of the lands with the best wind potential. About 10 percent of installed wind capacity in the U.S. is on public lands. BLM works with companies to find sites for wind farms and ensure the turbines do not disturb the land, wildlife, or people. Once wind turbines are installed, and the companies are generating electricity, BLM collects royalties on the sales.

Wind farm companies pay farmers and ranchers for the wind rights on their land. Wind turbines do not interfere with farming or ranching. Crops will grow around the turbines; cattle and sheep can graze under the turbines. Farmers and ranchers receive a share of the wind farm's earnings as extra income.

California is one state where wind turbines have been installed on public lands. Texas has the most wind capacity, followed by California, which produces about 20 percent of the nation's total wind energy. Production from BLM public lands in California contributes significantly, with more than 3,000 turbines producing 258-megawatt hours of electrical power. Most of this production comes from the San Gorgonio Pass area in Riverside County and the Tehachapi Pass area in Kern County.

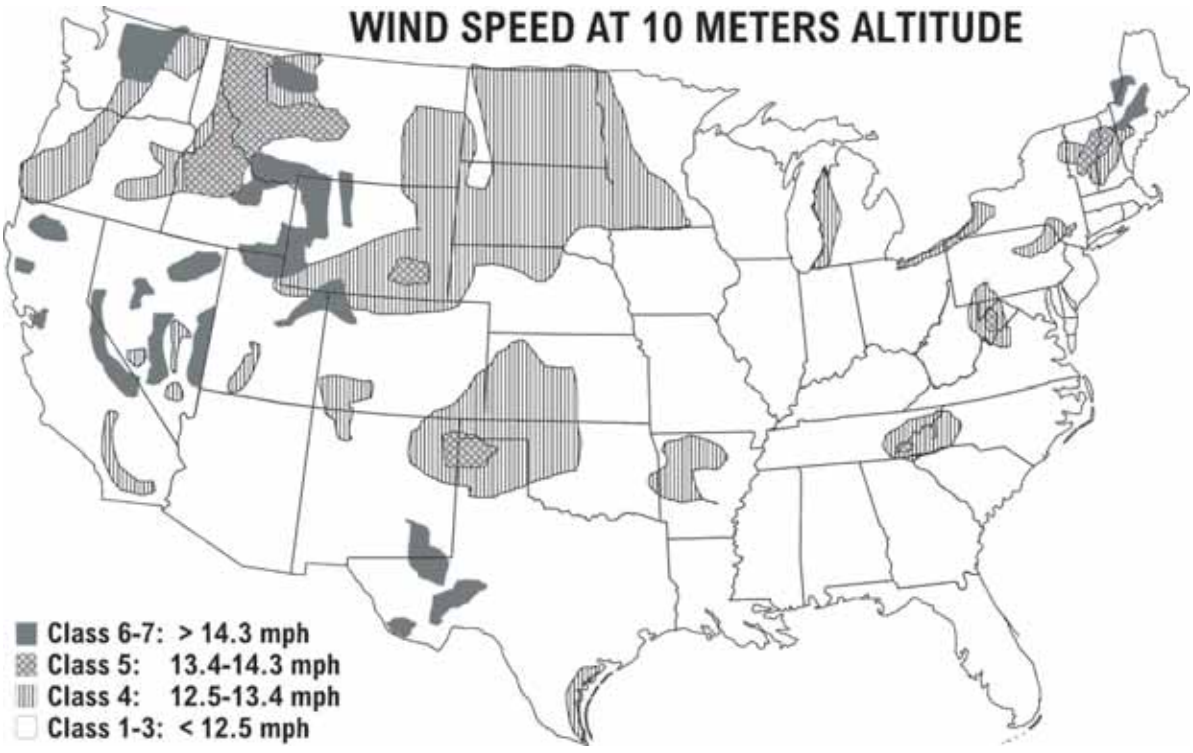
Offshore Wind Farms

The wind blows stronger and steadier over water than land. There are no obstacles on the water to block the wind. There is a lot of wind energy available offshore. Offshore wind farms are built in the shallow waters off the coast of major lakes and oceans. While offshore turbines produce more electricity than turbines on land, they cost more to build and operate. Underwater construction is difficult and expensive. The cables that carry the electricity must be laid under the water.

Some European countries are running out of room on land to build more turbines, so they have created large offshore wind farms to help meet their needs.

Wind—Advantages and Disadvantages

Wind is renewable and is a clean source of energy causing no air or water pollution. Wind is free and an economical source for producing electricity. It has the potential to produce up to 20 percent of U.S. electricity demand. One of the disadvantages of wind energy is that it is dependent on the weather. When there is not enough, or too much wind, turbines do not produce energy efficiently. In some areas, there is concern that birds and bats may be injured by collisions with wind turbines. Some people believe wind turbines produce a lot of sound, and some think turbines affect their view of the landscape. Wind power is not the perfect answer to all of the world's energy needs, but it is a valuable part of the solution.



THE HISTORY OF WIND POWER

3200 B.C.	Early Egyptians use wind to sail boats on the Nile River.
0	The Chinese fly kites during battle to signal their troops.
700s	People living in Sri Lanka use wind to smelt (separate) metal from rock ore. They would dig large crescent-shaped furnaces near the top of steep mountainsides. In summer, monsoon winds blow up the mountain slopes and into a furnace to create a mini-tornado. Charcoal fires inside the furnace could reach 1200°C (2200°F). Archaeologists believe the furnaces enabled Sri Lankans to make iron and steel for weapons and farming tools.
950 A.D.	The first windmills are developed in Persia (present-day Iran). The windmills look like modern day revolving doors, enclosed on two sides to increase the tunnel effect. These windmills grind corn and pump water.
1200s	Europeans begin to build windmills to grind grain.
1200s	The Mongolian armies of Genghis Khan capture Persian windmill builders and take them to China to build irrigation windmills. Persian-style windmills are built in the Middle East. In Egypt, windmills grind sugar cane. Europeans built the first postmills out of wood.
1300s	The Dutch invent the smock mill. The smock mill consists of a wooden tower with six or eight sides. The roof on top rotates to keep the sails in the wind.
1500s	The tower mill is developed in Spain, Greece, Southern Europe, and France.
1600s	The Dutch began to use drainage windmills to pump water. The windmills dried out flooded land below sea level, doubling the size of the country.
	European settlers begin building windmills in North America.
1700s	By the early 1700s, both the Netherlands and England have over 10,000 windmills.
	As a boy, Benjamin Franklin experiments with kites. One day, he floats on his back while a kite pulls him more than a mile across a lake.
1854	Daniel Halladay builds and sells the Halladay Windmill, which is the first windmill designed specifically for the West. It has thin wooden blades and turns itself into the wind.
1888	Charles F. Brush, a wealthy inventor and manufacturer of electrical equipment in Cleveland, Ohio builds a giant windmill on his property. The windmill generates power for 350 electric lights in his mansion. In the basement, a battery room stores 408 battery cells-glass jars filled with chemicals that store the electricity generated by the windmill. In later years, General Electric acquires Brush's company, Brush Electric Co.
Late 1880s	The development of steel blades makes windmills more efficient. Six million windmills spring up across America as settlers move west. These windmills pump water to irrigate crops and provide water for steam locomotives.
1892	Danish inventor Poul LaCour invents a Dutch-style windmill with large wooden sails that generates electricity. He discovers that fast-turning rotors with few blades generate more electricity than slow-turning rotors with many blades. By 1908, Denmark has 72 windmills providing low-cost electricity to farms and villages.
1898-1933	The U.S. Weather Service sends kites aloft to record temperature, humidity, and wind speed.
1900s	Wilbur and Orville Wright design and fly giant box kites. These experiments lead them to invent the first successful airplane in 1903.
1920s	G.J.M. Darrieus, a French inventor, designs the first vertical axis wind turbine.
1941-1943	In 1934, engineer Palmer Putman puts together a team of experts in electricity, aerodynamics, engineering, and weather to find a cheaper way to generate electrical power on a large scale. In 1941, the first large-scale turbine in the United States begins operating.

1941	The Smith-Putnam wind turbine is installed on Grandpa's Knob, a hilltop in Rutland, Vermont. The turbine weighs 250 tons. Its blades measure 175 feet in diameter. It supplies power to the local community for eighteen months until a bearing fails and the machine is shut down in 1943.
1945-1950s	After World War II ends in 1945, engineers decide to start the turbine up again, even though it has formed cracks on the blades. Three weeks later, one of the blades breaks off and crashes to the ground. Without money to continue his wind experiments, Putman abandons the turbine. By the 1950s, most American windmill companies go out of business.
1971	The first offshore wind farm operates off Denmark's coast.
1973	The Organization of Petroleum Exporting Countries (OPEC) oil embargo causes the prices of oil to rise sharply. High oil prices increase interest in other energy sources, such as wind energy.
1974	In response to the oil crisis, the National Aeronautics and Space Administration (NASA) develops a two-bladed wind turbine at the Lewis Research Center in Cleveland, Ohio. Unfortunately, the design does not include a "teetering hub"- a feature very important for a two-bladed turbine to function properly.
1978	The Public Utility Regulatory Policies Act (PURPA) requires utility companies to buy a percentage of their electricity from non-utility power producers. PURPA is an effective way of encouraging the use of renewable energy.
1980	The Crude Oil Windfall Profits Tax Act further increases tax credits for businesses using renewable energy. The Federal tax credit for wind energy reaches 25% and rewards businesses choosing to use renewable energy.
1980s	The first wind farms are built in California, Denmark, Germany and other European countries.
1983	Because of a need for more electricity, California utilities contract with facilities that qualified under PURPA to generate electricity independently. The price set in these contracts is based on the costs saved by not building planned coal plants.
1984	A large vertical axis turbine, Project École, is built in Quebec, Canada. It is 110 meters high (360 ft.).
1985	Many wind turbines are installed in California in the early 1980s to help meet growing electricity needs and take advantage of incentives. By 1985, California wind capacity exceeds 1,000 megawatts, enough power to supply 250,000 homes. These wind turbines are very inefficient.
1988	Many of the hastily installed turbines of the early 1980s are removed and later replaced with more reliable models.
1989	Throughout the 1980s, DOE funding for wind power research and development declines, reaching its lowest point in fiscal year 1989.
1990	More than 2,200 megawatts of wind energy capacity are installed in California-more than half of the world's capacity at the time.
1992	The Energy Policy Act reforms the Public Utility Holding Company Act and many other laws dealing with the electric utility industry. It also authorizes a production tax credit of 1.5 cents per kilowatt-hour for wind-generated electricity.
1993	U.S. Windpower develops one of the first commercially available variable-speed wind turbines, over a period of 5 years. The final prototype tests are completed in 1992. The $20 million project is funded mostly by U.S. Windpower, but also involves Electric Power Research Institute (EPRI), Pacific Gas & Electric, and Niagara Mohawk Power Company.
1994	Cowley Ridge, in Alberta, Canada, becomes the first utility-grade wind farm in Canada.
1999-2000	Installed capacity of wind-powered electricity generating equipment exceeds 2,500 megawatts. Contracts for new wind farms continue to be signed.
2003	North Hoyle, the largest offshore wind farm in the United Kingdom, is built.
2005	The Energy Policy Act of 2005 strengthens incentives for wind and other renewable energy sources.
	The Jersey-Atlantic wind farm, off the coast of Atlantic City, New Jersey, begins operating in December. It is the United States' first coastal wind farm.

WIND HISTORY TIME LINE

DIRECTIONS: Make a time line of the ten most important events or discoveries concerning wind energy and explain why you think each one is important.