Introduction to Wind

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.

Physics of Wind

The energy in wind comes from the sun. When the sun shines, some of its light or radiant energy reaches the Earth's surface. The Earth near the Equator receives more of the sun's energy than the North and South Poles.

Some parts of the Earth absorb more radiant energy than others. Some parts reflect more of the sun's rays back into the air. The fraction of light striking a surface that gets reflected is called albedo.

The Beaufort Scale

At the age of 12, Francis Beaufort joined the British Royal Navy. For more than twenty years, he sailed the oceans and studied the wind, which was the main power source for the Navy's fleet. In 1805, he created a scale to rate the power of the wind based on observations of common things around him rather than instruments.

The Beaufort Scale ranks winds from 0–12 based on how strong they are, with each wind given a name from calm to hurricane. The Beaufort Scale can be used to estimate the speed of the wind.

Some types of land absorb more radiant energy than others. Dark forests and pavement absorb sunlight while light desert sands, glaciers, and water reflect it. Land areas usually absorb more solar (radiant) energy than water in lakes and oceans.

When the Earth's surface absorbs the sun's energy, it turns the radiant energy into thermal energy. This thermal energy on the Earth's surface warms the air above it.

Source: National Oceanic and Atmospheric Administration
The air over the Equator gets warmer than the air over the poles. The air over the desert gets warmer than the air in the mountains. The air over land usually gets warmer than the air over water. As air warms, it expands. Its molecules get farther apart. The warm air is less dense than the air around it and rises into the atmosphere. Cooler, denser air nearby flows in to take its place. This moving air is what we call wind. It is caused by the uneven heating of the Earth's surface.

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 30 degrees north and south of the Equator, the warm air from the Equator begins to cool and sink. The trade winds, westerlies, and easterlies flow around the world and cause many of the Earth's weather patterns.

- **Trade Winds**
  Most of this cooling air moves back toward the Equator. The rest of the air flows toward the North and South Poles. The air streams moving toward the Equator are called **trade winds**—warm, steady breezes that blow almost all the time. The **Coriolis Effect**, caused by the rotation of the Earth, makes the trade winds appear to be curving to the west.

- **Doldrums**
  The trade winds coming from the south and the north meet near the Equator. As the trade winds meet, they turn upward as the air warms, so there are no steady surface winds. This area of calm is called the **doldrums**.

- **Prevailing Westerlies**
  Between 30 and 60 degrees latitude, the air moving toward the poles appears to curve to the east. Because winds are named for the direction from which they blow, these winds are called **prevailing westerlies**. Prevailing westerlies in the Northern Hemisphere cause much of the weather across the United States and Canada. This means in the U.S., we can look to the weather west of us to see what our weather will be like in the coming days.

- **Polar Easterlies**
  At about 60 degrees latitude in both hemispheres, the prevailing westerlies join with **polar easterlies**. The polar easterlies form when the air over the poles cools. This cool air sinks and spreads over the surface. As the air flows away from the poles, it curves to the west by the Coriolis Effect. Because these winds begin in the east, they are called polar easterlies.
## Local Winds

The wind blows all over the planet, but certain areas have land features that can make the wind blow faster or more frequently or slower and less frequently. Some places have great variation in wind from day to night, while other areas have great seasonal variation from summer to winter. Winds can blow fast and strong across prairies or on mountains or coasts. Local winds can change direction and speed frequently if land surfaces are uneven or if forests or buildings are in their path.

### Mountain and Valley Winds

Local winds form when land heats up faster in one place than another. A mountain slope, for example, might warm up faster than the valley below. The warm air is lighter and rises up the slope. Cold 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 can change direction. After the sun sets, the mountain slope cools off quickly. Warm air is pushed out of the way as cool air sinks, causing wind to blow down toward the valley. This is called a mountain wind, or katabatic winds.

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### Jet Streams

The highest winds are the jet streams. They are formed where the other wind systems meet. The jet streams flow far above the Earth where there is nothing to block their paths. These fast moving “rivers of air” pull air around the planet, from west to east, carrying weather systems with them.

These global winds—trade winds, prevailing westerlies, polar easterlies, and the jet streams—flow around the world and cause most of the Earth’s weather patterns.
When katabatic winds blow through narrow valleys between mountains, the speed of the wind increases. This is called the tunnel effect. Katabatic winds sometimes have special names throughout the world. In the United States, there are two—the Chinook is an easterly wind in the Rocky Mountains and the Santa Ana is an easterly wind in southern California.

**Sea and Land Breezes**

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, and 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. Winds flow from areas of high pressure to areas of low pressure, thus 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.
Measuring Wind Direction and Speed

- **Wind Direction**
  A weather vane, or wind vane, is used to show the direction of the wind. A wind vane points toward the source of the wind. Some locations such as airports use windsocks to show the direction in which the wind is blowing.

  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**
  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 into the optimal range of a turbine can result in eight times the amount of power produced. This huge difference 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:

  \[ \text{Power} = \frac{1}{2} \rho A V^3 \]

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

  \[ \rho = \text{air density; 1.2 kg/m}^3 \text{ at standard ambient temperature and pressure} \]

  \[ r = \text{radius} \]

  \[ \pi = 3.1416 \]

  \[ A = \text{swept area (A = } \pi r^2) \]

  \[ m = \text{meter} \]

  \[ s = \text{second} \]

  \[ V = \text{velocity} \]

  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 miles per hour (mph) or meters per second (m/s). A display on a recording device called a data logger shows the speed of the wind. There are also digital anemometers that measure wind speed.

- **Wind Shear and Turbulence**
  When 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 a 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 jet streams. Wind shear in an unstable atmospheric layer can result in turbulence.

  **Turbulence** is defined as a variation in the speed and direction of the wind in very short time periods (1 second) 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. 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 important factors for wind turbine engineers to study because they can affect the operation and output of turbines, and even cause them to fail. Studying the wind shear and turbulence in an area often tells engineers more about how high to place the tower of a turbine to get the best wind conditions.
What is Energy?

Wind is an energy source, but what exactly is energy? Energy makes change; it does things for us. We use energy to move cars along the road and boats over the water. We use energy to bake a cake in the oven and keep ice frozen in the freezer. We need energy to light our homes and keep them at a comfortable temperature. 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, motion, sound, and electricity. There are many forms of energy, but they can all be put into two general categories: potential and kinetic.

- **Potential Energy**
  Potential energy is stored energy and the energy of position. There are several forms of potential energy, including:
  - **Chemical energy** is energy that is stored in the bonds of atoms and molecules that holds these particles together. Biomass, petroleum, natural gas, and propane are examples of stored chemical energy.
  - **Nuclear energy** is energy stored in the nucleus of an atom. The energy can be released when the nuclei are combined (fusion) or split apart (fission). In both fission and fusion, mass is converted into energy, according to Einstein's Theory, $E = mc^2$.
  - **Elastic energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of elastic energy.
  - **Gravitational potential energy** is the energy of position or place. A rock resting at the top of a hill contains gravitational potential energy. Hydropower, such as water in a reservoir behind a dam, is an example of gravitational potential energy.

- **Kinetic Energy**
  Kinetic energy is motion—the motion of waves, electrons, atoms, molecules, substances, and objects. There are several forms of kinetic energy, including:
  - **Radiant energy** is electromagnetic energy that travels in transverse 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—the vibration and movement of atoms and molecules within substances. The faster molecules and atoms vibrate and move within substances, the more energy they possess and the hotter they become. Geothermal energy is an example of thermal energy.
  - **Motion energy** 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.
  - **Sound energy** 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 and the energy is transferred through the substance in a wave. Echoes and music are examples of sound energy.
  - **Electrical energy** is the movement of electrons. Lightning and electricity are examples of electrical energy.

Conservation of Energy

Conservation of energy is not just 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 simply change it from one form of energy into another. A car engine burns gasoline, converting the chemical energy in gasoline into motion energy. Solar cells change radiant energy into electrical energy. Energy changes form, but the total amount of energy in the universe stays the same.
Exploring Wind Energy

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, often as waste heat.

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 very inefficient at converting food into useful work. Most energy in your body is released as wasted heat.

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.

Wind is energy in motion—kinetic energy—and it is a renewable energy source. Along with wind, renewable energy sources include biomass, geothermal energy, hydropower, and solar energy. They are called renewable sources because they are replenished in a short time. Day after day, the sun shines, the wind blows, and the rivers flow. Renewable sources only make up about nine percent of the United States’ energy portfolio. We mainly use renewable energy sources to make electricity.

In the United States, more than 90 percent 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, or crude oil, for example, was formed hundreds of millions of years ago from the remains of ancient sea plants and animals. We cannot make more crude oil in a short time.

U.S. Consumption of Energy by Source, 2014

<table>
<thead>
<tr>
<th>Nonrenewable Sources</th>
<th>Renewable Sources</th>
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<tbody>
<tr>
<td>PETROLEUM 34.89%</td>
<td>BIOMASS 4.81%</td>
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<tr>
<td>NATURAL GAS 27.49%</td>
<td>HYDROPOWER 2.48%</td>
</tr>
<tr>
<td>COAL 18.00%</td>
<td>WIND 1.73%</td>
</tr>
<tr>
<td>URANIUM 8.33%</td>
<td>SOLAR 0.42%</td>
</tr>
<tr>
<td>PROPANE 1.63%</td>
<td>GEOTHERMAL 0.22%</td>
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Nonrenewable Sources and Percentage of Total Energy Consumption

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<tbody>
<tr>
<td>PETROLEUM 34.89%</td>
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</tr>
<tr>
<td>NATURAL GAS 27.49%</td>
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<tr>
<td>COAL 18.00%</td>
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<tr>
<td>URANIUM 8.33%</td>
<td>8.96%</td>
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<tr>
<td>PROPANE 1.63%</td>
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</tr>
<tr>
<td>SOLAR 0.42%</td>
<td>0.48%</td>
</tr>
<tr>
<td>GEOTHERMAL 0.22%</td>
<td>0.25%</td>
</tr>
</tbody>
</table>

*Total does not add to 100% due to independent rounding.
Electricity is a secondary energy source. We use primary energy sources, including coal, natural gas, petroleum, uranium, solar, wind, biomass, and hydropower, to convert chemical, nuclear, radiant, and motion energy into electrical energy. In the United States, coal generates 38.64 percent of our electricity. Just over two decades ago, wind contributed less than one-tenth of a percent to the electricity portfolio. Wind is still a small percentage of electrical power generation; however, it is the fastest-growing source of electricity. Since 2010, wind energy capacity in the United States has grown by over 80 percent and capacity continues to increase.

Most people do not usually think of how electricity is generated. We cannot see electricity like we see the sun. We cannot hold it like we hold coal. We know when it is working, but it is hard to know exactly what it is. Before we can understand electricity, we need to learn about atoms.

Atomic Structure

Atoms are composed of three particles, protons, neutrons, and electrons. Protons and neutrons occupy a small space at the center of an atom called the nucleus, which contains most of the mass of the atom. The electrons surround the nucleus in clouds whose shapes depend upon the type of atom present. Protons and neutrons are about equal in mass. The mass of a single proton is 1.67 x 10^-24 grams. This may seem small but the mass of an electron is 9.1 x 10^-28 grams or 1/1836 that of the proton. If the nucleus were the size of a tennis ball, the atom would be several kilometers in size. This means that atoms are mostly empty space.

Atoms are held together by two forces. Electrons are held in place by an attractive electrical force. The positively charged protons in the nucleus and negatively charged electrons are attracted to each other by electrical forces. Within the nucleus, a much stronger nuclear force of attraction holds the protons and neutrons together. This strong nuclear force overcomes the electrical force of repulsion between protons. A neutral atom has equal numbers of protons and electrons. The neutrons carry no charge, and their number can vary. An atom has a delicate balance of forces among the particles to keep it stable.

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 which element it is. A stable atom of hydrogen, for example, usually contains one proton and one electron with no neutrons. Every stable atom of carbon has six protons, six electrons, and typically six neutrons.

### U.S. Electricity Net Generation, 2014

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Coal</td>
<td>38.64%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>27.52%</td>
</tr>
<tr>
<td>Uranium</td>
<td>19.47%</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0.74%</td>
</tr>
<tr>
<td>Other</td>
<td>0.62%</td>
</tr>
<tr>
<td>Hydropower</td>
<td>6.19%</td>
</tr>
<tr>
<td>Wind</td>
<td>4.44%</td>
</tr>
<tr>
<td>Biomass</td>
<td>1.56%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.43%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.39%</td>
</tr>
</tbody>
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** Other: non-biogenic waste, fossil fuel gases.
Data: Energy Information Administration
Electrons

Electrons are located in areas of probability sometimes called energy levels. The energy level closest to the nucleus can hold up to two electrons. The next energy level can hold up to eight. Additional energy levels can hold up to 32 electrons.

The electrons in the energy levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost energy level—the valence energy level—do not. In this case, these electrons (the valence electrons) easily leave their energy levels. At other times, there is a strong attraction between valence electrons and the protons. Extra electrons from outside the atom can be attracted and enter a valence energy level. If an atom loses electrons it becomes a positively charged ion or cation. If the atom gains electrons, it becomes a negatively charged ion or anion.

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. 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, natural gas, or biomass 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.
The Grid

Once electricity is produced, it is distributed to consumers through the electric grid. The grid consists of power generators, powerlines that transmit electricity, and the components that make it all work, including substations, meters, homes, and businesses.

In the United States, there are nearly 160,000 miles of high-voltage electric transmission lines. They take electricity produced at power plants to transformers that step up the voltage so that it can travel more efficiently along the grid. Before entering your home, another transformer steps down the voltage so that it can be used to operate your lights, appliances, and other electrical needs.

One challenge facing renewable energy sources, including wind, is that the most efficient spots for producing electricity are often in secluded or rural areas. Most traditional power plants are built near population centers and the fuel source is transported to the plant. This allows the electricity produced to be quickly and economically transmitted to consumers. In order to distribute the energy produced from some renewable sources, the electricity must travel farther distances. The longer the electricity has to travel the more transmission lines are needed and the more energy is lost (as heat) along the way.

To overcome the challenge of distributing electricity quickly and efficiently, not only for renewable energy sources, but also for nonrenewable sources, steps are being taken to upgrade the U.S. electricity grid to a “smart grid.” Using new technology the smart grid will help to save money, operate reliably, reduce its impact on the environment, and handle the growing power needs of today and tomorrow.

High-Voltage Transmission Lines

Data: Federal Emergency Management Agency
## Evolution of the Windmill

Before we understood electricity, people were capturing the wind to do work. A mill is a machine used to shape materials or perform other mechanical operations. For many years, wind was the power source for mills of all kinds. 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 saw logs at sawmills and create paper at papermills. Wind power was an important part of the first Industrial Revolution in Europe.

## American Windmills

As Europeans came to America in the mid-1600s, they brought their windmill designs with them and windmills were a common sight in the colonies. In the 1800s, settlers began to explore the West. While there was plenty of space, they soon discovered that the land was too dry for farming. A new style of windmill, one that pumped water, was invented.

In 1854, a mechanic, Daniel Halladay, designed the first windmill specifically for life in the West. The Halladay Windmill, which is still in use today, sits on a tall wooden tower, has more than a dozen 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 for their farm or ranch. They could power lights, 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 one of the fastest growing sources of electricity in the world—increasing in capacity by 258 percent since 2008.
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 gear box. These parts work together to convert the wind’s kinetic energy into motion energy that generates electricity. The process works like this:

1. The moving air is caught by the blades and spins the rotor.
2. The rotor is connected to a low-speed shaft. When the rotor spins, the shaft turns.
3. The low-speed shaft is connected to a gear box. Inside the gear box, 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 in an area where winds blow consistently at a minimum of 8-16 miles per hour (3.5-7 meters per second). Faster winds generate more electricity. High above ground, winds are stronger and steadier.

There are many different types of wind turbines with different tower and hub heights, as well as varying blade designs and lengths. Wind turbines can be designed to optimize output for specific ranges of wind speed. Turbines typically can generate electricity when winds are between 7 and 55 mph (3-25 m/s). They operate most efficiently, however, when wind speeds fall between 18-31 mph (8-14 m/s).

Wind turbines also come in different sizes, based on the amount of electric 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. Most utility-scale turbines installed in the U.S. produce one to three megawatts of electricity, enough to power 300 to 900 homes. Large turbines are grouped together into wind farms, which provide bulk power to the electric grid.
Aerodynamics of Wind Turbine Blades

Why Turbine Blades Move

There are two important reasons why wind turbine blades are able to spin in the wind: Newton's Third Law and the Bernoulli Effect.

Newton's Third Law states that for every action, there is an equal and opposite reaction. In the case of a wind turbine blade, the action of the wind pushing air against the blade causes the reaction of the blade being deflected, or pushed. If the blade has no pitch (or angle), the blade will simply be pushed backwards (downhill). But since wind turbine blades are set at an angle, the wind is deflected at an opposite angle, pushing the blades away from the deflected wind. This phenomenon can be viewed on a simple, flat blade set at an angle. If you push the blade with your finger from the direction of the oncoming wind, the blade will deflect away from your finger.

Bernoulli’s Principle, or the Bernoulli Effect, tells us that faster moving air has lower pressure. Wind turbine blades are shaped so that the air molecules moving around the blade travel faster on the downwind side of the blade than those moving across the upwind side of the blade. This shape, known as an airfoil, is like an uneven teardrop. The downwind side of the blade has a large curve, while the upwind side is relatively flat. Since the air is moving faster on the curved, downwind side of the blade, there is low pressure on this side of the blade. This difference in pressure on the opposite sides of the blade causes the blade to be “lifted” towards the curve of the airfoil.

Understanding Wind

Wind turbine blades must be optimized to efficiently convert oncoming winds into motion energy to rotate the main driveshaft. But when designing turbine blades, the real wind is only one part of a larger equation. Good blades must also account for the apparent wind that is experienced as the blade passes through the air.

Imagine riding your bike on a day with a fresh breeze at your side. As you begin to ride and pick up speed, you feel this wind from the side, but also wind pushing back at you from the direction you are moving. When you stop riding, there is just the wind from the side again. This wind that is “created” as you are moving is known as headwind. The headwind, combined with the real wind, is known as apparent wind. A wind turbine blade experiences apparent wind as it passes through the air. This apparent wind is from a different direction than the “real” wind that has caused the blade to begin moving. Since the tips of large turbine blades may be moving through the air at speeds up to 322 km/h (200 mph), this apparent wind can be very significant!

Aerodynamics

Efficient blades are a key part of generating power from a wind turbine. The efficiency of a wind turbine blade depends on the drag, lift, and torque produced by the blade. These factors are affected by the size and shape of the blades, the number of blades, and the blade pitch.

Drag

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. Drag is a force that is working against the blades, causing them to slow down. Drag is always important when an object moves rapidly through the air or water. Airplanes, race cars, rockets, submarines, and wind turbine blades are all designed to have as little drag as possible.

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Imagine riding your bike down a big hill. To go faster, you might tuck your body to expose as little of it to the apparent wind as possible. This is a trick to reduce drag. Now imagine you have a big parachute strapped to your back when you ride down the hill. The parachute increases the drag significantly and this drag force slows you down. Drag increases with the area facing the wind. A large truck has a lot more drag than a motorcycle moving at the same speed. Wind turbine blades have to be streamlined so they can efficiently pass through the air. Changing the angle of the blades will change the area facing the apparent wind. This is why blade pitch angles of 10-20 degrees tend to have much less drag than greater angles.

Drag also increases with wind speed. The faster an object moves through the air, the more drag it experiences. This is especially important for wind turbine blades, since the blade tips are moving through the air much faster than the base of the blade. The shape and angle of wind turbine blades changes along the length of the blade to reduce drag at the blade tips.

**Reducing Drag on Wind Turbine Blades:**
1. Change the pitch—the angle of the blades dramatically affects the amount of drag.
2. Use fewer blades—each blade is affected by drag.
3. Use light-weight materials—reduce the mass of the blades by using less material or lighter material.
4. Use smooth surfaces—rough surfaces, especially on the edges, can increase drag.
5. Optimize blade shape—the tip of a blade moves faster than the base. Wide, heavy tips increase drag.

**Lift**

*Lift* is the aerodynamic force that allows airplanes and helicopters to fly. The same force applies to the blades of wind turbines as they rotate through the air. Lift opposes the force of drag, helping a turbine blade pass efficiently through air molecules. The main goal of a well-designed wind turbine blade is to generate as much lift as possible while minimizing drag.

The amount of lift a blade or wing can generate is determined by several factors—the shape of the blade, the speed of the air passing around the blade, and the angle of the blade relative to the apparent wind.

**Shape**

The airfoil shape of the blade helps to generate lift by taking advantage of the Bernoulli Effect. Wind turbine blade designers have experimented with many different airfoil shapes over the years in an effort to find the perfect shape that will perform well in a range of wind speeds. Even minor changes in this blade shape can dramatically affect the power output and noise produced by a wind turbine.

The airfoil profile (shape) of a turbine blade will actually change as you move down the length of the blade, generally getting flatter and narrower toward the tips of the blades. This is to optimize the lift and minimize drag.
Angle

The angle of the blades also greatly impacts how much lift is generated. On large wind turbines, the blade angle is constantly adjusted to give the blades the optimal angle into the apparent wind. The angle of the blade relative to the plane of rotation is known as the pitch angle. The angle of the blade relative to the apparent wind is called the angle of attack. The angle of attack is very important, but also complicated since it will change as the real wind speed changes and the speed of the blade (headwind) changes. On most airfoil blade shapes, an angle of attack of 10-15 degrees creates the most lift with the least drag.

Real wind turbine blades typically have a twisted pitch — meaning the blade angle is steeper at the root of the blade and flatter further away from the hub. Once again, this is due to the fact that the tips move so much faster through the air. By twisting the pitch, the blades are able to take advantage of a more ideal angle of attack down the length of each blade. The tips of a real turbine blade may have close to a 0 degree pitch angle, but this section of the blade generates a great deal of lift.

Torque

Torque is a force that turns or rotates something. When you use a wrench on a bolt or twist a screw loose with a screwdriver, you are generating torque. Torque is a lot like leverage. If you are trying to turn a wrench, sometimes you need a lot of leverage to loosen a tight bolt. Wind turbine blades are like big levers, but instead of your muscle turning them they use the force of the wind.

Torque is equal to the force multiplied by distance. This means that the longer your blades are, the more torque you can generate. For example, imagine someone trying to loosen a tight bolt. Pushing with all his might, he can exert 100 pounds of force. If his wrench was 1 foot long, he would be exerting 100 foot-pounds of torque. If he applied the same force to a 2 foot long wrench, he would be exerting 200 foot-pounds of torque on the bolt. This additional leverage makes it much easier to loosen the bolt.
**Gearing Up For More Power**

On a real wind turbine, the long blades give the turbine a lot of leverage to provide power to the generator. Utility scale large turbines often have large gear boxes that increase the revolutions per minute of the rotor by 80 or 100 times. This big gear reduction demands a lot of leverage from the blades. Think about riding your bicycle—when you shift into high gear it may be harder to pedal. A higher gear demands more torque.

Power output is directly related to the speed of the spinning drive shaft (revolutions per minute or rpm) and how forcefully it turns. A large wind turbine has a rotor with blades, a gear box, 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 gear box.

Inside the gear box, 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 revolutions per minute with a lot of torque. This large gear spins a smaller gear, with less torque, at about 1,500 revolutions per minute. 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 1,500 rpm gear and a 20 rpm gear is 75:1.

**Putting It All Together**

Increasing the torque generated by the blades often increases the drag they experience as they rotate. For example, longer blades will generate more torque and more drag. Increasing the blade pitch will generally increase the torque and increase the drag. Increasing the number of blades will generally give you more torque and more drag. For this reason, it is important to design blades to match the load application. If you are using a windmill to lift a bucket of weights, a slowly spinning rotor that generates lots of torque will be best. If you are using a turbine to light a string of LED bulbs wired in series, you will need a rotor that spins very rapidly with very little drag.
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 25-45 percent.

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. Most wind farms are owned by private companies and they sell the electricity to electric utility companies. Currently, the wind farm that generates the most electricity in the U.S. is Alta Wind Energy Center in Tehachapi, California. The farm’s 390 wind turbines produce 1,020 megawatts of electricity, which is enough to power more than 300,000 homes. Roscoe Wind Farm in Texas is also one of the country’s largest wind farms. It houses over 620 turbines, but has a smaller generating capacity of just over 780 MW. These two American wind farms are among the world’s largest.

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. Measuring the wind and obtaining construction permits requires the most time when building a wind farm.

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.

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 some of the U.S. lands with the best wind potential. About 917 megawatts 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 have a small impact on 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.

Texas produces the most electricity from wind energy in the United States, followed by Iowa and California. Combined, these three states produce almost 40 percent of the nation’s total electricity from wind energy.
Offshore Wind Farms

Because cool air from the water is always moving inland to take the place of warm air that has risen, the wind blows stronger and steadier over water than over 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. Offshore turbines produce more electricity than turbines on land, but they cost more to build and operate. Some challenges for offshore wind farms include the costs and difficulties involved with water-based construction and maintenance of parts.

Europe is currently leading the offshore wind industry with over 90% of global offshore wind installation. The United Kingdom, Denmark, China, Belgium, Sweden, Finland, Germany, the Netherlands, Norway, Japan, and Ireland all have offshore wind turbines.

The first offshore wind farm in the United States, the Deepwater Wind project, southeast of Block Island in Rhode Island, began construction in 2015 and was completed in 2016. The five turbine, 30-megawatt wind farm will come online late in 2016, and will have the ability to power roughly 17,000 homes per year, reducing the reliance on diesel-fired electricity generation and improving air quality for residents.

The Cape Wind project on Nantucket Sound, off the coast of Massachusetts, is another offshore wind project in the works for the U.S. The Cape Wind project was proposed to consist of 130 wind turbines with a capacity to produce 420 MW of electricity. The project, however, has stalled after a decade of legal and logistical concerns. Cape Wind still controls the leased area, but is required by the U.S. Courts to undergo further study of the offshore area before allowing construction to begin.

Small Wind Systems

Wind turbines are not only on wind farms or offshore, they can also be found on the property of private residences, small businesses, and schools. A typical home uses approximately 911 kilowatt-hours (kWh) of electricity each month. Many people are choosing to install small wind turbines to lower or eliminate their electricity bills.

Siting a small wind turbine is similar to siting a large wind turbine. Potential small wind users need to make sure that there is plenty of unobstructed wind. The tip of the turbine blades should be at least nine meters (30 feet) higher than the tallest wind obstacle. Sometimes this can be a little challenging for installing a residential wind turbine if local zoning laws have height limitations. The turbine also requires open land between the turbine and the highest obstacle. Depending on the size of the turbine, this may require a 70-150 meter (250–500 foot) radius. Specific siting recommendations can be obtained from the turbine manufacturer.

A Valuable Resource

Today, people use wind energy to make electricity. Wind is a renewable energy source because the wind will blow as long as the sun shines. Wind is a clean source of energy that causes no air or water pollution and wind is free. The Energy Information Administration forecasts that wind will be generating much more of the nation’s electricity in 2035. Wind has the potential to provide up to 20 percent of U.S. electricity.

One of the problems with wind energy is that it is dependent on the weather. When there is not enough, or too much wind, the turbines do not produce much electricity. In some areas, people are concerned that birds and bats might be injured flying into wind turbines. Some people do not like the sound made by spinning turbines and some think turbines affect their view of the landscape. Wind power is not the total answer to global energy needs, but it is a valuable part of the energy portfolio.
# Wind Energy Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>5000 BCE</td>
<td>Early Egyptians use wind to sail boats on the Nile River.</td>
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<tr>
<td>0</td>
<td>The Chinese fly kites during battle to signal their troops.</td>
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<tr>
<td>500-900 AD</td>
<td>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 grain and pump water.</td>
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<tr>
<td>700s</td>
<td>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 would 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.</td>
</tr>
<tr>
<td>1200s</td>
<td>Europeans begin to build windmills to grind grain. 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.</td>
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<tr>
<td>1300s</td>
<td>The Dutch invent the smockmill. The smockmill consists of a wooden tower with six or eight sides. The roof on top rotates to keep the sails in the wind.</td>
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<tr>
<td>1500s</td>
<td>The tower windmill is developed in Spain, Greece, southern Europe, and France.</td>
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<tr>
<td>1600s</td>
<td>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.</td>
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<tr>
<td>1700s</td>
<td>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.</td>
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<tr>
<td>1854</td>
<td>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.</td>
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<tr>
<td>1888</td>
<td>Charles F. Brush, a wealthy inventor and manufacturer of electrical equipment in Cleveland, OH, builds a giant windmill on his property. The windmill generates power for 350 incandescent 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.</td>
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<tr>
<td>Late 1880s</td>
<td>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.</td>
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<tr>
<td>1892</td>
<td>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.</td>
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<tr>
<td>1898-1933</td>
<td>The U.S. Weather Service sends kites aloft to record temperature, humidity, and wind speed.</td>
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<tr>
<td>1900s</td>
<td>Wilbur and Orville Wright design and fly giant box kites. These experiments lead them to invent the first successful airplane in 1903.</td>
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<tr>
<td>1920s</td>
<td>G.J.M. Darrieus, a French inventor, designs the first vertical-axis wind turbine.</td>
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<tr>
<td>1934-1943</td>
<td>In 1934, engineer Palmer Putman puts together a team of experts in electricity, aerodynamics, engineering, and weather to find a cheaper way to generate electric power on a large scale. In 1941, the first large-scale turbine in the United States begins operating. In 1941, the Smith-Putnam wind turbine is installed on Grandpa’s Knob, a hilltop in Rutland, VT. 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.</td>
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<tr>
<td>1945-1950s</td>
<td>After World War II ends in 1945, engineers decide to start the Smith-Putnam 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.</td>
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<tr>
<td>1971</td>
<td>The first offshore wind farm operates off Denmark’s coast.</td>
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<tr>
<td>Year</td>
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<tr>
<td>1973</td>
<td>The Organization of Petroleum Exporting Countries (OPEC) oil embargo causes the price of oil to rise sharply. High oil prices increase interest in other energy sources, such as wind energy.</td>
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<tr>
<td>1974</td>
<td>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, OH. Unfortunately, the design does not include a “teetering hub”—a feature very important for a two-bladed turbine to function properly.</td>
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<td>1978</td>
<td>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.</td>
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<tr>
<td>1980</td>
<td>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 percent and rewards businesses choosing to use renewable energy.</td>
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<tr>
<td>1980s</td>
<td>The first wind farms are built in California, as well as Denmark, Germany, and other European countries. Many wind turbines are installed in California in the early 1980s to help meet growing electricity needs and take advantage of incentives.</td>
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<tr>
<td>1983</td>
<td>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.</td>
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<tr>
<td>1984</td>
<td>A large vertical axis turbine, Project École, is built in Quebec, Canada. It is 110 meters high (360 ft.).</td>
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<tr>
<td>1985</td>
<td>By 1985, California wind capacity exceeds 1,000 megawatts, enough power to supply 250,000 homes. These wind turbines are very inefficient.</td>
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<tr>
<td>1988</td>
<td>Many of the hastily installed turbines of the early 1980s are removed and later replaced with more reliable models.</td>
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<tr>
<td>1989</td>
<td>Throughout the 1980s, Department of Energy funding for wind power research and development declines, reaching its lowest point in fiscal year 1989. More than 2,200 megawatts of wind energy capacity are installed in California—more than half of the world’s capacity at the time.</td>
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<tr>
<td>1992</td>
<td>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 delivered to the grid. 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 &amp; Electric, and Niagara Mohawk Power Company.</td>
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<tr>
<td>1994</td>
<td>Cowley Ridge in Alberta, Canada becomes the first utility-grade wind farm in Canada.</td>
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<td>1999-2000</td>
<td>Installed capacity of wind-powered electricity generating equipment exceeds 2,500 megawatts. Contracts for new wind farms continue to be signed.</td>
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<td>2003</td>
<td>North Hoyle, the largest offshore wind farm in the United Kingdom at that time, is built.</td>
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<td>2005</td>
<td>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, NJ, begins operating in December. It is the United States’ first coastal wind farm.</td>
</tr>
<tr>
<td>2006</td>
<td>The second phase of Horse Hollow Wind Energy Center is completed, making it the largest wind farm in the world at that time. It has a 735.5 megawatt capacity and is located across 47,000 acres of land in Taylor and Nolan Counties in Texas.</td>
</tr>
<tr>
<td>2008</td>
<td>The U.S. Department of Energy releases the 20% Wind Energy by 2030 report detailing the challenges and steps to having 20 percent of U.S. electricity produced by wind by the year 2030. The Emergency Economic Stabilization Act of 2008 provides a 30 percent tax credit to individuals installing small wind systems. The tax credit will be available through December 31, 2016.</td>
</tr>
<tr>
<td>2009</td>
<td>The Bureau of Ocean Energy Management, Regulation and Enforcement is given responsibility to establish a program to grant leases, easements, and rights-of-way for the development of offshore wind farms on the Outer Continental Shelf.</td>
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<tr>
<td>2010</td>
<td>Cape Wind on Nantucket Sound, MA receives final approval to build an offshore wind farm. Construction is still pending on this project.</td>
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<tr>
<td>2014</td>
<td>World wind energy capacity grew by 258% since 2008. China, Germany, and the United States are some of the largest installers of wind capacity.</td>
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<tr>
<td>2016</td>
<td>Deepwater Wind, off the coast of Block Island, Rhode Island, completed construction and will be the nation’s first offshore wind farm.</td>
</tr>
</tbody>
</table>
Question
• How reliable is an anemometer for calculating wind speed?

Materials
• 1 Pencil
• 5 Snow cone cups
• 2 Extra-long straws
• Masking tape
• Hole punch
• Scissors
• 1 Straight pin
• Marker
• Watch or stopwatch
• Ruler

Procedure
1. Cut the end off one cup to make a hole large 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 1.
3. Color one cup so that you can count the revolutions of the anemometer.
4. 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. Tape the cups to the straws.
5. Center the straws in the base cup. Slide the base 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.
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). Record the time at which each measurement is taken. Compare your results with those of other students in the class.

Conclusion
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?
<table>
<thead>
<tr>
<th>DATE</th>
<th>EVENT</th>
<th>HOW DID THIS EVENT COME TO BE?</th>
<th>WHAT HAPPENED AS A RESULT?</th>
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</tbody>
</table>
Wind Can Do Work

Question

• What is the maximum load that can be lifted all the way to the top of the windmill shaft?

Materials

• 4-Blade Windmill Template
• 1 Extra-long straw
• 1 Small straw
• Masking tape
• 50 cm String or thread
• Paper clips
• Large foam cup
• 2 Straight pins
• Binder clip
• Fan
• Ruler
• Hole punch
• Marker
• Scissors

Procedure

1. Turn the cup upside down.
2. Cut the longer straw so that you have an 8 cm length. Share the other portion with another student or group, or discard it. Tape this straw horizontally to the bottom of the cup (which is now the top) so that there is an equal amount of straw on both ends. Set this aside.
3. Prepare the windmill blades using the 4-Blade Windmill Template.
4. Measure 1.0 cm from the end of the small straw and make a mark. Insert a pin through the small straw at this mark. This is the front of the straw.
5. Slide the small straw through the windmill blades until the back of the blades rest against the pin. Gently slide each blade over the end of the straw. Secure the blades to the straw using tape.
6. Insert the small straw into the larger straw on the cup.
7. Tape the string to the end of the small straw. Tie the other end of the string to a paper clip. Make sure you have 30 cm of string from the straw to the top of the paper clip.
8. On the very end of the small straw near where the string is attached, fasten a binder clip in place for balance and to keep the string winding around the straw.
9. Slide the small straw forward to bring the binder clip next to the larger straw. Place a second straight pin through the small straw at the other end of the larger straw. This will keep the blades away from the cup while still allowing them to move and spin.
10. Place your windmill in front of the fan and observe. Record observations in your science notebooks.
11. Investigate: Keep adding paper clips one at a time to determine the maximum load that can be lifted all the way to the top. Record your data.

Conclusion

Draw a diagram of the system. Label the energy transformations that occurred in order for work to take place.

Extensions

• How could you change the design of your windmill to produce more work from the system?
• What variables can you change in this investigation? Create a new investigation changing one variable at a time.
Observing a Genecon

Question

- What is the difference between a motor and a generator?

Observations

1. How does the speed with which the handle turns affect the light?

2. How does reversing the direction you turn the handle affect the light?

3. What happens when the Genecon is connected to a battery?

4. What happens when the Genecon is attached to the model turbine?

5. How does the speed of the fan affect the Genecon?

Conclusion

1. Define generator and explain how a Genecon is a generator.

2. Define motor and explain how a Genecon is a motor.
Measuring Electricity

Included in the kit are three tools to measure electricity—two multimeters and one voltmeter. The multimeter allows you to measure current, resistance, and voltage, and displays the reading numerically. The voltmeter measures voltage only, but displays a visual reading as higher electrical outputs illuminate more lights.

When using either meter it should be noted that some measurements will never "stay still" at a single repeatable value. This is the nature of the variables being monitored in some circumstances. For example, if you were to measure the resistance between your two hands with the ohmmeter setting on the multimeter (megohm range—millions of ohms), you would find that the values would continuously change. How tightly you squeeze the metal probes and how "wet" or "dry" your skin is can have a sizable effect on the reading that you obtain. In this situation you need a protocol or standardized method to allow you to record data.

We recommend that you discuss with your class the variability of measurement and let them come up with a standard for collecting data. They may decide to go with the lowest reading, the highest reading, or the reading that appears most frequently in a certain time period.

Digital Multimeter

Visual Voltmeter

Directions:

DC VOLTAGE
1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to highest setting on DC VOLTAGE scale (1000).
3. Connect leads to the device to be tested using the alligator clips provided.
4. Adjust ROTARY SWITCH to lower settings until a satisfactory reading is obtained.
5. With the wind turbine, usually the 20 DCV setting provides the best reading.

DC CURRENT (must include a load in the circuit)
1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to 10 ADC setting.
3. Connect leads to the device to be tested using the alligator clips provided.

Note: The reading indicates DC AMPS; a reading of 0.25 amps equals 250 mA (milliamps).

NOTES:
- If the "Reverse Polarity" light flashes, switch the wires in the "GND" and "V+ Input" locations.
- The voltmeter's lowest reading is 0.25 volts. If you do not see any lights, connect the turbine to the multimeter for smaller readings.
Basic Measurement Values in Electronics

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>VALUE</th>
<th>METER</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Voltage (the force)</td>
<td>Voltmeter</td>
<td>volt</td>
</tr>
<tr>
<td>I</td>
<td>Current (the flow)</td>
<td>Ammeter</td>
<td>ampere</td>
</tr>
<tr>
<td>R</td>
<td>Resistance (the anti-flow)</td>
<td>Ohmmeter</td>
<td>Ohm</td>
</tr>
</tbody>
</table>

1 ampere = 1 coulomb/second

1 coulomb = 6.24 x 10^{18} electrons (about a triple axle dump truck full of sand where one grain of sand is one electron)

Prefixes for Units

- **Smaller**
  - (m)illi x 1/1 000 or 0.001
  - (µ) micro x 1/1 000 000 or 0.000 001
  - (n)ano x 1/100 000 000 or 0.000 000 001
  - (p)ico x 1/1 000 000 000 000 or 0.000 000 000 001

- **Bigger**
  - (k)ilo x 1,000
  - (M)ega x 1,000,000
  - (G)iga x 1,000,000,000

Formulas for Measuring Electricity

\[ V = I \times R \]
\[ I = \frac{V}{R} \]
\[ R = \frac{V}{I} \]

- **Series Resistance (Resistance is additive)**
  \[ R_T = R_1 + R_2 + R_3 + \ldots + R_n \]

- **Parallel Resistance (Resistance is reciprocal)**
  \[ \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n} \]

Note: ALWAYS convert the values you are working with to the "BASE unit." For example, don’t plug kiloohms (kΩ) into the equation—convert the value to ohms first.
1. Exploring Blade Pitch

**Question**

How does the blade’s pitch (angle) affect the turbine’s electrical output?

**Hypothesis**

Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because ...

**Independent Variable:** Blade Pitch  
**Dependent Variable:** Electrical Output  
**Controlled Variables:**

**Materials**

- Poster board  
- Dowels  
- Scissors  
- Masking tape  
- Hub  
- Protractor  
- Turbine testing station (turbine tower, multimeter, fan)  
- Benchmark Blade Template

**Procedure**

1. Using the benchmark blade template, make three blades out of poster board. Space them evenly around the hub.
2. Slip the protractor around the dowel. Set the blades to a pitch of 90 degrees.
3. Put your hub on the turbine tower and observe the results. Record the data.
4. Set your blades to a new pitch and test again. This is your second trial. Record your data.
5. Repeat Step 4 at least once more to try to find the optimum pitch for the greatest electrical output.

**Data Table**

<table>
<thead>
<tr>
<th>PITCH</th>
<th>ELECTRICAL OUTPUT (VOLTAGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIAL 1</td>
<td>90 DEGREES</td>
</tr>
<tr>
<td>TRIAL 2</td>
<td></td>
</tr>
<tr>
<td>TRIAL 3</td>
<td></td>
</tr>
</tbody>
</table>

**Graph Data**

The manipulated variable is written on the X axis (horizontal) and the responding variable is written on the Y axis (vertical).

**Conclusion**

Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain which blade pitch you will proceed with for your next investigations and why.

*Note: The pitch you found to be optimal for the greatest electrical output will now be a controlled variable. In future explorations you will continue to use this pitch as you investigate.*
2. Exploring Number of Blades

Question

• How do the number of blades on a turbine affect electrical output?

Hypothesis

Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because ...

Independent Variable: Number of Blades
Dependent Variable: Electrical Output
Controlled Variables: 

Materials

• Benchmark blades
• Poster board
• Dowels
• Scissors
• Masking tape
• Hub
• Turbine testing station
• Protractor

Procedure

1. Decide how many blades you will be testing and make enough blades for the maximum number you will be testing.
2. In the data table, put down the greatest electrical output from the blade pitch investigation of the three benchmark blades.
3. Put the number of blades you want to test into the hub. They should have the same pitch as in the previous investigation.
4. Put your hub onto the turbine tower and test the number of blades. Record the results as trial 1.
5. Repeat steps 3-4 at least two more times to try to find the optimum number of blades for the greatest electrical output.

Data Table

<table>
<thead>
<tr>
<th>NUMBER OF BLADES</th>
<th>ELECTRICAL OUTPUT (VOLTAGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BENCHMARK</td>
<td>3 BLADES</td>
</tr>
<tr>
<td>TRIAL 1</td>
<td></td>
</tr>
<tr>
<td>TRIAL 2</td>
<td></td>
</tr>
<tr>
<td>TRIAL 3</td>
<td></td>
</tr>
</tbody>
</table>

Graph Data

The manipulated variable is written on the X axis (horizontal) and the responding variable is written on the Y axis (vertical).

Conclusion

Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain how many blades are ideal for a turbine.

Note: The number of blades with the greatest electrical output should become the benchmark blades for your next investigation.
3. Exploring Surface Area

Question

How does the surface area of a turbine blade affect electrical output?

Hypothesis

Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because ...

Independent Variable: ____________________________________________________________________________

Dependent Variable: ____________________________________________________________________________

Controlled Variables: __________________________________________________________

Materials

- Benchmark blades
- Poster board
- Dowels
- Scissors
- Masking tape
- Hub
- Turbine testing station
- Protractor
- Ruler

Procedure

1. Calculate the surface area of the benchmark blade. In the data table, record the surface area and the greatest electrical output from your previous investigation of the benchmark blades. The formula for finding the area of a trapezoid is one half the sum of both bases, multiplied by the height or, \[ a = \frac{1}{2} (b_1 + b_2) \cdot h \].

2. Keep the same shape as the benchmark blade, but change the length and/or width. This will change the surface area of the blade.

3. Make your new blades. You should have the same number of blades that you found had the best results in your previous investigation.

4. Find the surface area for each of your new blades.

5. Put your blades into the hub and onto the turbine tower. Test for electrical output and record data.

6. Repeat steps 2-5 at least two more times to try to find the optimum surface area for the greatest electrical output.

Data Table

<table>
<thead>
<tr>
<th>SURFACE AREA</th>
<th>ELECTRICAL OUTPUT (VOLTAGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BENCHMARK</td>
<td></td>
</tr>
<tr>
<td>TRIAL 1</td>
<td></td>
</tr>
<tr>
<td>TRIAL 2</td>
<td></td>
</tr>
<tr>
<td>TRIAL 3</td>
<td></td>
</tr>
</tbody>
</table>

Graph Data

The manipulated variable is written on the X axis (horizontal) and the responding variable is written on the Y axis (vertical).

Conclusion

Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain how surface area affects the electrical output. Why do you think this is?

Note: The blades with the surface area that achieved the greatest electrical output should become the optimum blades for your next investigation.
4. Exploring Mass

Question

How does adding mass to the blades affect the turbine’s electrical output?

Hypothesis

Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because ...

Independent Variable: _____________________________________
Dependent Variable: ______________________________________
Controlled Variables: _____________________________________

Materials

- Optimum blades from previous investigation
- Pennies (or other mass)
- Masking tape
- Turbine testing station
- Protractor

Procedure

1. In the data table, record your results from your previous investigation on the row with zero grams.
2. Tape one penny near the base of each blade, an equal distance from the center of the hub.
3. Test and record the electrical output. Repeat, adding another penny. If adding mass increases the output, add more pennies one at a time until you determine the ideal mass for the greatest electrical output.
4. Distribute the pennies on the blades at different distances from the hub until you determine the optimal distribution of mass for the greatest electrical output.

Data Table

<table>
<thead>
<tr>
<th>ADDITIONAL MASS</th>
<th>ELECTRICAL OUTPUT (VOLTAGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPTIMUM</td>
<td>0 GRAMS</td>
</tr>
<tr>
<td>TRIAL 1</td>
<td></td>
</tr>
<tr>
<td>TRIAL 2</td>
<td></td>
</tr>
<tr>
<td>TRIAL 3</td>
<td></td>
</tr>
</tbody>
</table>

Graph Data

The manipulated variable is written on the X axis (horizontal) and the responding variable is written on the Y axis (vertical).

Conclusion

Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain how mass and mass distribution affect the electrical output. Why do you think this is?

Note: The blades with the mass that achieved the greatest electrical output should become the optimum blades or be considered for any further investigations, such as gear ratios and aerodynamics.
Blade Aerodynamics Graphic Organizer

Questions

• How do drag, lift, and torque influence the efficiency of a wind turbine?
• Why do turbine blades move in the wind?

Define apparent wind:
Blade Aerodynamics

**Question**

- How do drag, lift, and torque influence the efficiency of a wind turbine?

**Observations**

How does the shape of the blade in this demonstration differ from your original benchmark blades?

How many airfoil blades provide the optimal electrical output? Compare this to your findings from the previous explorations, and explain any similarity or difference.

How is blade pitch affected when using an airfoil blade? Compare to your findings from previous explorations, and explain any similarity or difference.

Describe how mass and surface area may be affected when using airfoil blades. Is there a shape of blade that works best? Cite evidence from previous investigations in your answer.

**Conclusion**

1. Would you choose to use an airfoil shape if designing the optimum blade for efficiency? Why or why not?

2. Describe what your plan might look like if you were to design the optimum blades for an actual wind turbine to be placed at your school.
Designing Optimum Blades

**Challenge**
The engineers at Wind for Tomorrow Turbine Co. want help to optimize their turbine blades for higher energy output. They are accepting bids from companies to design blades that more effectively convert kinetic energy than their current blade design.

**Explore**
Using data from your previous investigations and data from other groups, explore ideas for the best blade design.

**Make a Plan**
In your science notebook, sketch your design, list the materials you will need, and detail the steps you will take to make the blades. Construct blades that will give you the greatest electrical output.

**Data**
Test and record the electrical output from your new blades. Compare your data to the benchmark blades in Blade Investigation #1 and your optimum blades in Blade Investigation #4.

**Data Table**

<table>
<thead>
<tr>
<th>BLADES</th>
<th>ELECTRICAL OUTPUT (VOLTAGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INVESTIGATION #4 OPTIMUM BLADES</td>
<td></td>
</tr>
<tr>
<td>AIRFOIL TEST BLADES</td>
<td></td>
</tr>
<tr>
<td>1ST DESIGN</td>
<td></td>
</tr>
<tr>
<td>2ND DESIGN</td>
<td></td>
</tr>
</tbody>
</table>

**Analysis**
How did the output of your new blades compare to the output of the airfoil blades and the optimum blades from the #4 investigation? In your science notebook, explain why your blade design is more or less effective than the comparison blades.

**New Plan**
Using your data from the data table above, draw and describe specific changes you will make to your blade design to increase its electrical output and why you will make these changes.

**Redesign**
Using your changes, alter the design of your blades, test, and record your data.

**Analysis**
How did the outcome of your re-designed blades compare to the output of the airfoil blades, the optimum blades, and your first design? Explain your results.

**Report**
Write a report to the Wind for Tomorrow Turbine Co. detailing your best blade design. Use data to explain why the company should or should not go with your design.
Investigating Gear Ratios

**Question**

How do different gear ratios within the gear box affect the electrical output of a turbine?

**Hypothesis**

Make a hypothesis to address the question using the following format: If (manipulated variable) then (responding variable) because ...

**Independent Variable:**

**Dependent Variable:**

**Controlled Variables:**

- Multimeter
- Fan
- Turbine
- Gears
- Optimum blades (from the previous investigation or investigation #4)
- Watch with second hand
- Protractor

**Materials**

**Procedure**

1. In the table below, record your results from the previous investigation where you used the turbine with the standard gear ratio of 64:8 (64-tooth gear and 8-tooth gear).
2. Configure a new gear ratio (for example 32:8) with the turbine, making sure that you minimize all other variables (keep everything else the same). You have the option of three gear ratios (64:8, 32:8 or 16:8 – additional adjustment is required for 16:8 gear ratio).
3. Turn the fan on and record the voltage output every 20 seconds for one minute. Record your results below and find the average.
4. Test different gear ratios to compare their effect on voltage output.

**Data Table**

<table>
<thead>
<tr>
<th></th>
<th>20 SECONDS</th>
<th>40 SECONDS</th>
<th>60 SECONDS</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STANDARD GEAR, BEST RESULTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GEAR RATIO 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GEAR RATIO 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GEAR RATIO 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusion**

1. Were the different gear ratios giving you consistent results? Why or why not?
2. What did you notice about the different gear ratios?
3. What did you notice about rotations per minute?
Calculating Wind Power

Question

How do you calculate wind power?

Materials

- Fan
- Wind gauge
- Turbine with benchmark blades
- Meter stick

Formula

Power = \( \frac{1}{2} \rho AV^3 \)

where \( \rho = \) air density (\( \rho = 1.2 \text{ kg/m}^3 \) at standard ambient temperature and pressure); \( A = \) swept area (\( A = \pi r^2 \); \( \pi = 3.1416 \)); \( V = \) velocity

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

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 (m/s).

\( 1 \text{ mile} = 1609.344 \text{ meters} \)

Wind Velocity at Low Speed - 1 meter: \( \underline{\text{_________ mph}} = \underline{\text{_________ m/s}} \)

Wind Velocity at High Speed - 1 meter: \( \underline{\text{_________ mph}} = \underline{\text{_________ m/s}} \)

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

Wind Power at Low Speed - 1 meter: \( \underline{\text{_________ W}} \)

Wind Power at High Speed - 1 meter: \( \underline{\text{_________ W}} \)

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

Wind Power at \( \underline{\text{_________ m}} \) (distance A) on Low Speed: \( \underline{\text{_________ W}} \)

Wind Power at \( \underline{\text{_________ m}} \) (distance A) on High Speed: \( \underline{\text{_________ W}} \)

Wind Power at \( \underline{\text{_________ m}} \) (distance B) on Low Speed: \( \underline{\text{_________ W}} \)

Wind Power at \( \underline{\text{_________ m}} \) (distance B) on High Speed: \( \underline{\text{_________ W}} \)

Conclusion

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

2. Explain the relationships between the different variables and the power produced.
Role Group: ________________________________

<table>
<thead>
<tr>
<th>QUESTION 1</th>
<th>QUESTION 2</th>
<th>QUESTION 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESSENTIAL DETAILS</th>
<th>ESSENTIAL DETAILS</th>
<th>ESSENTIAL DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What is important to understand about this?
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>absorb</td>
<td>to take in or hold</td>
</tr>
<tr>
<td>aerodynamics</td>
<td>the study of the motion of air and its interactions with solid objects</td>
</tr>
<tr>
<td>air density</td>
<td>mass per unit volume of Earth's atmosphere</td>
</tr>
<tr>
<td>airfoil</td>
<td>the shape of a blade or wing from a side or cross-sectional view</td>
</tr>
<tr>
<td>albedo</td>
<td>the fraction of solar radiation reflected from the Earth back into space; average reflectivity of the Earth's surface</td>
</tr>
<tr>
<td>anemometer</td>
<td>instrument used for measuring wind speed</td>
</tr>
<tr>
<td>anion</td>
<td>an atom that has gained electrons to become a negatively charged ion</td>
</tr>
<tr>
<td>atom</td>
<td>the most basic unit of matter</td>
</tr>
<tr>
<td>baseload</td>
<td>minimum power a utility must provide to consumers</td>
</tr>
<tr>
<td>Bernoulli's Principle</td>
<td>the pressure in a fluid is reduced as the flow speed increases</td>
</tr>
<tr>
<td>Betz Limit</td>
<td>the maximum amount of kinetic energy of the wind that can be converted into mechanical or motion energy</td>
</tr>
<tr>
<td>blade</td>
<td>individual moving component of a turbine that is responsible for transferring energy</td>
</tr>
<tr>
<td>cation</td>
<td>an atom that has lost electrons to become a positively charged ion</td>
</tr>
<tr>
<td>Coriolis Effect</td>
<td>the deflection of moving objects due to the rotation of the Earth</td>
</tr>
<tr>
<td>current</td>
<td>flow of electric charge through a conductor; measured in amperes or amps</td>
</tr>
<tr>
<td>cyclone</td>
<td>winds that rotate rapidly inward to areas of lower atmospheric pressure, often associated with severe weather</td>
</tr>
<tr>
<td>doldrums</td>
<td>an area of calm where the trade winds converge near the Equator</td>
</tr>
<tr>
<td>drag</td>
<td>a mechanical force that acts on a solid object interacting with a fluid, typically slowing down a moving item or system</td>
</tr>
<tr>
<td>efficiency</td>
<td>the ratio of energy delivered by a machine to the energy supplied for its operation; often refers to reducing energy consumption by using technologically advanced equipment without affecting the service provided</td>
</tr>
<tr>
<td>electric grid</td>
<td>network of power stations, power lines, and transformers used to deliver electricity from generation to consumers</td>
</tr>
<tr>
<td>electricity</td>
<td>a form of energy created by the movement of electrons</td>
</tr>
<tr>
<td>electromagnetism</td>
<td>the interaction of forces occurring between electrically charged particles that can create an electric field or magnetic field</td>
</tr>
<tr>
<td>electron</td>
<td>very tiny, negatively charged subatomic particle that moves around the nucleus of the atom</td>
</tr>
<tr>
<td>element</td>
<td>most pure form of all matter; all matter is made of elements or combinations of elements</td>
</tr>
<tr>
<td>energy level</td>
<td>area where electrons can be found; describes the probable amount of energy in the atom</td>
</tr>
<tr>
<td>front</td>
<td>a term used when discussing weather describing the boundary lines between masses of air with different densities; often associated with changes in wind speed</td>
</tr>
<tr>
<td>gear box</td>
<td>device used in wind turbines to convert the slow rotation of the blades and rotor to a faster rotation in order to produce electricity</td>
</tr>
<tr>
<td>gear ratio</td>
<td>relationship between large and small gears in a generator</td>
</tr>
<tr>
<td>generator</td>
<td>a device that produces electricity by converting motion energy into electrical energy with spinning coils of wire and magnets</td>
</tr>
<tr>
<td>generation</td>
<td>refers to the creation of electric power by a generator</td>
</tr>
<tr>
<td>jet stream</td>
<td>a narrow current of air that rapidly moves through the atmosphere and creating boundaries at areas with differences in temperature; caused by Earth's rotation and solar radiation</td>
</tr>
<tr>
<td>katabatic wind</td>
<td>a wind that carries high-density cooler air from higher elevations to lower elevations down a slope, often called a mountain wind or fall wind</td>
</tr>
<tr>
<td>land breeze</td>
<td>a wind that blows from land toward the ocean in the evening, caused by different cooling rates of water and land surfaces</td>
</tr>
<tr>
<td>lift</td>
<td>a force that is perpendicular to the oncoming flow; allows objects to fly; opposes drag</td>
</tr>
</tbody>
</table>
Load

Magnet: A material with pairs of non-cancelling, spinning electrons that line up to form a magnetic field; magnetic materials are attracted to each other.

Magnetic Field: The area of force surrounding a magnet.

Megawatt: Standard unit of measurement for bulk electricity in power plants; 1 megawatt (MW) = 1 million watts.

Nacelle: The housing where all of the generating components are found within a turbine.

Neutron: A subatomic particle with no electric charge, found in the nucleus of the atom.

Newton's Laws of Motion: Laws that govern the motion of all items when a force is applied.

Nonrenewable Energy Sources: Sources of energy with limited supply due to their inability to be renewed or produced in a short amount of time.

Nucleus: The center of an atom, composed of protons and neutrons and houses the majority of the atom's mass.

Peak Demand: A period where many customers want electricity at the same time; often takes place during the day; utilities need to generate additional power to balance loads.

Pitch: The angle of the blade on a turbine, can be adjusted to reduce drag.

Polar Easterlies: Dry, cold winds that begin in the east and flow in a westerly direction away from the poles.

Prevailing Westerlies: Winds that blow from west to east and occur in temperate zones of the Earth.

Proton: A subatomic particle with a positive electric charge, found in the nucleus of an atom.

Radiant Energy: Energy that travels in electromagnetic waves like light or x-rays.

Reflect: To cast or bend back from a surface, experienced by radiant energy, thermal energy, and sound energy.

Renewable Energy Sources: Sources of energy with a more constant supply because they are replenished in a short amount of time.

Rotor Hub: The structure connecting the blades of the turbine to the generator shaft.

Sea Breeze: A wind that blows from the ocean to land during the day, caused by different cooling rates of water and land surfaces.

Secondary Energy Source: Often called an energy carrier, secondary energy sources requires another source, like coal, to be converted for creation; electricity and hydrogen are examples.

Siting: The process of choosing a location for a wind turbine or farm.

Smart Grid: A computer-based remote control and automated system for electricity delivery that includes two-way interaction between the generation facilities, utilities, and consumers.

Specific Heat: Amount of thermal energy required to raise the temperature of one gram of a substance by one Celsius degree.

Stable: An electron configuration when the outer-most energy level of an atom is full.

Thermal Energy: Internal energy within substances, movement or vibration of molecules.

Torque: The tendency of a force to rotate an object about its axis or pivot, a twist.

Tower: Structural support of the turbine.

Trade Wind: Warm, steady easterly breeze flowing towards the Equator in tropical latitudes.

Transformer: A device that changes the voltage of electricity.

Transmission: The movement or transfer of electricity via power lines.

Transmission Line: Power lines that carry electricity at higher voltages long distances.

Tunnel Effect: When air becomes compressed in narrow spaces and its speed increases.

Turbine: A machine of blades that converts kinetic energy of a moving fluid to mechanical power.

Turbulence: An irregular motion within a moving fluid.

Valley Wind: A wind that blows up the slope of a mountain allowing cooler air to sweep into the valley.

Voltage: A measure of the pressure (or potential difference) under which electricity flows through a circuit.

Watt: Unit of measurement of electric power.

Wind: Moving air created by uneven heating of Earth's surface.

Wind Shear: A change in wind speed and/or direction along a straight line or within a short distance.

Wind Turbine: A system that converts motion energy from the wind into electrical energy.

Wind Vane: An instrument used to show the direction of the wind.
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