EXPLORING WIND ENERGY
Student Guide

NEED
2007
Putting Energy into Education

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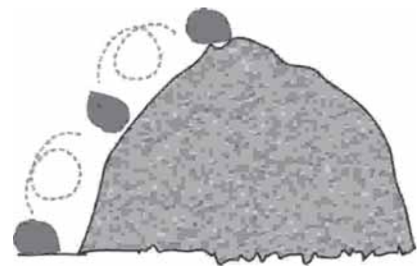
What Is Energy?

Energy makes change; it does things for us. It moves cars along the road and boats over the water. It bakes a cake in the oven and keeps ice frozen in the freezer. It plays our favorite songs on the radio and lights our homes. Energy helps our bodies grow and allows our minds to think. Scientists define energy as ***the ability to do work***.

Energy is found in different forms, such as light, heat, sound, and motion. There are many forms of energy, but they can all be put into two categories: potential and kinetic.

Potential and Kinetic Energy

Potential Energy is stored energy and the energy of position. Potential energy is the chemical energy stored in the bonds of molecules and stored gravitational energy.



A rock on the top of a hill, for example, has potential energy because of its position. If a force pushes the rock, it will roll down the hill because of the force of gravity. Its potential energy will be converted into kinetic energy until it reaches the bottom of the hill and stops.

Kinetic Energy is motion; it is the motion of electromagnetic and radio waves, electrons, atoms, molecules, substances, and objects.

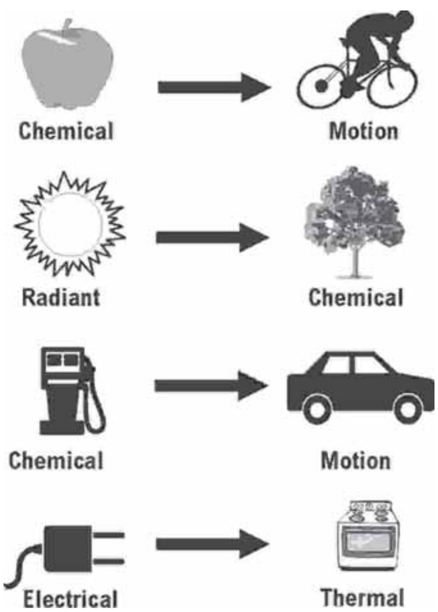
Electrical Energy is the movement of electrons. Everything is made of tiny particles called atoms. Atoms are made of even smaller particles—electrons, protons, and neutrons. Applying a force can make some of the electrons move. The movement of electrons in a wire is called electricity. Lightning is another example of electrical energy.

Radiant Energy is electromagnetic energy that travels in waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Light is one type of radiant energy. Solar energy is an example of radiant energy.

Thermal Energy, or heat, is the internal energy in substances; it is the vibration and movement of the atoms and molecules within substances. The more thermal energy in a substance, the faster the atoms and molecules vibrate and move. Geothermal energy is an example of thermal energy.

Sound is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate; the energy is transferred through the substance in a longitudinal wave.

Motion is the movement of objects and substances from one place to another. Objects and substances move when a force is applied according to Newton's Laws of Motion. Wind is an example of motion energy.



Conservation of Energy

Conservation of energy is not saving energy. The **law of conservation of energy** says that energy is neither created nor destroyed. When we use energy, it doesn't disappear. We change it from one form of energy into another. A car engine burns gasoline, converting the chemical energy in gasoline into mechanical energy. Solar cells change radiant energy into electrical energy. Energy changes form, but the total amount of energy in the universe stays the same.

Energy Efficiency

Energy efficiency is the amount of useful energy you get from a system compared to the energy input. A perfect, energy-efficient machine would change all the energy put in it into useful work—an impossible dream. Converting one form of energy into another form always involves a loss of usable energy.

Most energy transformations are not very efficient. The human body is a good example. Your body is like a machine, and the fuel for your machine is food. Food gives you the energy to move, breathe, and think. Your body is less than five percent efficient at converting food into useful work. The rest of the energy is lost as heat. You can really feel that heat when you exercise!

Sources of Energy

We use many different sources to meet our energy needs every day. They are usually classified into two groups—***renewable*** and ***nonrenewable***.

In the United States, most of our energy comes from nonrenewable energy sources. Coal, petroleum, natural gas, propane, and uranium are nonrenewable energy sources. They are used to make electricity, heat our homes, move our cars, and manufacture all kinds of products. They are called nonrenewable because their supplies are limited. Petroleum, for example, was formed millions of years ago from the remains of ancient sea plants and animals. We can't make more crude oil in a short time.

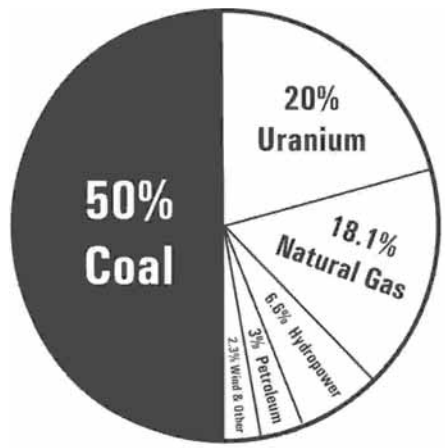
U.S. Energy Consumption by Source 2006

Source	%	Type	Uses	Source	%	Type	Uses
PETROLEUM	38.8%	nonrenewable	transportation, manufacturing	BIOMASS	3.3%	renewable	heating, electricity, transportation
COAL	22.6%	nonrenewable	electricity, manufacturing	HYDROPOWER	2.9%	renewable	electricity
NATURAL GAS	21.6%	nonrenewable	heating, manufacturing, electricity	GEOTHERMAL	0.35%	renewable	heating, electricity
URANIUM (U 235)	8.2%	nonrenewable	electricity	WIND	0.25%	renewable	electricity
PROPANE	1.9%	nonrenewable	manufacturing, heating	SOLAR	0.1%	renewable	light, heating, electricity

Renewable energy sources include biomass, geothermal energy, hydropower, solar energy, and wind energy. They are called renewable because they are replenished in a short time. Day after day, the sun shines, the wind blows, and the rivers flow. We use renewable energy sources mainly to make electricity.

Electricity

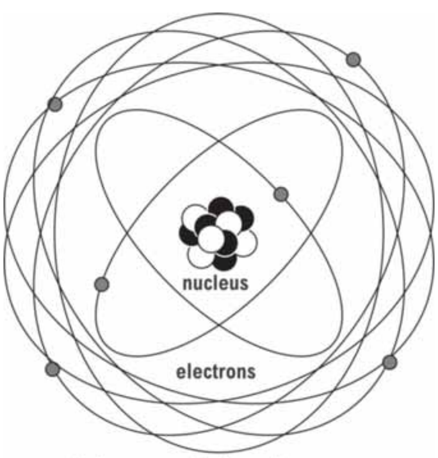
Electricity is different from primary energy sources; it is a secondary source of energy. That means we must use another energy source to produce electricity. Electricity is sometimes called an ***energy carrier*** because it is an efficient and safe way to move energy from one place to another, and it can be used for so many tasks. As we use more technology, the demand for electricity grows. In the U.S., coal generates half the electricity we use today.



U.S. ELECTRICITY PRODUCTION

A Mysterious Force

What exactly is the mysterious force we call electricity? It is simply moving electrons. And what exactly are electrons? They are tiny particles found in atoms. Everything in the universe is made of atoms—every star, every tree, every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

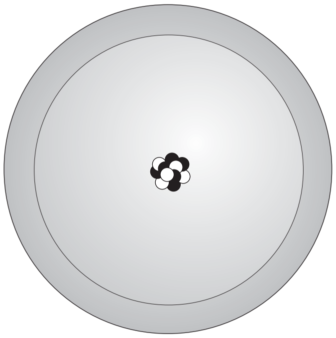


Atom of Carbon

Atomic Structure

Atoms are made of even smaller particles. The center of an atom is called the ***nucleus***. It is made of particles called ***protons*** and ***neutrons***. The protons and neutrons are very small, but electrons are much, much smaller. ***Electrons*** move around the nucleus in orbits a great distance from the nucleus. If the nucleus were the size of a tennis ball, the atom would be the size of the Empire State Building. Atoms are mostly empty space.

If you could see an atom, it would look a little like a tiny center of balls surrounded by giant invisible clouds (or shells). Electrons are held in their shells by an electrical force. The protons and electrons of an atom are attracted to each other. They both carry an electrical charge. An ***electrical charge*** is a force within the particle.



Protons have a positive charge (+) and electrons have a negative charge (-). The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other.

When an atom is in balance, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons act as a glue to hold the nucleus together.

Elements

An ***element*** is a substance in which all of the atoms are identical. The number of protons in an atom determines the kind of atom or element it is.

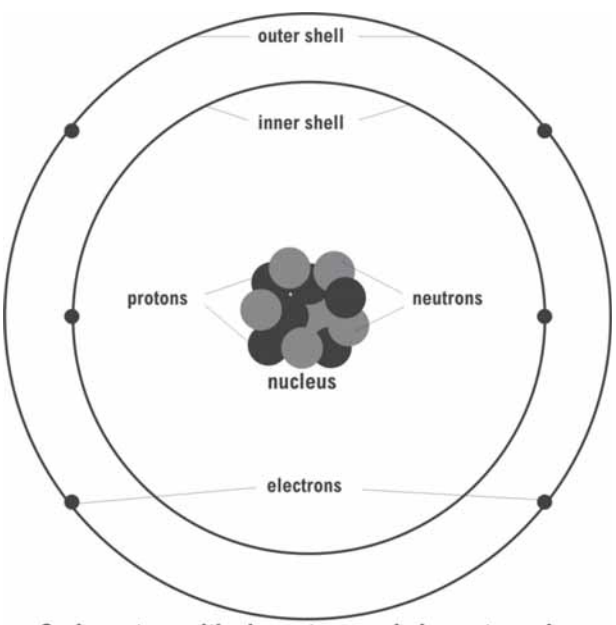
Every atom of hydrogen, for example, has one proton and one electron, with no neutrons. Every atom of carbon has six protons, six electrons, and six neutrons. The number of protons determines which element it is.

SEVERAL COMMON ELEMENTS

ELEMENT	SYMBOL	PROTONS	ELECTRONS	NEUTRONS
HYDROGEN	H	1	1	0
LITHIUM	Li	3	3	4
CARBON	C	6	6	6
NITROGEN	N	7	7	7
OXYGEN	O	8	8	8
MAGNESIUM	Mg	12	12	12
COPPER	Cu	29	29	34
SILVER	Ag	47	47	51
GOLD	Au	79	79	118
URANIUM	U	92	92	146

Electrons

The electrons usually remain a constant distance from the nucleus in precise shells. The shell closest to the nucleus can hold two electrons. The next shell can hold up to eight. The outer shells can hold even more.



Carbon atom with six protons and six neutrons in the nucleus, two electrons in the inner shell and four electrons in the outer shell.

The electrons in the shells closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost shells do not. These electrons can be pushed out of their orbits. Applying a force can make them move from one atom to another. These electrons moving from atom to atom are called ***electricity***.

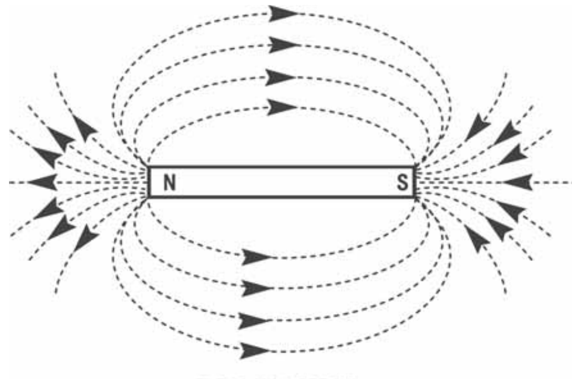
Electricity

Electricity has been moving in the world forever. Lightning is a form of electricity. It is electrons moving from one cloud to another or jumping from a cloud to the ground.

Have you ever felt a shock when you touched an object after walking across a carpet? A stream of electrons jumped to you from that object. This is called ***static electricity***. Have you ever made your hair stand straight up by rubbing a balloon on it? If so, you rubbed some electrons off the balloon. The electrons moved into your hair from the balloon. They tried to get far away from each other by moving to the ends of your hair. They pushed against each other and made your hair move—they repelled each other. While opposite charges attract each other, like charges repel each other.

Magnets

In most objects, the molecules are arranged randomly. They are scattered evenly throughout the object. Magnets are different—they are made of molecules that have North- and South-seeking poles. Each molecule is really a tiny magnet. The molecules in a magnet are arranged so that most of the North-seeking poles point in one direction and most of the South-seeking poles point in the other.



BAR MAGNET

This creates a ***magnetic field*** around a magnet—an imbalance in the forces between the ends of a magnet. A magnet is labeled with North (N) and South (S) poles. The magnetic field in a magnet flows from the North pole to the South pole.

Electromagnetism

A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called **electromagnetism**. Every time there is a change in a magnetic field, an electric field is produced. Every time there is a change in an electric field, a magnetic field is produced.

We can use this relationship to produce electricity. Some metals, like copper, have electrons that are loosely held. They can be pushed from their shells by moving magnets. If a coil of copper wire is moved in a magnetic field, or if magnets are moved around a coil of copper wire, an electric current is generated in the wire.

Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire.

Producing Electricity

Power plants use huge turbine generators to generate the electricity that we use in our homes and businesses. Power plants use many fuels to spin a turbine. They can burn coal, oil, or natural gas to make steam to spin a turbine. They can split atoms of uranium to heat water into steam. They can also use the power of rushing water from a dam or the energy in the wind to spin the turbine.

What Is Wind?

Wind is simply air in motion. It is produced by the uneven heating of the earth's surface by energy from the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's radiant energy at different rates. Much of this energy is converted into heat as it is absorbed by land areas, bodies of water, and the air over these formations.

On the coast, for example, the land heats up more quickly than the water. The warm air over the land expands and rises, and the heavier, cooler air over the water rushes in to take its place, creating winds. In the same way, the large atmospheric winds that circle the earth are produced because the earth's surface near the equator receives more of the sun's energy than the surface near the North and South Poles.

Local Winds

The wind blows all over the planet, but mountainous and coastal areas have more steady and reliable winds than other places. Local winds are affected by changes in the shape of the land. Wind can blow fast and strong across the open prairie. Wind slows down and changes directions a lot when the land surface is uneven—covered with forests or buildings.

Mountains and valleys

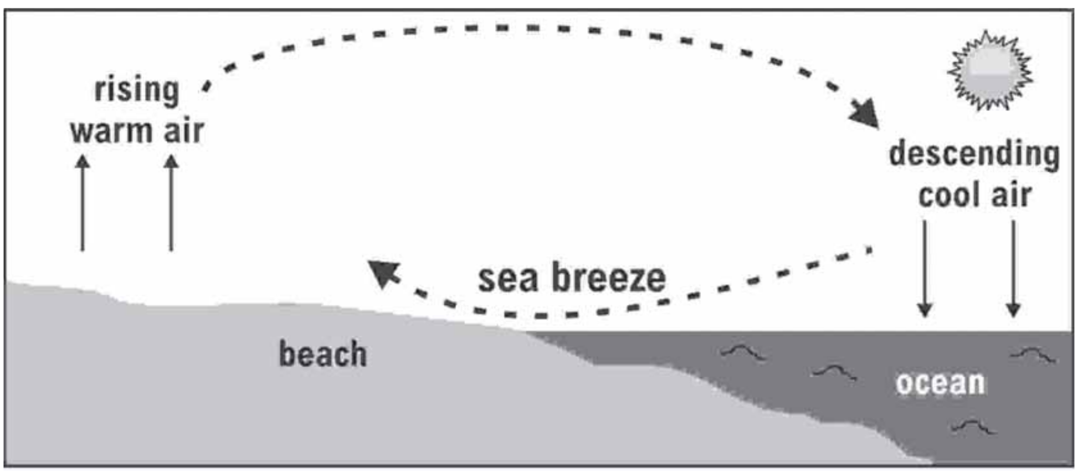
Local winds can occur when land heats faster in one place than another. A mountain slope may receive more sun and warm faster than the valley below. Warm air rises up the slope. Cool air rushes in near the base of the mountain, causing wind to sweep through the valley. This is called a ***valley wind***.

At night, the wind changes directions. After the sun sets, the mountain slope cools off quickly. Warm air is pushed out of the way as cool air sinks, causing winds to blow down toward the valley. This is called a ***mountain wind***. Mountain winds are also called ***katabatic winds***. When they blow through narrow valleys between mountains, wind speeds increase. This is known as the ***tunnel effect***. Katabatic winds have their own special names throughout the world. In the United States, we have two. Chinook is an easterly wind in the Rocky Mountains, and the Santa Ana is an easterly wind in Southern California.

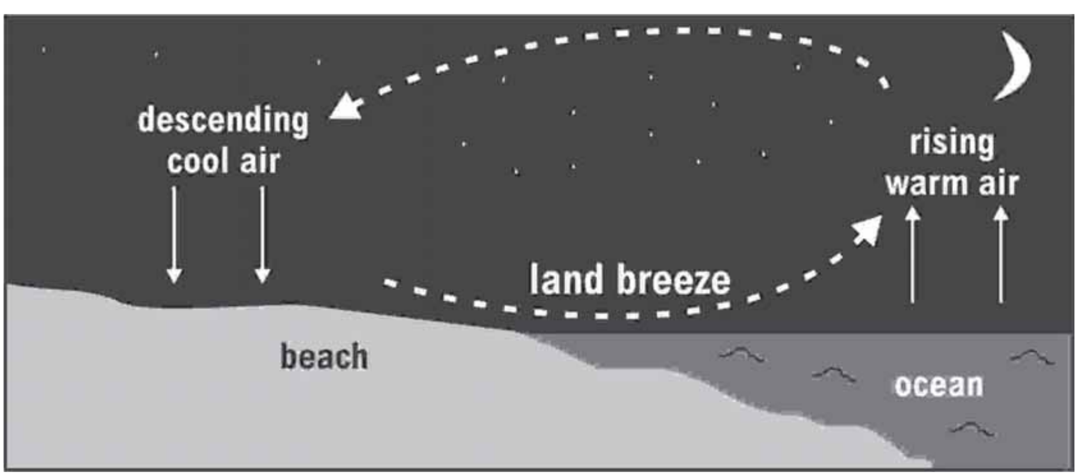
Local winds at the seashore

During the day along the coast, the land and water absorb radiant energy from the sun. They do not, however, change temperature at the same rate, because they are made of substances with different specific heat values. **Specific heat** is the amount of heat energy needed to raise the temperature of one gram of a substance one degree Celsius. Water has the highest specific heat of common substances, which means it takes more energy to increase the temperature of water than to raise the temperature of the same quantity of other substances.

Because of its lower specific heat, land heats faster and cools more rapidly than water; the air over the land also heats more rapidly than air over the water. The heated air over the land rises, creating an area of low pressure. The air over the sea is cooler, creating an area of higher pressure. The cooler air in the high-pressure area over the sea moves to the area of low pressure over land. This is called a **sea breeze** because the wind is coming from the sea toward the land.



At night, the land cools more rapidly than the water, which means the sea is now warmer than the shore, and the air over the sea becomes warmer than the air over the land. The warm, rising sea air creates an area of low pressure, and the cooler air over the land creates an area of higher pressure. The air again moves from higher to lower pressure, from land to sea. This breeze is called a **land breeze**.



Global Wind Patterns

The equator receives the sun's most direct rays. Here, air is heated and rises, leaving low-pressure areas. Moving to about thirty degrees north and south of the equator, the warm air from the equator begins to cool and sink.

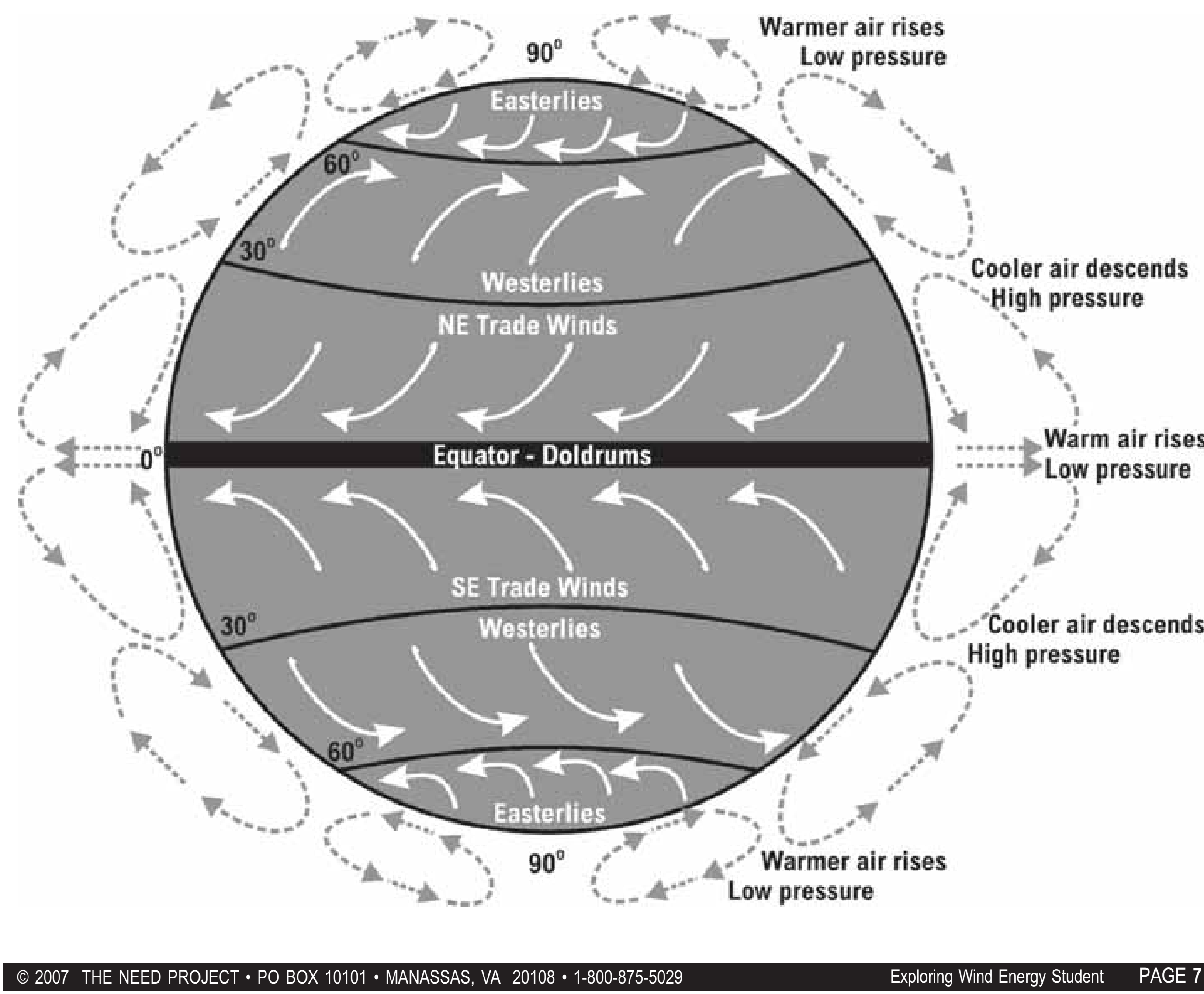
Trade winds Most of the cooling, sinking air moves back to the equator. The rest of the air flows toward the poles. The air movements toward the equator are called trade winds—warm, steady breezes that blow almost continuously. The ***Coriolis Effect***, caused by the rotation of the Earth, makes the trade winds appear to be curving to the west, whether they are traveling toward the equator from the south or north.

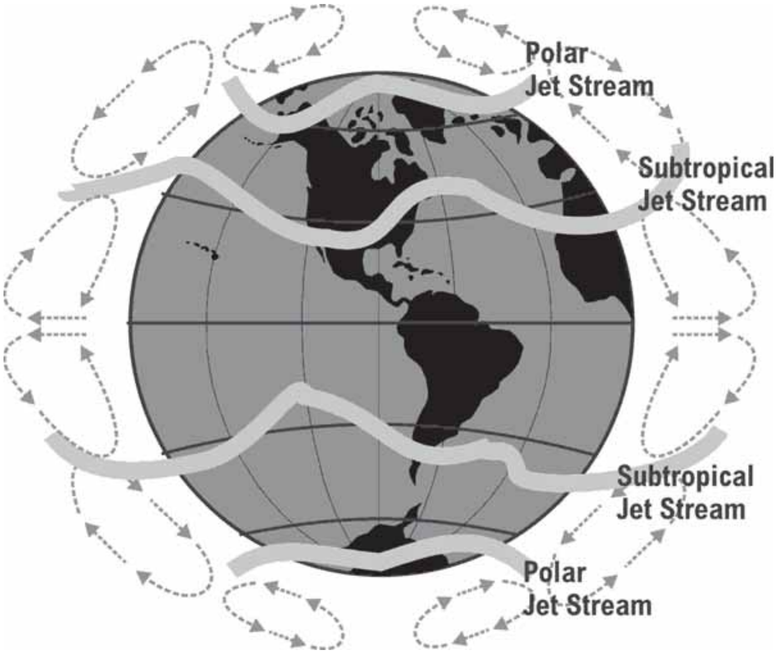
Doldrums The trade winds coming from the south and the north meet near the equator. These converging trade winds produce general upward winds as they are heated, so there are no steady surface winds. This area of calm is called the doldrums.

Prevailing westerlies Between thirty and sixty degrees latitude, the winds that move toward the poles appear to curve to the east. Because winds are named from the direction in which they originate, these winds are called prevailing westerlies. Prevailing westerlies in the northern hemisphere are responsible for many of the weather movements across the United States and Canada. In the U.S., we can look at the weather to our west to see what kind of weather is heading our way.

Polar easterlies At about sixty degrees latitude in both hemispheres, the prevailing westerlies join with polar easterlies to reduce upward motion. The polar easterlies form when the atmosphere over the poles cools. This cool air then sinks and spreads over the surface. As the air flows away from the poles, it is turned to the west by the Coriolis Effect. Because these winds begin in the east, they are called easterlies.

The trade winds, westerlies, and easterlies flow around the world and cause many of the earth's weather patterns.





Jet streams The highest winds are the jet streams. The jet streams blow far above the earth where there is nothing to block their paths. Jet streams form more than 9 kilometers (5.6 miles) up in the atmosphere at the boundaries of adjacent air masses with significant differences in temperature.

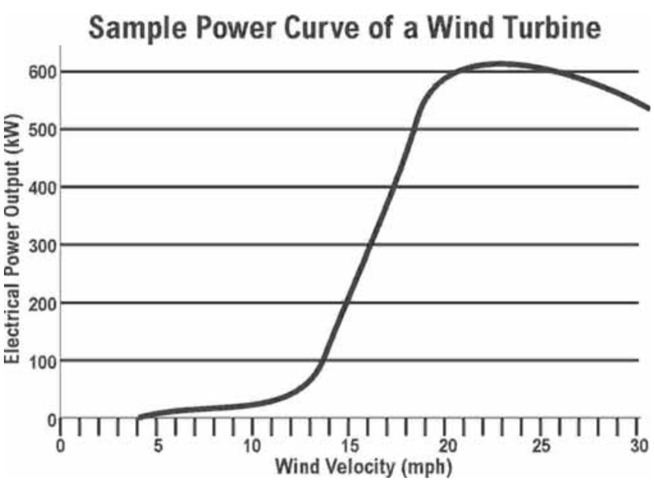
These fast moving "rivers of air" move 92 kilometers per hour (57 mph) or faster. Jet streams pull air around the planet, from west to east, carrying weather systems with them.

There are also low–level jet streams (100–200 meters in altitude) in some areas that are significant for siting wind turbines.

Monitoring Wind Direction

A weather vane, or wind vane, is a device used to monitor the direction of the wind. It is usually a rotating, arrow-shaped instrument mounted on a shaft high in the air. It is designed to point in the direction of the source of the wind. There are also digital instruments that measure wind direction.

Wind direction is reported as the direction ***from which the wind blows***, not the direction toward which the wind moves. A north wind blows from the north, toward the south.



Wind Velocity

It is important in many cases to know how fast the wind is blowing. Wind speed is important because the amount of electricity that wind turbines can generate is determined in large part by wind speed, or **velocity**.

A doubling of wind velocity from the low range to optimal range of a turbine can result in eight times the amount of power produced. This is a huge difference and helps wind companies decide where to site wind turbines.

Wind **power** (measured in watts) is determined by **air density**, the **area** swept by the turbine blades, and wind **velocity**, according to the following formula:

$$\text{Power} = \tfrac{1}{2}\rho A V^3 \quad (\rho = \text{air density, } A = \text{area, } V = \text{velocity})$$

$$\text{Watts} = \tfrac{1}{2}\left(\frac{kg}{m^3}\right) \times \left(m^2\right) \times \left(\frac{m}{s}\right)^3$$

Measuring Wind Speed

Wind speed can be measured using an instrument called an **anemometer**. One type of anemometer is a device with three arms that spin on top of a shaft. Each arm has a cup on its end. The cups catch the wind and spin the shaft. The harder the wind blows, the faster the shaft spins. A device inside counts the number of rotations per minute and converts that figure into **mph—miles per hour** or **m/s—meters per second**. A display on a recording device called a **datalogger** shows the speed of the wind. There are also digital anemometers to measure wind speed.

The Beaufort Scale

When he was twelve years old, Francis Beaufort joined the British Royal Navy. For more than twenty years he sailed the oceans and studied the characteristics of the wind. During his career, he became Admiral Sir Francis Beaufort.

In 1805, he created a scale to determine wind speed by looking at common things around him such as trees. The Beaufort scale is still used today by meteorologists and sailors. *(In the United States, 74 miles per hour is the speed criterion for a Class I hurricane.)*

Beaufort Scale of Wind Speed

BEAUFORT NUMBER	NAME OF WIND	LAND CONDITIONS	WIND SPEED MPH
0	Calm	Calm, smoke rises vertically	<1
1	Light Air	Smoke drifts, indicating wind direction	1-3
2	Light Breeze	Wind felt on face, leaves rustle, flags stir	4-7
3	Gentle Breeze	Leaves and small twigs in constant motion	8-12
4	Moderate Breeze	Small branches move, wind raises dust and loose paper	13-18
5	Fresh Breeze	Smaller trees sway	19-24
6	Strong Breeze	Large branches in motion	25-31
7	Near Gale	Whole trees in motion	32-38
8	Gale	Twigs broken from trees	39-46
9	Severe Gale	Light structure damage	47-54
10	Storm	Trees uprooted, considerable structural damage	55-63
11	Violent Storm	Widespread structural damage	64-72
12	Hurricane	Massive and widespread damage to structure	73-82

Wind shear and turbulence

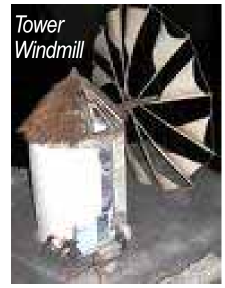
As wind moves across the earth's surface, it is slowed by friction as it runs into and flows around obstacles on the surface or meets other air masses. Friction also affects the direction of the wind. Higher in the atmosphere, away from the earth, the wind meets fewer obstacles, and therefore, less friction is produced. Winds there are smooth and fast.

Wind shear is defined as an abrupt change in wind speed and/or wind direction at different heights in the atmosphere or within a short distance. It can be in a horizontal direction, a vertical direction, or in both directions. Some wind shear is common in the atmosphere. Larger values of wind shear exist near fronts, cyclones, and the jet stream. Wind shear in an unstable atmospheric layer can result in turbulence.

Turbulence is defined as a disturbance in the speed and direction of the wind that results in random, disordered movement of air molecules. It occurs when the flow of wind is disturbed, and the direction or speed is changed. Trees and buildings cause wind turbulence. When wind mixes warm and cold air together in the atmosphere, turbulence is also created. This turbulence is sometimes felt as a bumpy ride during an airplane flight.

Wind shear and turbulence are concerns to wind turbine engineers because they can affect the operation and output of turbines, and even cause them to fail.

Evolution of the 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.

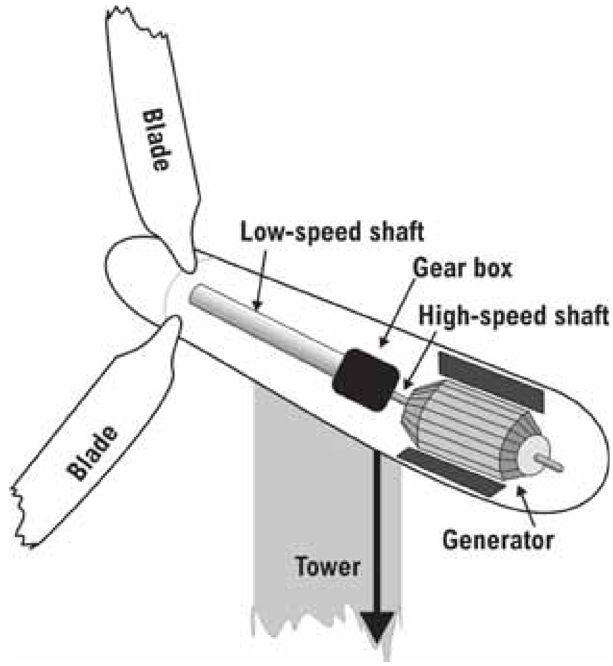
In the 1890s, Poul LaCour, an inventor in Denmark, invented a wind turbine generator with large wooden sails that could generate electricity. At this time, lights and small appliances were available in America, but there were no power lines in the West to transmit electricity. Small-scale windmills became 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

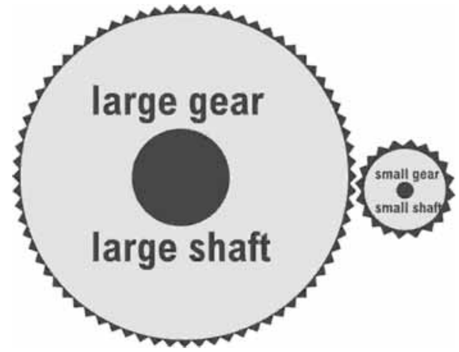
Efficient blades are a key part of generating power from a wind turbine. The blades are turned by the wind and spin the motor drive shaft while, at the same time, they experience drag. This mechanical force slows down the whole system, reducing the amount of power that is generated.

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.

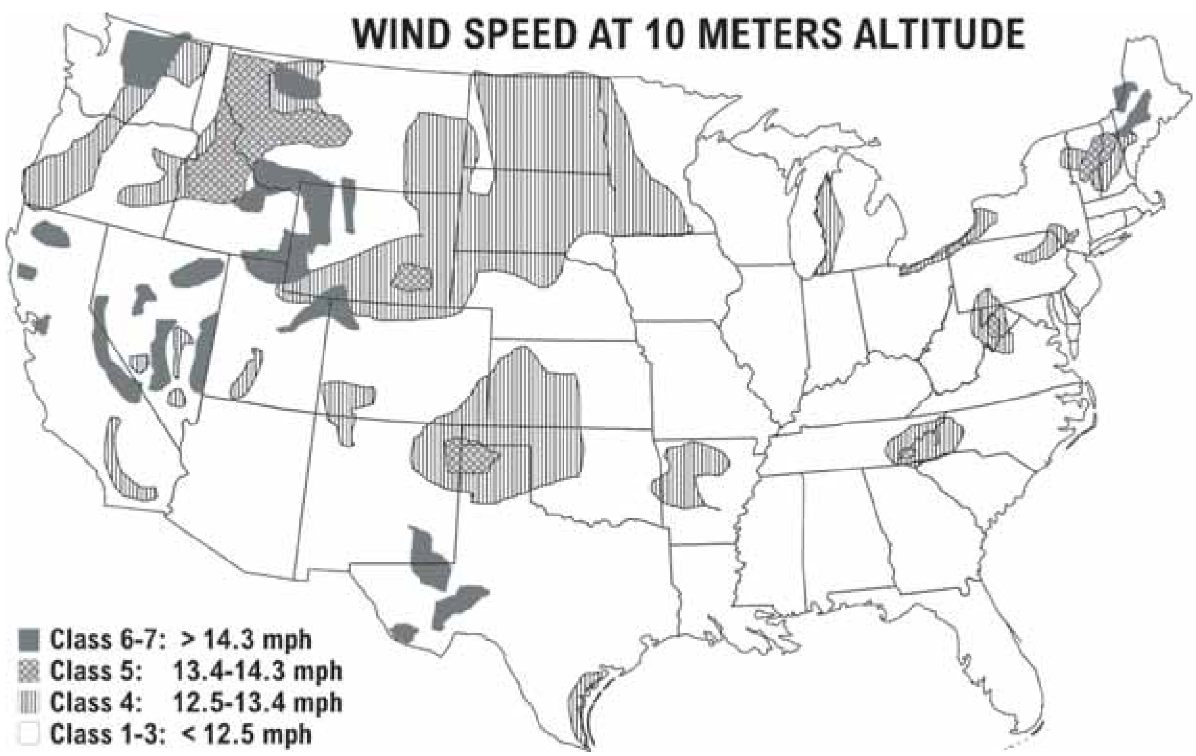
Offshore Wind Farms

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.



Living on a Remote Island: All in a Day's Work for Dusty Murdock


Photo courtesy of Dusty Murdock

If you like solving problems, "roughing it" style camping and seeing the world, you'll find Dusty Murdock's job in the wind industry fascinating. Dusty grew up in Minnesota and works as a Development Engineer for Powercorp Pty Ltd, in Darwin, Australia.

At Powercorp, Dusty works on some really cool projects. A recent project took him to the Cocos Keeling Islands in the Indian Ocean. One remote island had a small power station fueled by four diesel engines. Using the fuel farm as the primary source of power was very expensive, since diesel fuel must be shipped on a barge to the island. So the Cocos Islands purchased four 25 kW wind turbines, and hired Powercorp to create a wind/diesel system.

While working in the Cocos Islands, Dusty lived on a larger, more inhabited island in a hotel, and took a barge across to the remote island during installation of the wind turbines. Once the system was up and running, most of the other workers went home. Dusty remained to set up the system so it would work efficiently. He moved to the small, remote island and lived with a local Malaysian family. They cooked all of his meals, including a memorable one of tiny octopus.

Once Dusty returned to Australia, the job wasn't over. For six months, Dusty kept an eye on the remote power station using his computer. Since it would cost thousands of dollars and several days of time to travel back to the sland, it was important for Dusty to be able to fix problems over the computer, through the power electronics he created, from thousands of miles away!

Dusty says the most rewarding part of his job is, "After I've spent a couple of years designing a box and commissioning it, I turn it on and it works. Everything comes together. It's really cool." He enjoys the travel and adventure, too. His travels have taken him to an island off Portugal, a mine in western Australia, and to New Zealand to design and manufacture new equipment.

Does Dusty miss living in America? "Yeah, sure," he says, "America is home, always will be. I'll live there again someday, but for now, I have this opportunity to do cool things in the wind industry."

Photo courtesy of Dusty Murdock

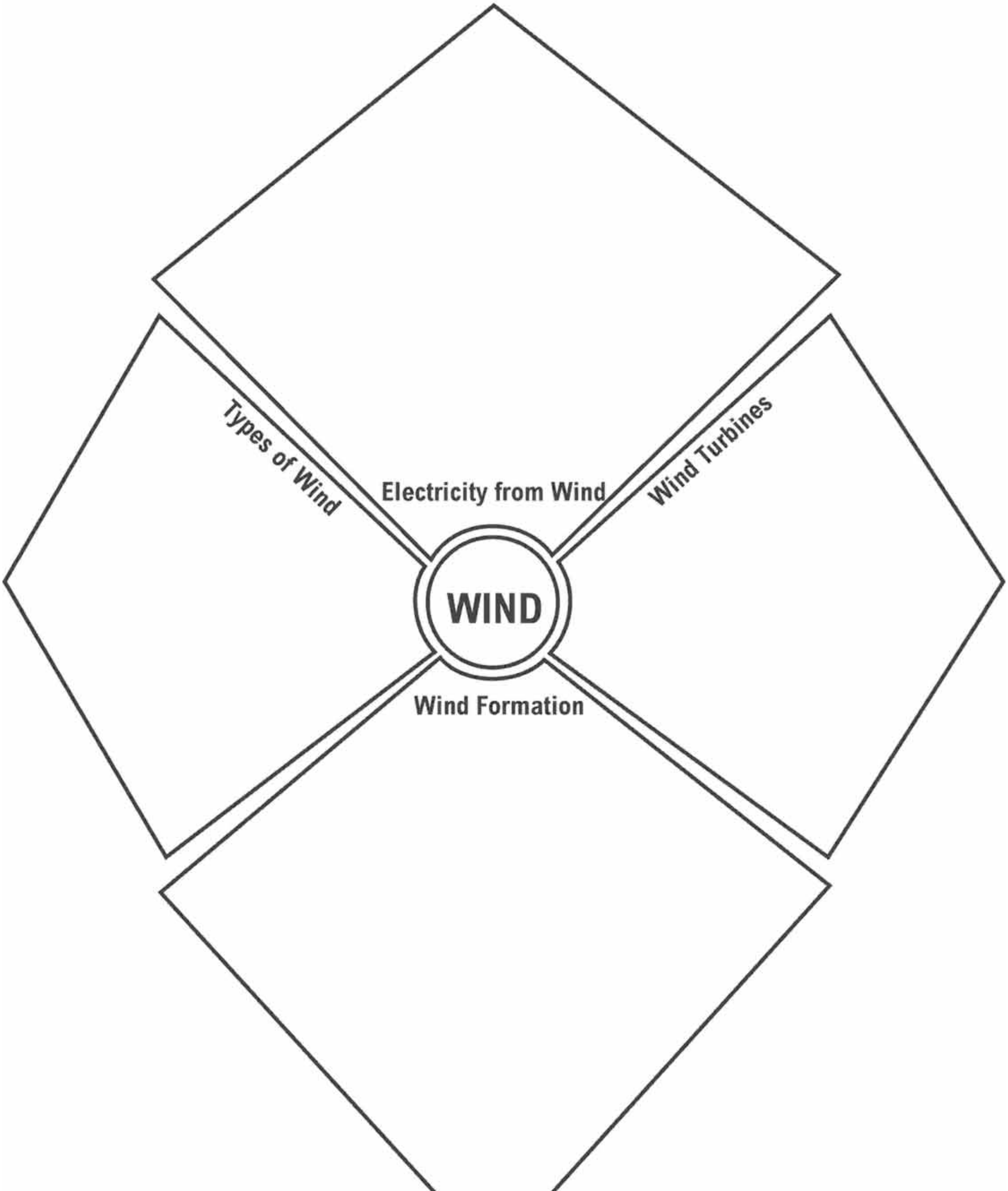
THE HISTORY OF WIND POWER

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 INFORMATION ORGANIZER

DIRECTIONS: As you read the backgrounder, write down the essential facts about each topic listed in the sections below.



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.

DATES

WIND SPEED EXPLORATION

PURPOSE: To make an anemometer to measure wind speed.

MATERIALS: wind gauge, 1 pencil, 5 cone paper cups, 2 long straws, glue, hole punch, scissors, straight pin, marker, watch with second hand

PROCEDURE:

1. Cut the end off one cup to make a hole big enough for the pencil to fit in. Use the hole punch to make four holes in the top of the cup: two holes opposite each other very near the rim and two holes on opposite sides about a half-centimeter below the first holes, as shown in Diagram 1.

2. Slide the straws through the holes in the cup, as shown in Diagram 2.

3. Use the hole punch to make two opposite holes in the other cups about 1 centimeter from the rim. Slide one cup onto the end of each straw, making sure the cups face in the same direction. Glue the cups to the straws.

4. Center the straws in the cup. Slide the cup over the pencil as shown in Diagram 2 and push the pin through the middle of both straws and into the pencil eraser as far as you can to anchor the apparatus. Lift the straws slightly away from the eraser on the pin so that the apparatus spins easily. You might need to stretch the pin holes in the straws by pulling gently on the straws while holding the pin in place.

5. Draw a stripe on the end of one cup so that you can count the revolutions of the anemometer.

6. Take your anemometer outside and measure the speed of the wind in several areas around the school by counting the number of revolutions in 10 seconds and using the chart to determine miles per hour (mph). Compare your results with those of others in the class.

7. Use the wind gauge to measure the wind speed and compare the results to those of your anemometer.

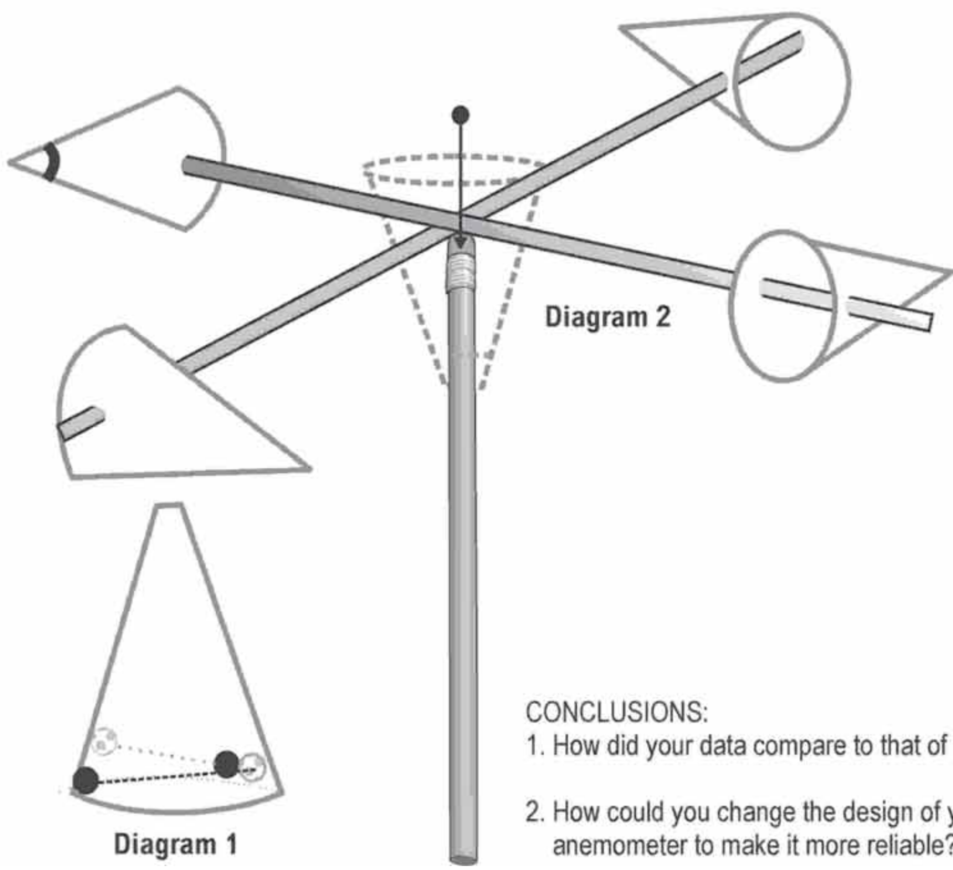


Diagram 2

Diagram 1

Revolutions per 10 sec	mph
2-4	1
5-7	2
8-9	3
10-12	4
13-15	5
16-18	6
19-21	7
22-23	8
24-26	9
27-29	10
30-32	11
33-35	12
36-37	13
38-40	14
41-43	15
44-46	16
47-49	17
50-51	18
52-54	19
55-57	20

CONCLUSIONS:

1. How did your data compare to that of your class?

2. How could you change the design of your anemometer to make it more reliable?

CALCULATING WIND POWER

PURPOSE: To calculate wind power

MATERIALS: fan, wind gauge, turbine with benchmark blades, meter stick

FORMULA: Power = $\frac{1}{2} \rho A V^3$, where ρ = air density, A = swept area ($A = \pi r^2$), V = velocity ($\pi = 3.1416$)

$$\text{Watts} = \frac{1}{2}\left(\frac{kg}{m^3}\right) \times \left(m^2\right) \times \left(\frac{m}{s}\right)^3$$

($\rho \approx 1.2\ kg/m^3$ at standard ambient temperature and pressure)

PROCEDURE:

1. Measure the radius of the turbine blade assembly and calculate the area swept by the blades ($A = \pi r^2$)

2. Use the wind gauge to measure the wind velocity at a distance of 1 meter from the fan on low and high speeds. Convert the measurements from miles per hour to meters per second (mps). (1 mile = 1609.344 meter)

   Wind Velocity at Low Speed - 1 meter: ____________ mph = ____________mps

   Wind Velocity at High Speed - 1 meter: ____________ mph = ____________mps

3. Use the formula above to calculate the power of the wind at both fan speeds.

   Wind Power at Low Speed - 1 meter: ____________W

   Wind Power at High Speed - 1 meter: ____________W

4. Vary the distance from the fan and calculate the power on low and high speeds.

   Wind Power at ___________m (distance A) on Low Speed: ___________W

   Wind Power at ___________m (distance A) on High Speed: ___________W

   Wind Power at ___________m (distance B) on Low Speed: ___________W

   Wind Power at ___________m (distance B) on High Speed: ___________W

RESULTS: Compare the power at different distances from the fan and on different fan speeds.

CONCLUSION: Explain the relationships between the different variables and the power produced.

WIND DIRECTION EXPLORATION

PURPOSES: To make a wind (or weather) vane - a device that measures the direction of the wind.
To measure wind direction using your wind vane.

MATERIALS: 1 pencil, 1 pin, 1 tall foam cup, 1 compass, 1 piece of foam board (6 cm x 18 cm), 1 marker

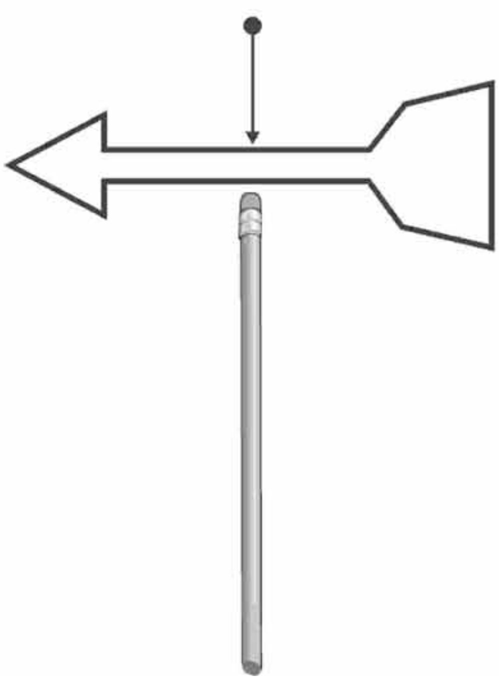
PROCEDURE:

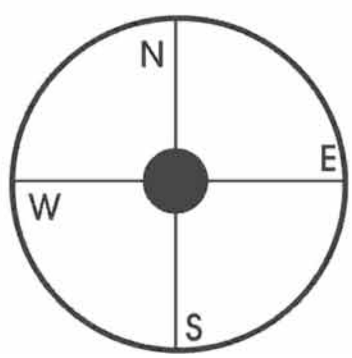
1. Cut the foam board into an arrow using the template from your teacher .
2. Attach the arrow to the pencil eraser with the pin, as shown in the diagram below.
3. Draw lines on the bottom of the cup and label the ends N, S, E, & W as shown in the diagram below.
4. Make a hole in the middle of the cup. Place the pencil in the hole and make sure it can spin freely.
5. Use the wind vane to measure the direction of the wind three times a day for a week in the same place. Place the directions on the cup so that they match the compass. The arrow on the compass should point North.

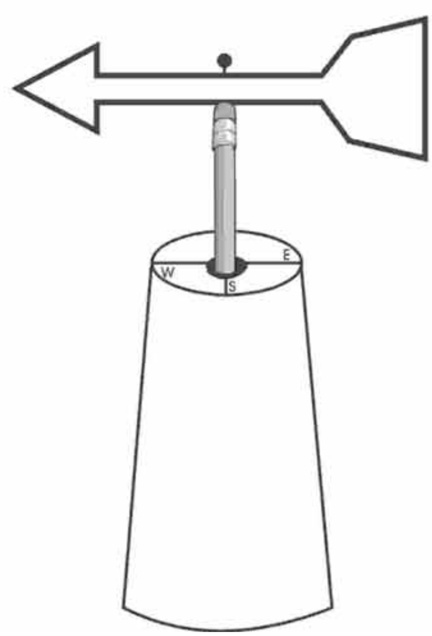
CONCLUSIONS:

1. From what direction does the wind usually blow?
2. Does the time of day affect the direction of the wind?

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
MORNING					
NOON					
AFTERNOON					







DESIGNING TURBINE BLADES 1

PURPOSE: To design turbine blades that will effectively convert the kinetic energy in wind into electricity.

MATERIALS: dowels, tape, multimeter, fan, turbine

ASSIGNMENT: Design turbine blades of any size, shape, material, and number.

DESCRIPTION: Write and draw a detailed description of your blades on the next page.

PROCEDURE:

1. Attach your turbine blades to the dowels with tape.
2. Record the output of the turbine with your blades using the multimeter.
3. Make changes to your blades in 10 minutes.
4. Test your blades again and record the output.
5. Compare the output of your blades to the benchmark and to the output of others in the class.

DESCRIPTION: Write and draw a detailed description of your redesigned blades on the next page.

CONSTANTS:

1.
2.
3.
4.

VARIABLES:

1.
2.
3.
4.
5.

RESULTS: BENCHMARK: ____________ TRIAL 1: ____________ TRIAL 2: ____________

CONCLUSIONS:

1. How did the output of your blades compare to the benchmark output and the output of others in the class?
2. Explain specific changes you would make to your blades.

DESIGNING TURBINE BLADES 1-2

DESCRIPTION: Write and draw a detailed description of your blades:

DESCRIPTION: Write and draw a detailed description of your redesigned blades:

DESIGNING TURBINE BLADES 2

DESCRIPTION: Write and draw a detailed description of your new blades.

PROCEDURE:

1. Attach your turbine blades to the dowels with tape.
2. Record the output of the turbine with your new blades using the multimeter.

RESULTS:

CONCLUSIONS:

1. How did the output of your new blades compare to the output of your old blades?
2. Explain specific changes you would make to your blades.

DESIGNING TURBINE BLADES 3

GROUP #: ________________ VARIABLE: ____

PURPOSE: To determine the optimum shape, length, and number of turbine blades that will effectively convert the kinetic energy in wind into electricity.

MATERIALS: dowels, tape, multimeter, fan, turbine, poster board

ASSIGNMENT: As a group, design turbine blades and a procedure to determine the optimum for your assigned component.

DESCRIPTION: Write and/or draw a detailed description of your blades.

PROCEDURE: Explain the procedure you will use.

1.

2.

3.

4.

5.

RESULTS:

BRAINSTORM: Compare your results with the results of the other group with your assigned component. Determine as one large group the optimum design for your variable.

DESCRIPTION: Write and/or draw a detailed description of the group's decision.

DESIGNING TURBINE BLADES 4

GROUP #: ________________

PURPOSE: To combine the information from the three variable groups to design turbine blades that will effectively convert the kinetic energy in wind into electricity. The design with the highest output will be used in the next experiments.

MATERIALS: dowels, tape, multimeter, fan, turbine, poster board

DESCRIPTION: Write and/or draw a detailed description of your blades.

PROCEDURE: Explain the procedure you will use to test and refine your blades.

1.

2.

3.

4.

5.

RESULTS:

CONCLUSION: How would you change your design to make it more efficient?

DESIGNING TURBINE BLADES 5

GROUP #: ________________ VARIABLE: ____

PURPOSE: To determine the optimum mass, distribution of mass, and pitch of turbine blades that will effectively convert the kinetic energy in wind into electricity.

MATERIALS: dowels, tape, multimeter, fan, turbine, poster board, template of winning blade design, pennies, protractor

ASSIGNMENT: As a group, design and implement a procedure to determine the optimum for your assigned component.

PROCEDURE: Explain the procedure you will use.

1.

2.

3.

4.

5.

6.

RESULTS: Record the results of each trial.

CONCLUSIONS:

DESIGNING TURBINE BLADES 6

GROUP #: ________________ HIGHEST OVERALL OUTPUT: ____________

PURPOSE: To combine the information from the two variable groups to design turbine blades with the optimum pitch, mass, and distribution of mass that will effectively convert the kinetic energy in wind into electricity. The group with the highest output will receive bonus points.

MATERIALS: dowels, tape, multimeter, fan, turbine, poster board, template of winning blade shape & size

DESCRIPTION: Write and/or draw a detailed description of the amount and distribution of mass, and the pitch, of your blades.

PROCEDURE: Explain the procedure you will use to test and refine your blades at different fan speeds and different distances from the fan.

1.

2.

3.

4.

5.

RESULTS: Record the variables and results of each trial.

CONCLUSION: Is there anything else you would change about your turbine blades to make them more efficient?

THE EFFECT OF ADDING A GEARBOX

PURPOSE: To observe the gearbox's effect on electrical output of the wind turbine.

MATERIALS: multimeter, fan, turbine, gearbox, optimum blades

HYPOTHESIS: What effect will the addition of the gearbox have on the electrical output of the wind turbine?

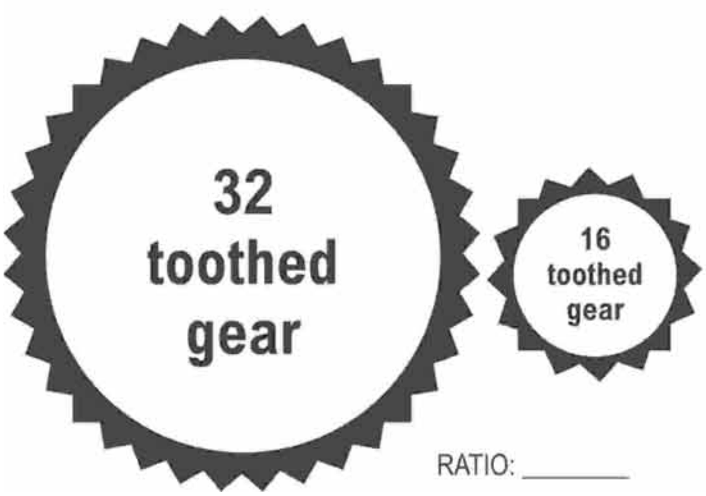
PROCEDURE:

1. Measure and record the electrical output of the optimum blades using a non-geared turbine.
2. Measure and record the electrical output of the optimum blades using the geared turbine, making sure that you minimize all other variables.

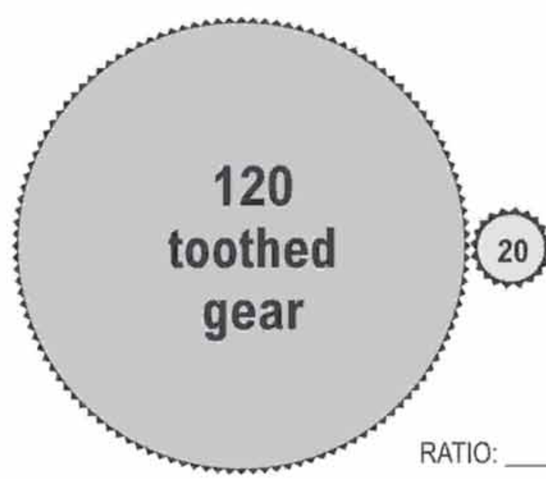
RESULTS: Compare the electrical output of the non-geared and geared turbines. Calculate the effective gear ratio.

CONCLUSION: The gear ratio of the gearbox is 7:1. How does this compare to your calculated gear ratio? What factors might explain the difference between the gear ratio of the gearbox and your calculated gear ratio?

EXTENSIONS:
1. Calculate the gear ratios of the gears shown below.
2. If the 32-toothed gear and the 120-toothed gear are rotating at 50 rpm (revolutions per minute), how fast are the 16-toothed gear and 20-toothed gear rotating?



RATIO: ________



RATIO: ________

Siting a Wind Farm Roles and Key Questions

The Bureau of Land Management has received a proposal from a developer to build a wind farm on public land in your community. You understand that developing renewable resources is a way to meet the growing electricity needs of your area, but you are concerned about the impact a wind farm might have on your community. You and other stakeholders have been invited to present your perspectives at a public forum. Based on your research, followed by your panel presentation, the community will vote on whether or not to support building the wind farm.

Governmental Agency Representative—BLM

The Bureau of Land Management is an agency in the Federal Government that is responsible for managing and conserving the resources that are on public land. The BLM has a policy of encouraging multiple uses of public lands. If a wind farm is built on the public land under your control, you will be responsible for overseeing and managing the project. The federal government would receive lease payments and/or royalties from the developer.

1. What are the advantages and disadvantages to the BLM of allowing the development of the wind farm?
2. What are the major issues that the BLM must consider before allowing the development of the wind farm?
3. One of the jobs of the BLM is to protect the public's interest in the land. Will allowing the development of the wind farm be in the best interest of the public?

Developer

As the developer of the wind farm project, you must create a plan that details the advantages of establishing a wind farm in your particular area. You must also be able to answer questions from those groups that might oppose the wind farm. It is important as the developer that you understand the "big picture" of the positive and negative impacts of developing the wind farm.

1. What are the long-term benefits to the community of developing the wind farm?
2. What are the disadvantages? How will potential risks be minimized?
3. How will the environment be protected during the installation, operation, and maintenance of the wind farm?

Investor

An investor is someone who uses his or her money now, in order to make money later. A developer has approached you with a proposal to build a wind farm in a nearby community. As an investor, you are interested in paying money now to build a wind farm, with the idea that you will earn money later as the wind farm becomes productive. You need to determine the costs, risks, earning potential, and benefits of investing in the wind farm.

1. How much will it cost to build and maintain the wind farm? What costs do you need to consider?
2. How much return of income can you expect from your investment? Over how many years?
3. What are the biggest risks to investing in the wind farm?

Site Planner

The site planner of a wind farm considers many factors to determine the best location for a wind farm. You must take into consideration the important concerns that community members have. You need to determine the optimum areas for the turbines in regard to local weather patterns. You must also take into consideration any other environmental factors that might affect the siting of the wind farm.

1. What information about local and global weather patterns and wind technology must you research before siting a wind farm?
2. What environmental factors must you consider before siting a wind farm?
3. What other factors must you consider? Are there roads and power lines nearby?

Farmer/Rancher

You are a farmer and rancher who has a long-term lease of 10,000 acres of public land that you use to grow crops and graze your cattle. The Bureau of Land Management has informed you that it is considering a proposal to allow a wind farm to be built on part of the land. You think that using renewable energy and having multiple uses of the land are good ideas, but you are concerned about the impact of a wind farm on your crops and animals.

1. What impacts will siting, building, and operating a wind farm have on your crops and cattle?
2. Will you have to reduce the acres of crops you grow or the number of cattle that graze on the land?
3. Are there any benefits to you of building the wind farm on your leased land?

Consumer/Neighbor

You are a neighbor of the farmer/rancher on whose land the wind farm might be built. You have heard that large wind turbines generate a great deal of noise and that concerns you because the chinchillas you raise are very sensitive to noise. You are aware that there have been predictions of blackouts in the near future in your area because of a lack of electricity capacity. You are also wondering how the price of electricity in your area might be affected if a wind farm were installed.

1. How much noise do wind turbines generate?
2. How would a wind farm affect the property values of the surrounding properties?
3. How would local electricity rates be affected by the installation of a wind farm?

Environmentalist

You are very concerned with protecting the environment. You would like to know how wind energy impacts the environment during the manufacture, installation, maintenance, and removal of the wind turbines. Also, there have been reports in the past of wind turbines injuring birds and bats that fly into them. You would like to know how wind energy installations might affect birds and animals in your area.

1. How would the manufacture and installation of wind turbines affect the local environment?
2. How would the operation of the wind turbines affect the surrounding environment and the plants and animals in the area?
3. Would the amount of electricity generated by the wind turbines be enough to offset the 'cost' to the environment?

Economist

An economist is a person who can analyze the financial impacts of actions. The community that will be affected by the development of the wind farm has consulted you. They have asked you to determine the costs of generating electricity from fossil fuels and wind energy and to do a comparison study. This includes comparing construction costs, transmission costs, generation costs, and potential tax credits available for using wind.

1. How does the cost of using wind to generate electricity compare to other sources?
2. What economic advantages/disadvantages would the wind farm bring to the area?
3. Will the wind farm impact the economy of the area by bringing more jobs to the area?

Utility Company Representative

You are an employee of the local utility company and are responsible for making sure that your utility has the necessary capacity to provide electricity to all of your customers. There is increased demand for electricity in your community and you know you must secure reliable sources of additional generation in the near future. You would be the main purchaser of electricity from the wind farm.

1. How expensive would the electricity be from the wind farm?
2. Will the wind farm produce enough electricity with reliability to meet the growing needs of the community?
3. Will there be additional costs to the utility company that might be passed along to consumers?

Member of the County Commission

The County Commission manages the public services of the community and determines how they are paid for. The County Commission is a political group and must take into consideration all political sides of the issue. You must consider the impacts on the community if the BLM allows the wind farm to be developed in the area.

1. What impacts would the wind farm have on the need to provide local services?
2. What economic impacts would the wind farm have on the local community and taxes?
3. What political impact would supporting the wind farm have on your community?

Role Group:

Question 1	Question 1	Question 1
Essential Details	**Essential Details**	**Essential Details**

So what? What's important to understand about this?

WEB Resources for Wind Research

American Wind Energy Association
www.awea.org/faq/wwt_environment.html

American Wind Energy Association – Economics of Wind Energy
www.awea.org/pubs/factsheets/EconomicsofWind-March2002.pdf

Audubon Society
www.audubon.org/campaign/windPowerQA.html

Danish Wind Industry
www.windpower.org/en/core.htm

Department of Administration – Wind Siting Guidance
www.doa.state.wi.us/pagesubtext_detail.asp?linksubcatid=976

European Wind Energy Association
www.ewea.org/index.php?id=204

FPL Energy – Wind Siting and Development
www.fplenergy.com/portfolio/wind/siting_develop.shtml

Harvesting Clean Energy
www.harvestcleanenergy.org/wind/

KidWind
www.kidwind.org

NEED Project: Energy on Public Lands
www.need.org/needpdf/EnergyonPublicLands2006BLM.pdf

Our Wind Co-op is a unique cooperative of small-scale wind turbines on farms, ranches and public and private facilities across the Northwest. Through this collaborative effort, 10-kW turbines were installed at numerous rural sites serviced by publicly-owned utilities.
www.ourwind.org/windcoop/

Renewable Energy Access
www.renewableenergyaccess.com/rea/news/story?id=46840

Wind Energy Easements and Leases: Information for Landowners and Good Practices for Wind Developers
www.windustry.org/opportunities/lease.htm

Wind Energy Siting Handbook - Kansas
www.kec.kansas.gov/reports/wind_siting_handbook.pdf

Wind Power Maps
www.windpowermaps.org/default.asp

Wind Powering America
www.eere.energy.gov/windandhydro/windpoweringamerica/ne_economics_determine.asp

Windustry – Learn How to Harvest the Wind
www.windustry.org/

Windustry Wind Calculator
www.windustry.org/calculator/default.htm

Google: “planning commissions wind” for many sites.

Harry Spotter & the Chamber of Windy Myths

CAST OF CHARACTERS

RONI – a girl
HERMAN – a boy
HARRY SPOTTER – a boy
PROFESSOR HUGGDATREAZ – a science teacher
CLOUDIA – a girl
BREEZUS – a boy
CLASS – chorus

Scene One: Classroom at Hogwatts School

Roni: I'm so excited about this new class. This professor is really supposed to be energetic!

Herman: I just hope I pass this one.

Harry: We'd better hurry, or we're going to be late.

(They enter the classroom and find seats.)

Professor: Welcome to Windseekers Class. This is a new class at Hogwatts. Your first project will impact the entire school. Due to increased enrollment, our current electrical capacity is no longer meeting our needs.

Roni: *(Waving hand excitedly.)* Is that why the lights went off in our dorm last night? I couldn't finish reading ahead for my classes.

Professor: Yes, Roni. Professor Dieseldore invited me to teach this class since I'm an expert in siting wind farms. You are going to assist me in picking the perfect location for a wind turbine.

Cloudia: Cool.

Herman: *(quietly to Harry)* Do you know what he's talking about?

Roni: Shhhhh…

Professor: Can anyone tell me what wind energy is?

(Roni waves her hand wildly.)

Professor: Harry?

Harry: The stuff that blew out the candle last night.

Professor: One point for Harry. But, wind is much more. Breezus?

Breezus: Wind is magic. It helps our broomsticks fly and fills dragons' wings.

Roni: *(shouts)* Wind is moving air.

Professor: One point for Breezus. Yes, wind does seem like magic. Roni, you would receive points too, if you'd waited to be called on. Yes, wind is moving air that we can harness to do work. Class, repeat after me: wind is moving air - energy is there.

Class: Wind is moving air—energy is there.

Professor: For homework tonight, everyone needs to find the perfect location for us to build a wind turbine here at Hogwatts. Class dismissed.

Herman: A wind what?

Harry: A wind turbine. It works like a windmill, but the blades catch the wind and turn it into electricity.

Roni: It converts nature's kinetic energy into electrical energy.

Herman: Thank you, HARRY. Roni, how far ahead did you read?

Harry: Stop bickering; let's get this homework done.

Class: *(Exiting the classroom.)* Wind is moving air—energy is there.

Scene Two: The Next Day in Windseekers Class

Professor: It's time to share your ideas. Where should we build the wind turbine?

(Roni waves her hand wildly.)

Professor: Breezus?

Breezus: In the middle of the Frightening Forest, so we don't have to see it. The giant tower and spinning blades will blend right in with the hideous trees and won't ruin our view.

Cloudia: But I think the wind turbine will look cool. I don't want to go into the Frightening Forest to see it.

Professor: Although some people don't like the look of turbines, that shouldn't be our first consideration.

Roni: And the trees in the forest would block the wind, so that would defeat the purpose.

Herman: (*Sighs loudly*). So I guess that means my idea of putting the turbine inside of the science building wouldn't work either?

Professor: That's right, Herman. Any other suggested sites? Remember what wind is?

Class: Wind is moving air—energy is there.

Cloudia: How about near Zagrid's house, or even on his roof?

Harry: But wouldn't the noise keep him and his menagerie up at night?

Professor: Actually, the sound from a wind turbine isn't as loud as you might think given how big it is and how much energy it makes. The sound it makes is a rhythmical whooshing, sort of like the sound of a dragon's wings flapping—whoosh, whoosh, whoosh. Who can see why building it on Zagrid's house wouldn't work?

Breezus: Same reason as the woods. There can't be anything near it that would block the wind before it gets to the blades. His house is so tiny, even some of the trees are taller.

Roni: How about the roof of the school? It is the tallest building at Hogwatts, so nothing will block the wind's path.

Professor: Good suggestion, Roni; however, it won't work for two reasons.

Herman: Roni's wrong?

Professor: Hogwatts' roof is tall, but the vibrations from the turbine might damage the building AND does anything else use that airspace?

Cloudia: The Owlery is up there. Our owls could fly into the spinning blades!

Breezus: Good thing I don't have an owl.

Professor: Birds are a consideration in siting a wind turbine. We've learned that you need to study the birds in an area before building a wind project and avoid areas where there are significant risks of collisions.

Harry: This shouldn't be so hard.

Herman: Does this mean that if we find a perfect location, we'll only have power when there is a storm and it's really windy out?

Roni: No, Herman. Current technology allows a large wind turbine to run efficiently on winds as low as 13 miles per hour.

Cloudia: So we just need to find a location away from tall structures that might block the wind, with a wind speed of at least 13 miles per hour, and in a place that won't disturb wildlife.

Breezus: Maybe there's a windseeker spell to help figure this out!

Professor: Five points to Cloudia for summing up the discussion so nicely. For homework tonight, you can take anemometers out to check wind speed at various locations. Remember, the tower could be up to 100 meters high, so you will have to find a way to get to that height to accurately check the speed.

Harry: Wooo…flying time!

Scene Three: The Next Day in Windseekers Class

Professor: Good morning class.

Class: Wind is moving air—energy is there.

Professor: It seemed to be pretty windy last night. Did you have fun using the anemometers to measure the wind speed?

Breezus: It was great, until I fell off my broomstick trying to get a reading.

Class: (*Laughs.*)

Breezus: The edge of the cliff had sustained gusts up to 80 miles per hour. We'd get tons of energy from that!

Roni: Actually, that's too much wind. Those gusts would shut the turbine down. They need to protect themselves from incredibly strong winds, so when the wind gets too powerful they shut down. Also, did you notice what direction the wind was blowing?

Harry: The wind came right up the face of the cliff. I actually leaned out over the edge, holding my broom tight in case I fell, and the wind held me up! My cap blew off and flew up, up, up into the air.

Professor: This is actually another reason why the edge of a cliff will not work. Wind turbines are designed to capture air that is moving parallel to the ground. They cannot capture wind that is moving upwards.

Cloudia: The field where the gardens are planted got between 15 and 25 mile per hour winds the whole time we were there.

Herman: But would we have to move all those plants? Some of them take years to bloom.

Professor: Many wind farms use the land under the towers for farming or grazing. We could continue to use the area around the turbine for plants. There is plenty of room for both.

Harry: I know from flying that the wind changes depending on the weather and the season.

Professor: Ten points to Cloudia for finding a good spot and a point to Harry for noticing that the wind isn't always constant. We only took measurements for one night, which really isn't sufficient for determining a good site, but since it was windy, it will give us a good idea of where to look.

Roni: Wind measurements should really be taken at a site for at least one full year to get an idea of what the wind is like at all times. Many people who are considering where to put a turbine will measure the wind speeds for three years or more!

Breezus: If wind isn't reliable, why use it?

Professor: A point for Roni. As she said, you really need long term data to determine if a site is a good one for a wind turbine. A team of our professors has just finished reviewing many years of Hogwatt's weather records and has determined that winds in the garden area are very reliable. The average wind speed is calculated to be 15 miles per hour. The wind doesn't blow over the garden all of the time, but it is predicted that the turbine will be generating some power for the school 80 percent of the time. What other benefits does this location have?

Cloudia: It isn't near the Owlery.

Breezus: There are no tall buildings or trees near it.

Herman: We probably won't even hear the sound from the turbines when we're inside mixing potions.

Roni: By using wind power, we are using a renewable energy source. We'll never run out of wind energy, and we're taking care of the environment.

Professor: I'm proud of all of you for putting the facts together and deciding on the same site the experts did. We know we will need reliable energy to meet the electrical needs of our growing population of students. For our next assignment…

(Lights go out.)

Harry: I guess Professor Dieseldore was right. We need to use wind energy at Hogwatts.

Class: Wind is moving air—energy is there, and that's why we should care!

WIND

Pauly Power: Welcome a band that just blew into town for this performance. Many of their electric concerts are performed in California during the summer when people need to hear their music the most. Let's hear a big Totally Energy Show welcome for Darrieus and the Wind Spinners, singing "Watts on the Wind" from their "Power Tower" album.

(Darrieus and the Wind Spinners perform their song to the tune of "Oh! Susanna.")

ORIGINAL

Oh, I come from Alabama
With a banjo on my knee
I'm a-goin' to Louisiana
My true love for to see

Rained all night the day I left
The weather it was dry
Sun so hot I froze to death
Susanna, don't you cry

Oh! Susanna
Oh, don't you cry for me
For I come from Alabama
With my banjo on my knee

PARODY

The sun shines down to heat the lands
The oceans keep their cool
The hot air rises and expands
Let's use that wind as fuel

The wind blows down the mountain pass
And turns the turbine blades
No burning coal, or oil or gas
As electric power is made

Oh, wind power
You are the fuel for me
For three-fourths of every hour
You make electricity

INTERVIEW

Pauly Power: What gives your band the energy to perform day and night?

Darrieus: If it weren't for the sun heating the earth unevenly, we would not be turning out our music today.

Pauly Power: Where did the band get its first big break?

Milly: Our first big break came in Holland in the 17th century. We paid our dues, though. We really got put through the mill!

Pauly Power: I've heard your band isn't always reliable; that you don't always show up at performances. Tell me why.

Lolly: Well Pauly, that's true; we only perform about three-fourths of the time. And, even then, the energy we get from the wind isn't always strong enough for us to be heard in the back row.

Pauly Power: I hear your concert halls take up a lot of space.

Gale: That's true. Just one of our wind towers needs an acre or two. And we usually have dozens of towers on a wind farm. The good thing is you can plant crops around our wind machines or graze cattle.

ELECTRICITY

Pauly Power: Our next band is a blow-out. They follow a concert circuit that reaches almost every person in the country—in fact, they travel extensively worldwide. Let's hear a big welcome for Lightning and the Zappers, singing "Power to the People" from their "It's Electric!" album.

(Lightning and the Zappers perform their song to the tune of "Wheels on the Bus").

ORIGINAL

The wheels on the bus go
round and round
round and round
round and round

The wheels on the bus go
round and round
All through the town.

PARODY

The turbine blades spin round and round, round and round, round and round
A copper coil spins round and round inside a magnet.

Electrons in the coil flow round and round, round and round, round and round
Flow in a loop going round and round in a closed circuit.

Voltage in the wires steps up and down, up and down, up and down
Transformers step it up and down, from power plant to town.

The switches on the walls go up and down, up and down, up and down
Closed is up and open is down. The circuits in our town.

There's no power when the switch is down, switch is down, switch is down
Close the circuit and electrons go round, powering our town.

INTERVIEW

Pauly Power: What gives your band the energy to perform day and night, all over the world?

Lightning: We go with the flow—the flow of electrons.

Pauly Power: How long has your band been on the concert circuit?

Jenny Rator: We've been around forever, but people really began to get turned on by us in the 1930s and 40s.

Pauly Power: I've heard your band is the most reliable on the circuit; you always show up at performances. Tell me why.

Reely Able: Well, Pauly, that's true, here in the U.S. we travel on a network that gets us to concerts over 99 percent of the time. In other countries, we have a harder time.

Pauly Power: Why do so many people like your concerts?

Lightning: Our songs have something for everybody. Our tickets are a bargain and our tunes have a powerful message.

Wind Logic Puzzle

Professor Huggdatreaz asked Nevi to take the researchers' reports to Professor Deiseldore. Unfortunately, a gust of wind came up and blew the reports out of Nevi's hands into the lake. Nevi remembered a few details from the reports, such as different wind speeds at the sites tested. The five researchers had rejected four sites for different reasons (too windy, not enough wind, too many trees, and bird sanctuary before picking the perfect site. Use the notes that Nevi remembered to match the researchers with their sites – why each was accepted or rejected and what the average wind speed was.

1. Becca's and Maria's wind speeds were rejected because the wind was either too fast or too slow to make the turbine run efficiently.
2. Marta and Keith both had good wind speeds at their sites.
3. The perfect site had winds that were 5 mph faster than the site with the bird sanctuary. The site with the bird sanctuary wasn't rejected because of its wind speed.
4. The five sites included the one Maria researched, the one with wind speeds of 8 mph, the perfect site, Marta's site, and the one with too many trees.
5. Keith did not pick the perfect site or have average winds of 18 mph.
6. Karem's site had 23 mph winds.
7. Marta did not pick the perfect site.

		RESEARCHERS					AVERAGE WIND SPEED - MPH				
		Karem	Keith	Maria	Marta	Becca	8	13	18	23	64
DESCRIPTION OF SITE	Too Windy										
	Not Enough Wind										
	Too Many Trees										
	Bird Sanctuary										
	Perfect Site										
AVERAGE WIND SPEED	8 mph										
	13 mph										
	18 mph										
	23 mph										
	64 mph										

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