# Student Informational Text

*WIND ENERGY*

## Wind

**Wind** is moving air. You cannot see air, but it is all around you. You cannot see the wind, but you know it is there.

You hear leaves rustling in the trees. You see clouds moving across the sky. You feel cool breezes on your skin. You witness the destruction caused by strong winds from storms such as tornadoes and hurricanes. Each of these examples of wind demonstrate that wind has energy.

Wind resources can be found across the country. Science and technology are providing more tools to accurately predict when and where the wind will blow. This information is allowing people to use wind energy on small and large scales. Electricity from wind energy is an increasingly important part of the United States' energy portfolio.

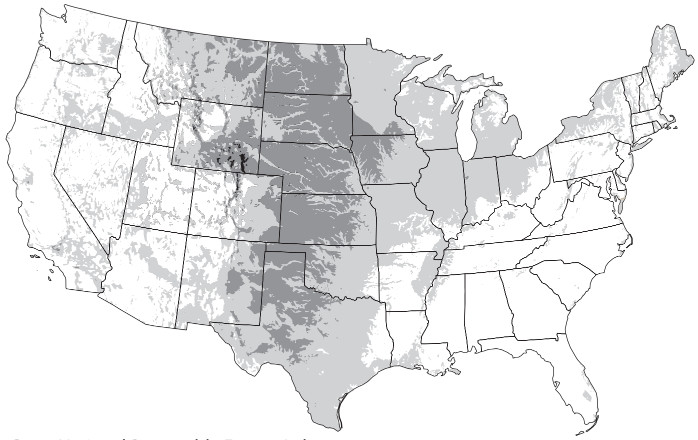
## The Beaufort Scale

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.

### Average Wind Speed at 80 Meters Altitude

- Faster than 9.5 m/s (faster than 21.3 mph)
- 7.6 to 9.4 m/s (17 to 21.2 mph)
- 5.6 to 7.5 m/s (12.5 to 16.9 mph)
- 0 to 5.5 m/s (0 to 12.4 mph)



Data: National Renewable Energy Laboratory

**BEAUFORT SCALE OF WIND SPEED**

| BEAUFORT NUMBER | NAME OF WIND | LAND CONDITIONS | WIND SPEED (MPH) |
|---|---|---|---|
| 0 | Calm | Smoke rises vertically | Less than 1 |
| 1 | Light air | Direction of wind shown by smoke drift but not by wind vanes | 1 - 3 |
| 2 | Light breeze | Wind felt on face, leaves rustle, ordinary wind vane moved by wind | 4 - 7 |
| 3 | Gentle breeze | Leaves and small twigs in constant motion, wind extends light flag | 8 - 12 |
| 4 | Moderate breeze | Wind raises dust and loose paper, small branches move | 13 - 18 |
| 5 | Fresh breeze | Small trees and leaves start to sway | 19 - 24 |
| 6 | Strong breeze | Large branches in motion, whistling in wires, umbrellas used with difficulty | 25 - 31 |
| 7 | Near gale | Whole trees in motion, inconvenient to walk against wind | 32 - 38 |
| 8 | Gale | Twigs break from trees, difficult to walk | 39- 46 |
| 9 | Strong gale | Slight structural damage occurs, shingles and slates removed from roof | 47 - 54 |
| 10 | Storm | Trees uprooted, considerable structural damage occurs | 55 - 63 |
| 11 | Violent storm | Widespread damage | 64- 72 |
| 12 | Hurricane | Widespread damage, devastation | Greater than 72 |

Source: National Oceanic and Atmospheric Administration

## Physics of Wind

The energy in wind comes from the sun. When the sun shines, some of its light (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, due to the tilt of the Earth's axis.

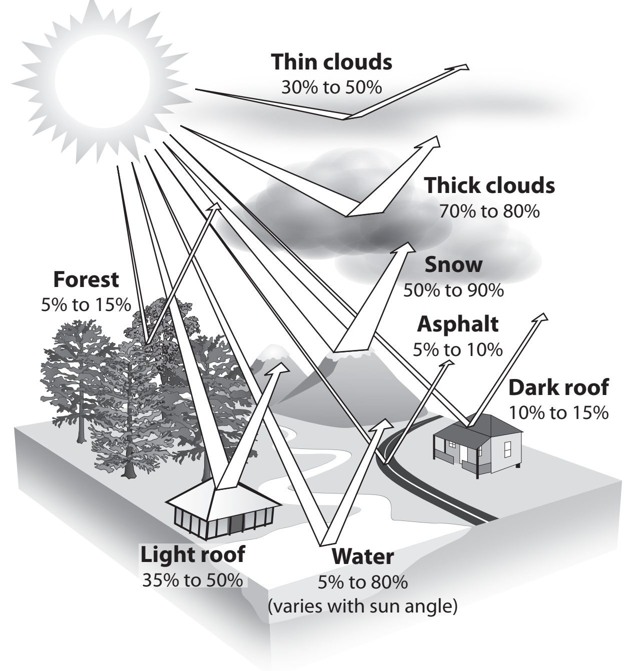
Some of the Earth's surfaces absorb more radiant energy than others. Some parts reflect more of the sun's rays back into the air. The fraction of light striking a surface that gets reflected is called **albedo**.

Some types of land absorb more radiant energy than others. Dark forests absorb a good amount of sunlight, while light desert sands reflect a good amount of sunlight. Land areas usually absorb more energy than water in lakes and oceans.

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

The air over the Equator gets warmer than the air over the poles. The air over the desert gets warmer than the air over 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.

## Albedo

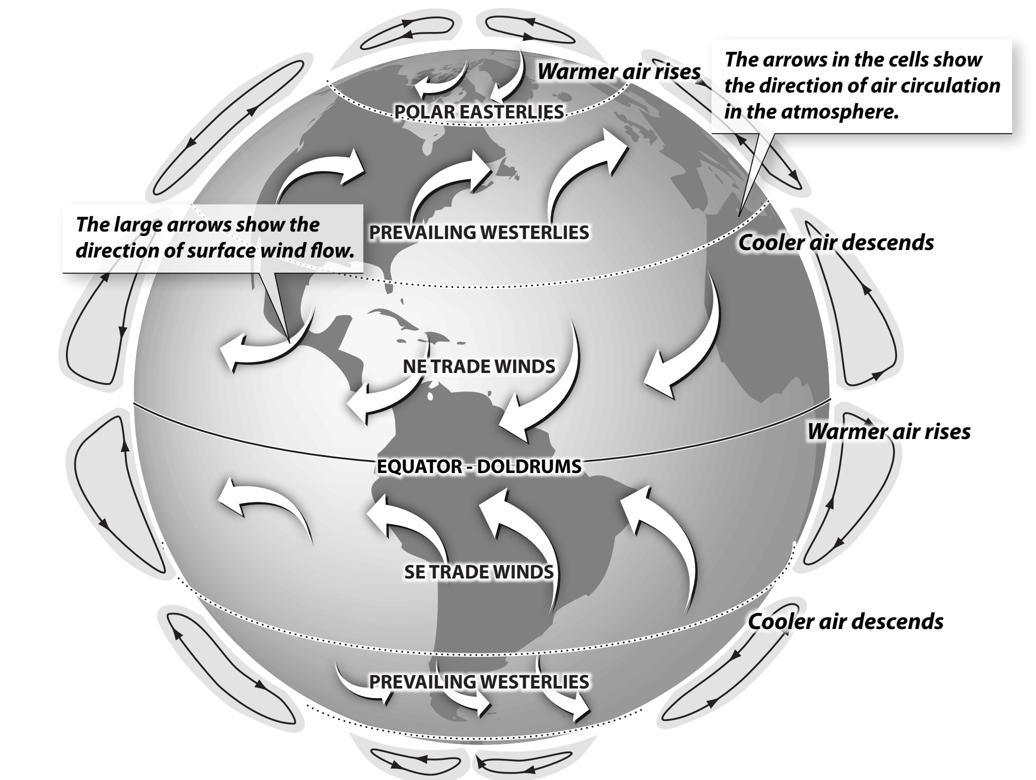


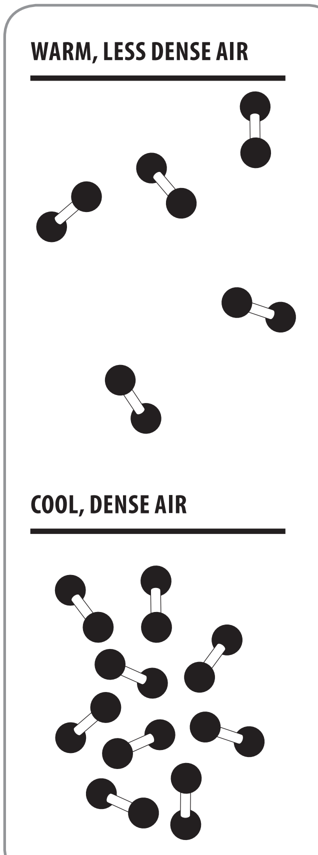

**The Earth's surface and objects reflect different amounts of sunlight.**

## Global Wind Patterns

The area near the Earth's Equator receives the sun's direct rays. The air over the surface warms and rises. The warmed air moves north and south about 30 degrees latitude, and then begins to cool and sink back to Earth.

## Global Wind 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 tomorrow.

### ▪ Polar Easterlies

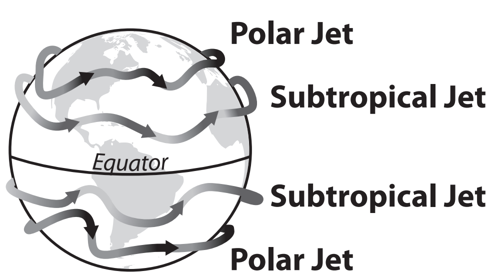
At about 60 degrees latitude in both hemispheres, the prevailing westerlies join with **polar easterlies**. The polar easterlies form when the air over the poles cools. This cool air sinks and spreads over the surface. As the air flows away from the poles, it curves to the west by the Coriolis Effect.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

### ▪ 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.

## Jet Streams




## Local Winds

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

### ▪ 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** (kat-*uh*-bat-ik).

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.

**MOUNTAINS AND VALLEYS**

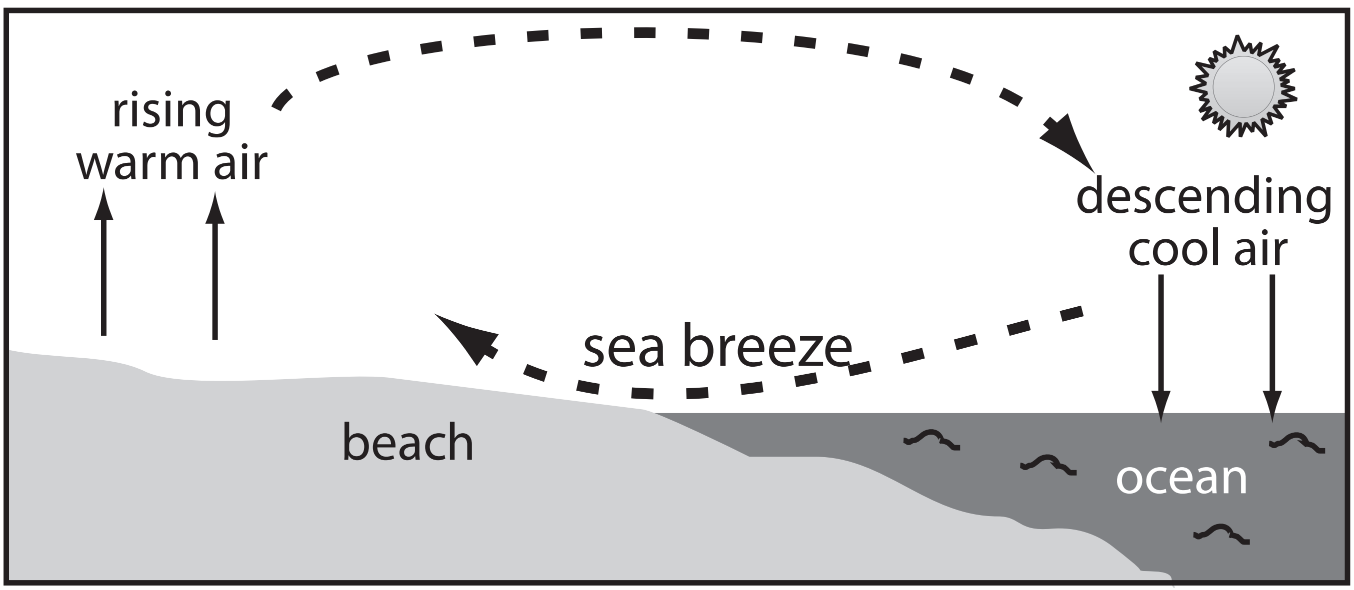
### ▪ Sea and Land Breezes

During the day, the sun heats both land and water, but not to the same temperature. Water reflects some of the light energy while land absorbs it. It takes more energy to heat water than it does land because they have different thermal properties. When the sun shines, the land heats faster than the water. Land also gives up its heat faster than the water at night when the sun is not shining.

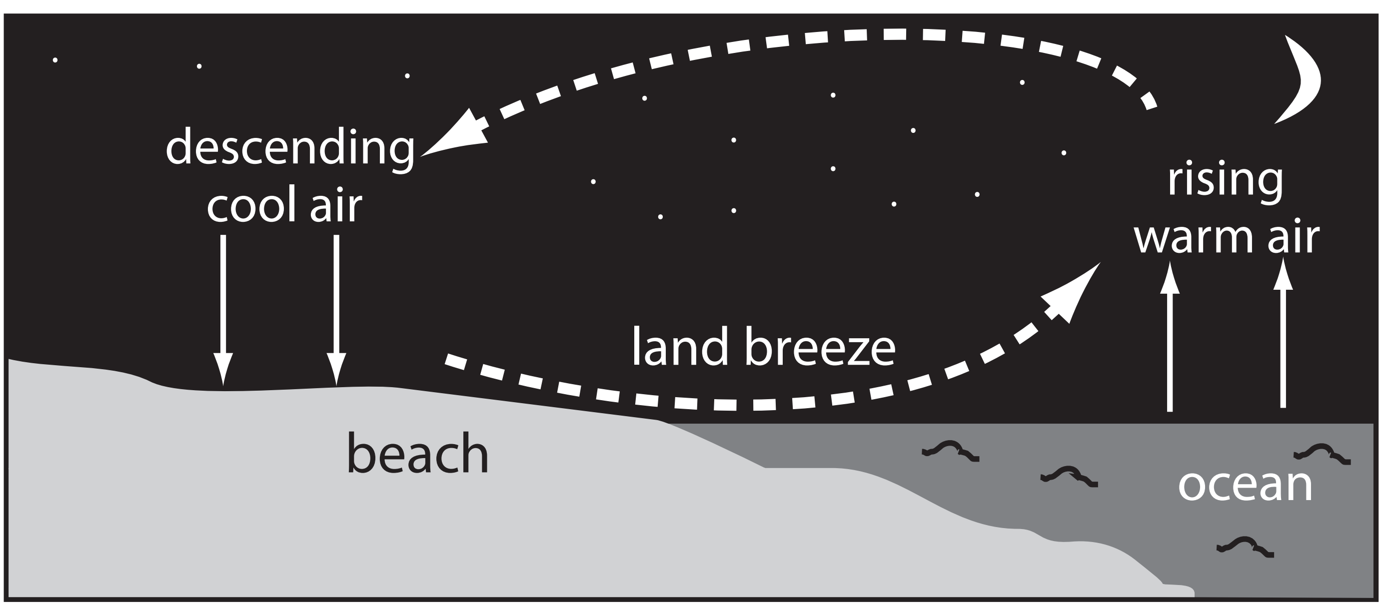
Since land changes temperature faster than water during the day, the air above land becomes warmer faster than the air above water. The heated air above land rises, creating an area of low pressure. The air above the water is cooler, creating an area of higher pressure. The cooler air over the water moves to the area of low pressure over land. This is called a **sea breeze** because the breeze is coming from the sea.

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

**Sea Breeze**




**Land Breeze**



# Monitoring Wind

## Wind Direction

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

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

## Wind Velocity

Wind speed is important because the amount of electricity that wind turbines can generate is determined in large part by wind speed, or velocity.

A doubling of wind velocity from the low range to optimal range of a turbine can result in eight times the amount of power available in the wind. Most, but not all, of this additional power is transformed into increased electrical output by the turbine. (Not all of the power can be converted due to energy conversion losses.) This is a huge difference and helps wind companies decide where to site wind turbines.

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

**Power = ½ ρAV³**

$$\text{Power} = \tfrac{1}{2}\rho A V^3$$

**Watts = ½ (kg/m³) x (m²) x (m/s)³**

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

ρ = air density; 1.2 kg/ $m^3$ at standard ambient temperature and pressure

A = swept area ($A = \pi r^2$)

V = velocity

r = radius

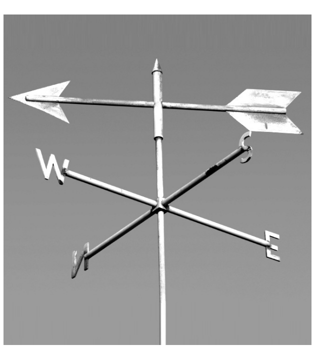
π = 3.1416

m = meter

s = second

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 to measure wind speed.

**WIND VANE**



**ANEMOMETER**

## Wind Shear and Turbulence

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

**Wind shear** is defined as 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 the jet stream. 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 cause wear and tear, which may lead to extra maintenance costs and turbine failure. 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.

**WIND TURBINE BLADE TESTING**

Image courtesy of Mike Jenks, NREL Staff

**Wind turbine blades are tested to make sure they can withstand wind shear and turbulence.**

# Energy

## 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 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, or gravitational potential energy. 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

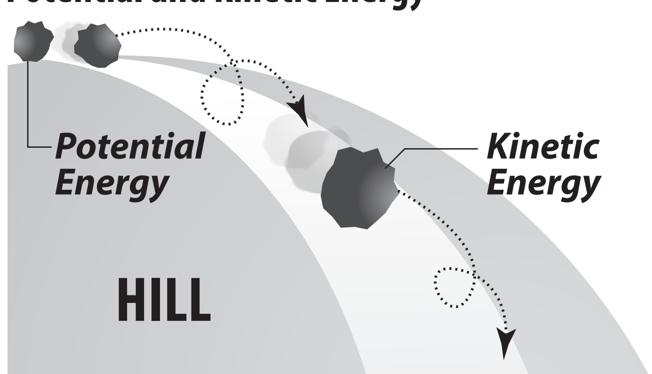
**Kinetic energy** is motion—the motion of waves, electrons, atoms, molecules, substances, and objects.

- **Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. 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 an unbalanced force is applied according to Newton's Laws of Motion. Wind contains 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.
- **Electrical energy** is the movement of electrons. Lightning and electricity are examples.

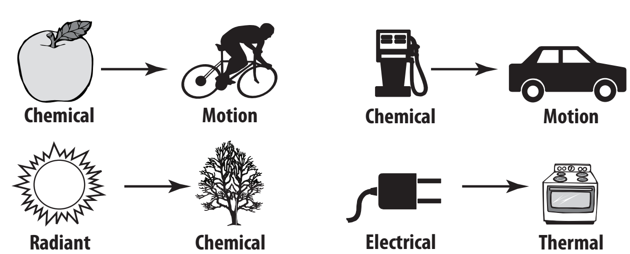
## Conservation of Energy

Conservation of energy can mean more than 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.

### Potential and Kinetic Energy




### Energy Transformations



## Energy Efficiency

**Energy efficiency** is the amount of useful energy output you get from a system compared to the energy input. A perfect, energy-efficient machine would change all the energy input 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 heat.

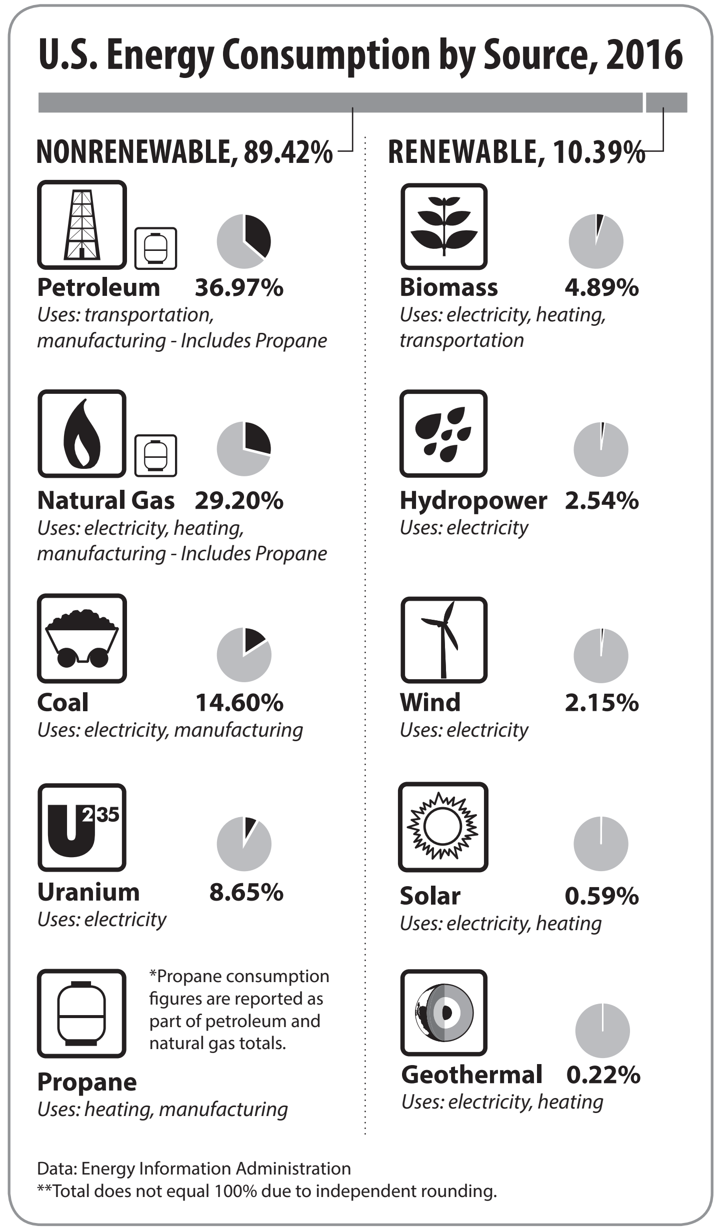
## Sources of Energy

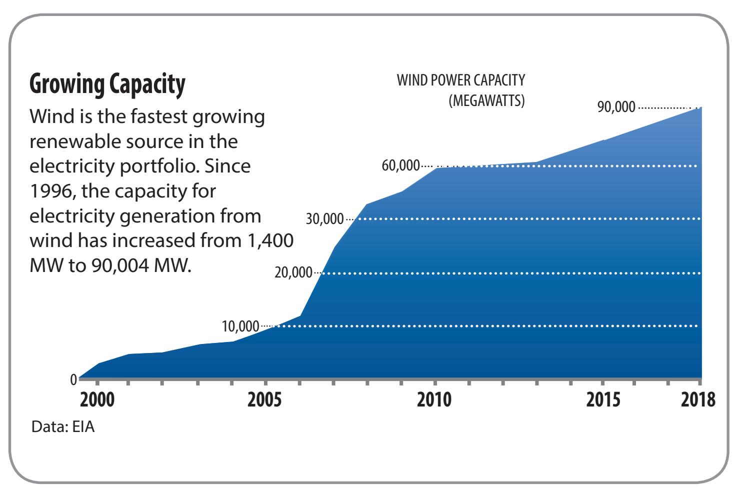
We use many different sources to meet our energy needs every day. They are usually classified into two groups—renewable and nonrenewable.

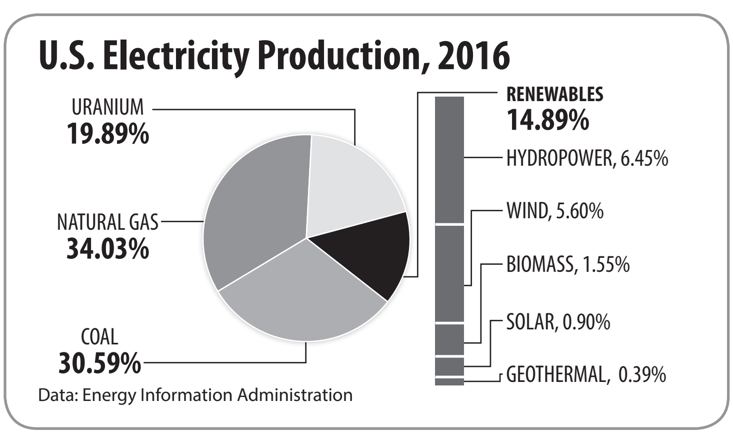
Wind is energy in motion—kinetic energy—and it is a renewable energy source. Along with wind, **renewable energy sources** include biomass, geothermal energy, hydropower, and solar energy. They are called renewable because they are replenished in a short time. Day after day, the sun shines, the wind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

In the United States, about 90 percent of our energy comes from nonrenewable sources. Coal, petroleum, natural gas, propane, and uranium are **nonrenewable energy sources**. They are used to make electricity, heat our homes, move our cars, and manufacture all kinds of products. They are called nonrenewable because their supplies are limited. Petroleum, for example, was formed millions of years ago from the remains of ancient sea plants and animals. We cannot make more crude oil in a short time.

**Electricity** is a **secondary energy source**. We use primary energy sources, including natural gas, coal, petroleum, uranium, solar, wind, biomass, and hydropower, to convert chemical, nuclear, radiant, and motion energy into electrical energy. In the United States, natural gas generates 34.03 percent of our electricity. Twenty years ago, wind contributed less than one-tenth of a percent to the electricity portfolio, while today it contributes nearly six percent. Wind is still a small fraction of electric 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.



# Harnessing the Wind's Energy

## Evolution of the Windmill

Using the wind's energy to do work is not a new idea. People have been capturing the wind to do work for a long time. 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 postmill could be rotated when the wind changed directions. Millers operated the postmill or windmill and it was their job to rotate the postmill so they could grind grain using wind from any direction.

In the 1300s, smockmills were invented. The sails are attached to the cap, the top of the windmill, and that is the only part that rotates. The miller still had to physically rotate the cap into the wind when it changed directions. These mills were bigger, heavier, and stronger, since the building didn't move. In the 1500s, tower windmills were built in Spain, Greece, and the Mediterranean Islands. Tower windmills were small and made out of stone. They had many small, lightweight sails, which worked well in the lighter winds of southern Europe. They were used to pump water and grind grain. The Dutch began to use drainage windmills in the 1600s to pump water that flooded the land below sea level. Using windmills to dry out the land, they doubled the size of their country.

Windmills made work easier and faster. In addition to grinding grain, windmills in the 1700s were used to grind cocoa, gunpowder, and mustard. Hulling mills removed the outer layer of rice and barley kernels. Oil mills pressed oil from seeds. Glue mills processed cowhides and animal bones. Fulling mills pounded wool into felt. Paint mills ground pigments for paint as well as herbs and chemicals for medicines and poisons.

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

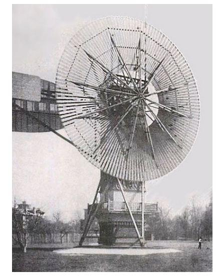
### American Windmills

As Europeans came to America in the mid 1600s, they brought 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 in the West, they soon discovered that the land was too dry for farming. A new style of windmill was invented, one that pumped water.

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

**WINDMILLS**



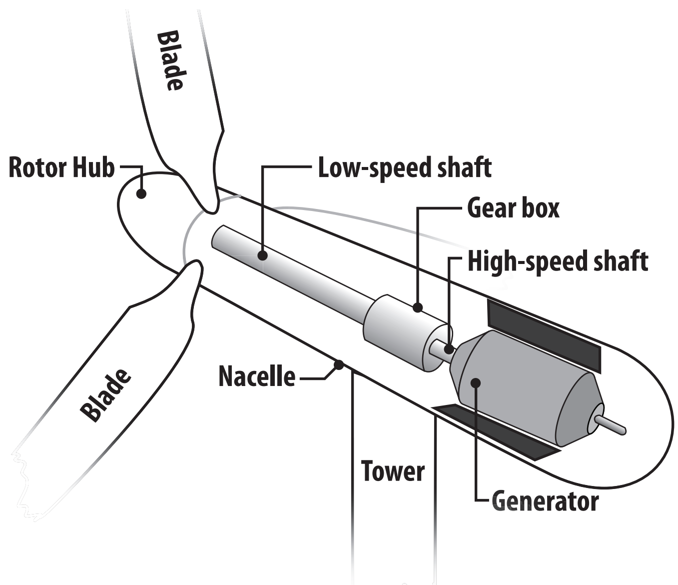


As the West was settled, railroads were built across the Great Plains. Steam locomotives burned coal for fuel, which needed thousands of gallons of water to produce steam to run the engines. Windmills were vital in the railroad industry to provide water at railroad stations. A large windmill could lift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

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

Wind power became less necessary as power plants and transmission lines were built across America, connecting rural and remote areas to the grid as part of the Rural Electrification Act of 1936. This New Deal era infrastructure improvement brought electricity to many parts of the U.S. that had not had grid-tied electricity before. 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 as interest in alternative energy sources and generation grew. 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.

## Wind Turbine Diagram




### ▪ Modern Wind Turbines

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 the 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 (motion) energy into **mechanical energy** that generates electricity.

How a turbine works:

1. The moving air pushes 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 one end of 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** comes out of the other end of the gear box and is connected to a **generator**. As the high-speed shaft turns the generator, it produces electricity. This electricity has variable voltage and current.

6. The electric current is sent through cables down the turbine tower to a **transformer** that converts the electricity into a fixed voltage that can safely be sent out on **transmission lines**.

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. Large turbines typically can generate electricity when winds are between 7 and 55 mph (3-25 m/s). Below 7 mph (3 m/s), there is not enough energy in the wind to generate electricity. As the wind speed increases from 7-30 mph (3-13 m/s), the wind turbine generates more electricity. They operate most efficiently, however, when wind speeds fall between 18-31 mph (8-14 m/s). Most large wind turbines produce at their rated power when wind speeds are between 22-55 mph (11-25 m/s), though the wind is rarely this fast, except in extreme storms. When wind speed rises over 55 mph (25 m/s), the wind is so strong, it can damage the turbine. Turbines are designed to shut down in high winds.

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** (MW) of electricity, enough to power 300 to 900 homes. Large turbines are grouped together into wind farms, which provide large amounts of power to the electric grid.

## What a Drag—Aerodynamics

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

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

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

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

## Gearing Up For More Power

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

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 rpm with a lot of torque. This large gear spins a smaller gear, with less torque, at about 1,500 rpm. The small gear is attached to a small shaft that spins the generator at high speed, generating power. The relationship between the large and small gears is called the **gear ratio**. The gear ratio between a 1,500 rpm gear and a 20 rpm gear is 75:1. Some small residential wind turbines spin much faster and do not have gears.

## Wind Turbine Efficiency—Betz Limit

Wind turbines must convert as much of the available wind energy into electricity as possible to be efficient and economical. As turbines capture energy from the wind, the resultant wind has less energy and moves more slowly. If the blades were 100 percent efficient, they would extract all of the wind's energy and the wind would be stopped. The maximum theoretical percentage of wind that can be captured has been calculated to be about 59 percent by Albert Betz, a German physicist. 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. There are many factors to consider – among them are wind speed, available land (or people willing to lease their land), roughness of the terrain, distance to transmission lines, environmental concerns, distance to towns or residential areas, endangered species, etc. A wind developer will work to optimize a wind farm for energy production while weighing all of the relevant factors.

The wind speed and direction must be studied to determine where to put the turbines. The site must have reasonably strong, steady winds. Scientists measure the winds in an area for several years to determine the best sites to optimally lay out a wind farm. As a general rule, wind speed increases with height in most locations, but taller towers cost more. Wind developers try to optimize the turbine height balanced with other factors to maximize energy production.

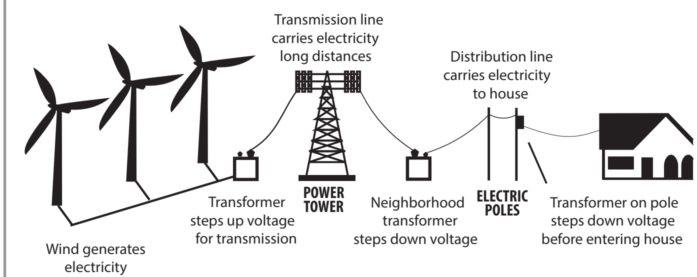
Turbines are usually built in rows facing into the prevailing wind. The turbines have internal controls to rotate (**yaw**) so they are always facing into the wind. Placing turbines too far apart wastes space. If turbines are too close together, they block each other's wind. Developers optimize the turbine spacing based on the wind speed and direction characteristics to maximize energy production.

The best sites for wind farms are on ridges, on the open plains, through mountain passes, and near the coasts of oceans or large lakes. Texas, the number one producer of wind electricity in the U.S., has plentiful open space with steady winds, relatively easy permitting requirements, and good transmission from the windy areas in the north and west to the cities in central and southeastern Texas.

## 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**.

### Transporting Wind Electricity




**WIND FARM**

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, operate, and maintain. Some challenges for offshore wind farms include the costs and difficulties involved with water-based construction and the impact of salt water corrosion on the 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 came online late in 2016, and has the ability to power roughly 17,000 homes per year, reducing the reliance on diesel-fired electricity generation and improving air quality for residents. Additional offshore turbines are proposed off the coast of Long Island, NY and Virginia.

**BLOCK ISLAND WIND FARM, RHODE ISLAND**

Image courtesy of Deepwater Wind

Texas generates the most electricity from wind energy in the United States, followed by Iowa and Oklahoma. Combined, these three states produce nearly 43 percent of the nation's total wind-generated electricity.

## Energy on Public Lands

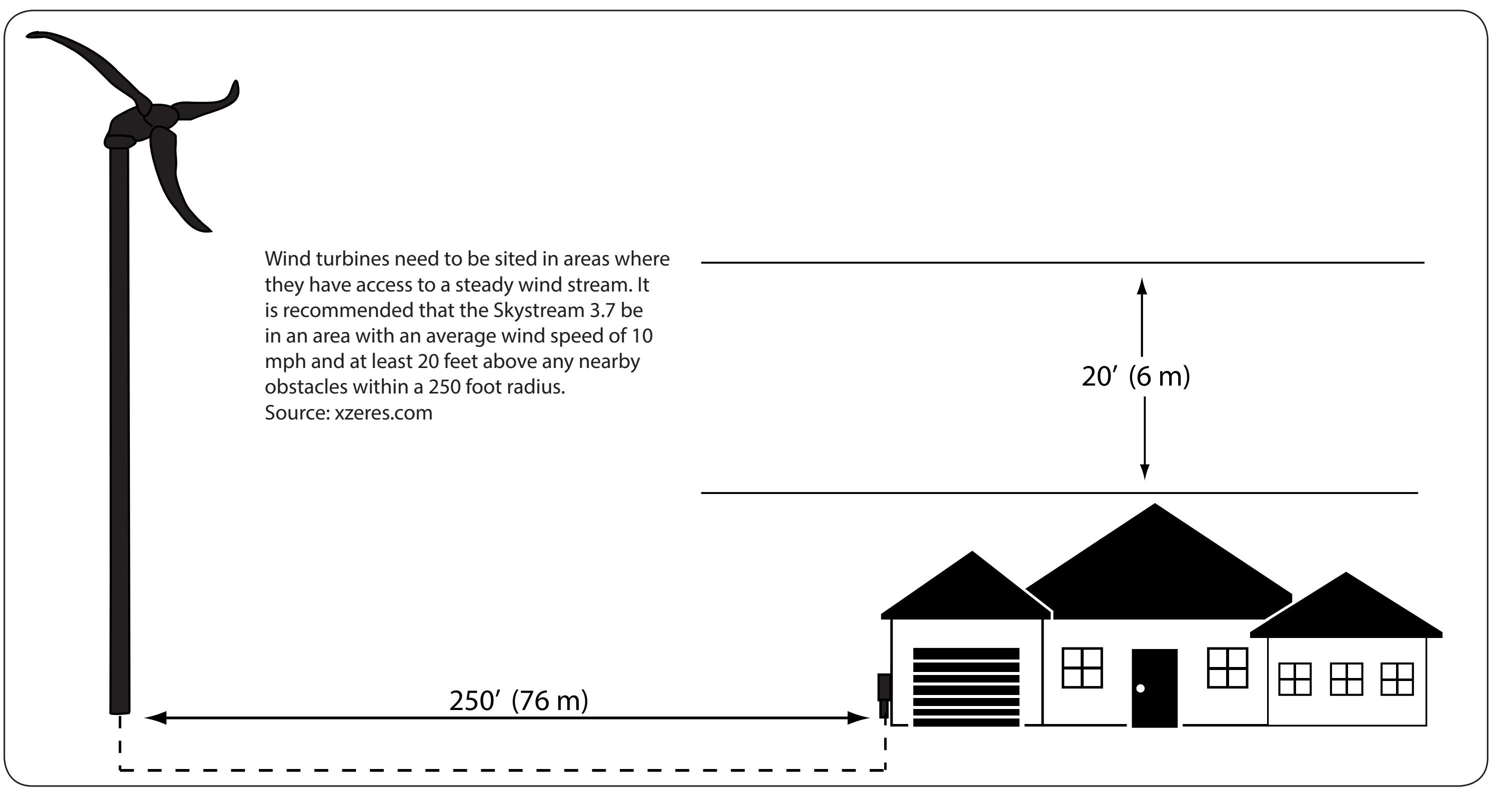
Finding open lands for wind farms is important for the future of wind energy. The Bureau of Land Management (BLM) controls many of the lands with the best wind potential. About 917 megawatts of installed wind capacity in the U.S. is on public lands. BLM works with companies to find sites for wind farms 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 electricity sales.

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

## 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 900 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 large turbines, though financial resources required to investigate are much smaller. Potential small wind turbine users typically rely on available wind data and maps. They should try to make sure to minimize obstructions in the direction of the prevailing wind to maximize energy production. The tip of the turbine blades should be at least 9 meters (30 feet) higher than the tallest wind obstacle. Sometimes



this can be a challenge 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.

The Emergency Economic Stabilization Act of 2008 created energy tax incentives to encourage large and small companies, along with individuals, to make energy improvements and invest in renewable energy. These tax credits ran through 2016. Some states and utilities offer additional incentives to residents that install renewable energy systems.

## Opportunities and Challenges

Wind is renewable and is a clean source of energy, causing no air or water pollution. Wind is free and an economical energy source for producing electricity. It has the potential to produce up to 20 percent of U.S. electricity demand.

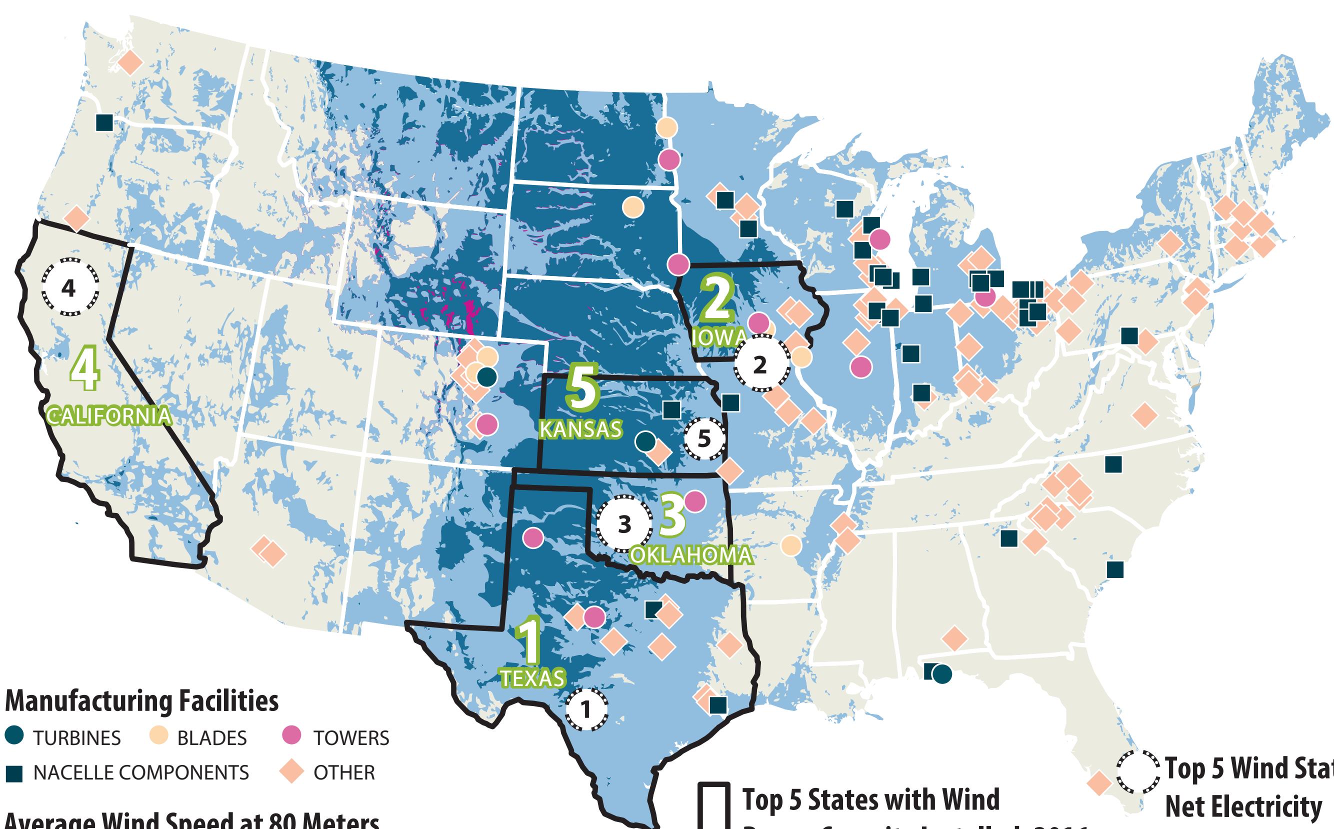
Wind turbines are most effective in areas with consistent wind patterns. While this used to be a limitation, weather data and monitoring and increased technology have allowed for wind turbines to be functional in many types of areas.

There is also concern that wind turbines can harm birds and bats. The wind industry has greatly increased the extent of its environmental monitoring at wind farms before construction and during operation. Wind farm operators can halt or slow operations during certain times of the year or weather events to minimize impacts on migrating birds or endangered species.

Wind turbines can affect the view of the landscape. Some people like the large, modern turbines with their graceful rotation (~12-20 rpm); others prefer the landscape only have trees, mountains, and valleys.

### Where the Wind Blows, the Jobs Go

About 50 percent of the parts used to manufacture U.S. wind turbines are produced domestically. Take a look at where the wind blows the strongest and where current manufacturing facilities are located. Also, take note of the top 5 states for wind installation, and the top 5 states for wind generation. What trends do you see?




**Manufacturing Facilities**

- TURBINES
- BLADES
- TOWERS
- NACELLE COMPONENTS
- OTHER

**Average Wind Speed at 80 Meters**

- Faster than 9.5 m/s (faster than 21.3 mph)
- 7.6 to 9.4 m/s (17 to 21.2 mph)
- 5.6 to 7.5 m/s (12.5 to 16.9 mph)
- 0 to 5.5 m/s (0 to 12.4 mph)

Data: AWEA, NREL
Note: Does not include potential offshore wind resources.

**Top 5 States with Wind Power Capacity Installed, 2016**

| | | |
|---|---|---|
| 1. | Texas | 20,320 MW |
| 2. | Iowa | 6,911 MW |
| 3. | Oklahoma | 6,645 MW |
| 4. | California | 5,656MW |
| 5. | Kansas | 4,451 MW |

**Top 5 Wind States Net Electricity Generation, 2015**

1. Texas
2. Iowa
3. Oklahoma
4. California
5. Kansas

# Wind Energy Timeline

| | |
|---|---|
| **5000 BCE** | Early Egyptians use wind to sail boats on the Nile River. |
| **0** | The Chinese fly kites during battle to signal their troops. |
| **500-900 AD** | 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. |
| **700s** | People living in Sri Lanka use wind to smelt (separate) metal from rock ore. They would dig large, crescent-shaped furnaces near the top of steep mountainsides. In summer, monsoon winds 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. |
| **1200s** | 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. |
| **1300s** | 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. |
| **1500s** | The tower windmill is developed in Spain, Greece, southern Europe, and France. |
| **1600s** | The Dutch began to use drainage windmills to pump water. The windmills dried out flooded land below sea level, doubling the size of the country. European settlers begin building windmills in North America. |
| **1700s** | By the early 1700s, both the Netherlands and England have over 10,000 windmills. |
| | As a boy, Benjamin Franklin experiments with kites. One day, he floats on his back while a kite pulls him more than a mile across a lake. |
| **1854** | Daniel Halladay builds and sells the Halladay Windmill, which is the first windmill designed specifically for the West. It has thin wooden blades and turns itself into the wind. |
| **1888** | Charles F. Brush, a wealthy inventor and manufacturer of electrical equipment in Cleveland, 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. |
| **Late 1880s** | The development of steel blades makes windmills more efficient. Six million windmills spring up across America as settlers move west. These windmills pump water to irrigate crops and provide water for steam locomotives. |
| **1892** | Danish inventor Poul LaCour invents a Dutch-style windmill with large wooden sails that generates electricity. He discovers that fast-turning rotors with few blades generate more electricity than slow-turning rotors with many blades. By 1908, Denmark has 72 windmills providing low-cost electricity to farms and villages. |
| **1898-1933** | The U.S. Weather Service sends kites aloft to record temperature, humidity, and wind speed. |
| **1900s** | Wilbur and Orville Wright design and fly giant box kites. These experiments lead them to invent the first successful airplane in 1903. |
| **1920s** | G.J.M. Darrieus, a French inventor, designs the first vertical-axis wind turbine. |
| **1934-1943** | In 1934, engineer Palmer Putman puts together a team of experts in electricity, aerodynamics, engineering, and weather to find a cheaper way to generate electric power on a large scale. In 1941, the first large-scale turbine in the United States begins operating.<br>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. |
| **1945-1950s** | 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. |
| **1971** | The first offshore wind farm operates off Denmark's coast. |

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| **1973** | 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. |
| **1974** | In response to the oil crisis, the National Aeronautics and Space Administration (NASA) develops a two-bladed wind turbine at the Lewis Research Center in Cleveland, OH. Unfortunately, the design does not include a "teetering hub"—a feature very important for a two-bladed turbine to function properly. |
| **1978** | The Public Utility Regulatory Policies Act (PURPA) requires utility companies to buy a percentage of their electricity from non-utility power producers. PURPA is an effective way of encouraging the use of renewable energy. |
| **1980** | The Crude Oil Windfall Profits Tax Act further increases tax credits for businesses using renewable energy. The federal tax credit for wind energy reaches 25 percent and rewards businesses choosing to use renewable energy. |
| **1980s** | 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. |
| **1983** | Because of a need for more electricity, California utilities contract with facilities that qualified under PURPA to generate electricity independently. The price set in these contracts is based on the costs saved by not building planned coal plants. |
| **1984** | A large vertical axis turbine, Project École, is built in Quebec, Canada. It is 110 meters high (360 ft.). |
| **1985** | By 1985, California wind capacity exceeds 1,000 megawatts, enough power to supply 250,000 homes. These wind turbines are very inefficient. |
| **1988** | Many of the hastily installed turbines of the early 1980s are removed and later replaced with more reliable models. |
| **1989** | Throughout the 1980s, 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. |
| **1992** | The Energy Policy Act reforms the Public Utility Holding Company Act and many other laws dealing with the electric utility industry. It also authorizes a production tax credit of 1.5 cents per kilowatt-hour for wind-generated electricity. |
| | U.S. Windpower develops one of the first commercially available variable-speed wind turbines, over a period of 5 years. The final prototype tests are completed in 1992. The $20 million project is funded mostly by U.S. Windpower, but also involves Electric Power Research Institute (EPRI), Pacific Gas & Electric, and Niagara Mohawk Power Company. |
| **1994** | Cowley Ridge in Alberta, Canada becomes the first utility-grade wind farm in Canada. |
| **1999-2000** | Installed capacity of wind-powered electricity generating equipment exceeds 2,500 megawatts. Contracts for new wind farms continue to be signed. |
| **2003** | North Hoyle, the largest offshore wind farm in the United Kingdom at that time, is built. |
| **2005** | The Energy Policy Act of 2005 strengthens incentives for wind and other renewable energy sources. |
| | The Jersey-Atlantic wind farm off the coast of Atlantic City, NJ, begins operating in December. It is the United States' first coastal wind farm. |
| **2006** | 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. |
| **2008** | 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 provided a 30 percent tax credit to individuals installing small wind systems. The tax credit was available through December 31, 2016. |
| **2009** | 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. |
| **2016** | Deepwater Wind, off the coast of Block Island, Rhode Island, completed construction and became the nation's first offshore wind farm. |
| **2017** | World wind energy capacity grew by 118% since 2010. China, Germany, and the United States are some of the largest installers of wind capacity. |

# Wind Glossary

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| **aerodynamics** | the branch of dynamics that deals with the motion of air and other gaseous fluids, and the forces acting on solids in motion relative to such fluids |
| **aerofoil** | a device, much like an airplane wing, that creates lift and minimizes drag, the blades have a specialized shape, which creates lift when moving air passes over the surface |
| **albedo** | the fraction of solar radiation reflected from the Earth back into space; average reflectivity of the Earth's surface |
| **anemometer** | an instrument that measures wind speed or wind speed and direction |
| **array (turbine)** | the positioning and spatial arrangement of wind turbines relative to each other |
| **Betz Limit** | the maximum fraction of the power in the wind that can theoretically be extracted by a wind turbine, usually given as 16/27 (about 59%) |
| **blades** | most wind turbines have 2 or 3 blades, which catch the wind and turn the generator |
| **brake** | device that stops the rotor in emergencies |
| **capacity** | the power generating or carrying potential of a device |
| **capacity factor** | the practically available power (usually expressed as a percentage) from a wind turbine; defined as the ratio of the annual energy output of a wind turbine to the turbine's rated power times the total number of hours in a year (8,760) |
| **Coriolis Effect** | the deflection sideways of free-moving air or water bodies (e.g., wind, ocean currents, airplanes, and missiles) relative to the solid earth beneath, as a result of the Earth's eastward rotation; the Coriolis Effect must be taken into account when projectile trajectories, terrestrial wind systems, and ocean currents are being evaluated |
| **cut-in speed** | the wind speed below which a wind turbine cannot economically produce electricity; it is unique for each turbine |
| **cut-out speed** | the wind speed above which a wind turbine cannot economically produce electricity without also potentially suffering damage to its blades or other components |
| **decibel (db)** | a standard unit for measuring the loudness or intensity of sound; in general, a sound doubles in loudness with every increase of 10 decibels |
| **decibel, a-weighted [db(a)]** | a measurement of sound approximating the sensitivity of the human ear and used to characterize the intensity or loudness of a sound |
| **distribution line** | wire that carries electricity to the consumer |
| **doldrums** | an area of calm where the trade winds converge near the Equator |
| **drag** | a mechanical force that acts on a solid object interacting with a fluid, typically slowing down a moving item or system |
| **electric motor** | a device that takes electrical energy and converts it into motion energy to turn a shaft |
| **electric power** | the amount of energy produced per second; the power produced by an electric current |
| **electrical energy** | the energy of moving electrons |
| **electricity** | a form of energy characterized by the presence and motion of electrically charged particles generated by friction, induction, or chemical change |
| **electricity generation** | the process of producing electrical energy or the amount of electrical energy produced by transforming other forms of energy, commonly expressed in kilowatt-hours (kWh) or megawatt-hours (MWh) |
| **emission** | a discharge or something that is given off; generally used in regard to discharges into the air or releases of gases to the atmosphere from some type of human activity (cooking, driving a car, etc.); in the context of global climate change, they consist of greenhouse gases (e.g., the release of carbon dioxide during fuel combustion) |
| **energy** | the ability to do work or the ability to move an object; electrical energy is usually measured in kilowatt-hours (kWh), while heat energy is usually measured in British thermal units (Btu) |
| **energy consumption** | the use of energy as a source of heat or power or as a raw material input to a manufacturing process |

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| **energy efficiency** | refers to activities that are aimed at reducing the energy used by substituting technically more advanced equipment, typically without affecting the services provided; examples include high-efficiency appliances, efficient lighting programs, high-efficiency heating, ventilating and air conditioning (HVAC) systems or control modifications, efficient building design, advanced electric motor drives, and heat recovery systems |
| **gear box** | increases the rpm of the low-speed shaft, transferring its energy to the high-speed shaft in order to provide enough speed to generate electricity |
| **gear ratio** | relationship between large and small gears in a generator |
| **generating capacity** | the amount of electric power a power plant can produce |
| **generator** | a device that turns motion energy into electrical energy; the motion energy is sometimes provided by an engine or turbine |
| **guy wire** | wire or cable used to secure and stabilize wind turbines, meteorological towers, and other vertical objects in wind resource areas |
| **high-speed shaft** | transmits force from the gear box to the generator |
| **hub** | the central portion of the rotor to which the blades are attached |
| **interconnected system** | a system consisting of two or more individual power systems, normally operating with connecting lines |
| **interconnection** | two or more electric systems having a common transmission line that permits a flow of energy between them; the physical connection of the electric power transmission facilities allows for the sale or exchange of energy |
| **intermittent electric generator** or **intermittent resource** | an electric generating plant with output controlled by the natural variability of the energy resource rather than dispatched based on system requirements; intermittent output usually results from the direct, non-stored conversion of naturally occurring energy fluxes such as solar energy, wind energy, or the energy of free-flowing rivers (that is, run-of-river hydroelectricity) |
| **jet stream** | a narrow current of air that rapidly moves through the atmosphere creating boundaries at areas with differences in temperature; caused by Earth's rotation and solar radiation |
| **katabatic wind (mountain wind)** | 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 |
| **kilowatt** | a unit of power, usually used for electric power or energy consumption (use); one kilowatt equals 1000 watts |
| **kilowatt-hour (kWh)** | a measure of electricity defined as a unit of work or energy, measured as 1 kilowatt (1,000 watts) of power expended for one hour; one kWh is equivalent to 3,412 Btu or 3.6 million joules |
| **kinetic energy** | the energy of a body that results from its motion |
| **land breeze** | a wind that blows from land toward the ocean in the evening, caused by different cooling rates of water and land surfaces |
| **leeward** | away from the direction of the wind; opposite of windward |
| **load** | the power and energy requirements of users on the electric power system in a certain area or the amount of power delivered to a certain point |
| **load balancing** | keeping the amount of electricity produced (the supply), equal to the consumption (the demand); this is one of the challenges of wind energy production, which produces energy on a less predictable schedule than other methods |
| **low-speed shaft** | connects the rotor to the gear box |
| **mechanical energy** | the energy of motion used to perform work, also called motion energy |
| **mechanical power** | the power produced by motion |
| **megawatt** | a unit of electric power equal to 1000 kilowatts or one million watts |
| **nacelle** | the portion of the turbine that encompasses the drive train, the bedplate on which it rests, and the cover that protects the components from the elements; the nacelle for offshore turbines is specially designed to seal the interior from salt spray and moisture; the nacelle also includes maintenance cranes, access hatches, and wind sensors |
| **nonrenewable energy sources** | fuels that cannot be easily made or "renewed;" we can use up nonrenewable fuels; oil, natural gas, propane, uranium, and coal are nonrenewable fuels |
| **offshore** | the geographic area that lies seaward of the coastline; in general, the coastline is the line of ordinary low water along with that portion of the coast that is in direct contact with the open sea or the line marking the seaward limit of inland water |

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| **ohm** | the unit of resistance to the flow of an electric current |
| **peak load plant** | a plant usually housing old, low-efficiency steam units, gas turbines, diesels, or pumped-storage hydroelectric equipment normally used during the high energy usage time periods |
| **pitch** | the orientation of a turbine blade relative to the direction of the wind |
| **polar easterlies** | dry, cold winds that begin in the east and flow in a westerly direction away from the poles |
| **power** | the rate at which energy is transferred; electric power is usually measured in watts |
| **power coefficient** or **rotor power coefficient** | the ratio of the rotor power density to the wind |
| **power degradation** | the loss of power when electricity is sent over long distances |
| **power density** or **rotor power density** | the mechanical power available at the rotor shaft divided by the swept area of the rotor |
| **power-generating efficiency** | the percentage of the total energy content of a power plant's fuel that is converted into electric energy; the remaining energy is lost to the environment as heat |
| **power plant** | a facility where power, especially electricity, is generated |
| **prevailing westerlies** | winds that blow from west to east and occur in temperate zones of the Earth |
| **renewable energy sources** | fuels that can be easily made or "renewed;" we can never use up renewable fuels; types of renewable fuels are hydropower (water), solar, wind, geothermal, and biomass |
| **rotational speed** | the rate (in revolutions per minute) at which a turbine blade makes a complete revolution around its axis; wind turbine speeds can be fixed or variable |
| **rotor** | the portion of a modern wind turbine that interacts with the wind; it is composed of the blades and the central hub to which the blades are attached |
| **rotor diameter** | the diameter of the circular area that is swept by the rotating tip of a wind turbine blade; equal to twice the blade length |
| **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** | a source of energy that requires another source material (wind, coal, etc.) to produce it; electricity and hydrogen are secondary energy sources |
| **siting** | determining the appropriate location for a turbine |
| **start-up speed** | the wind speed at which a rotor begins to rotate |
| **swept area** | the circular area that is swept by the rotating blades; doubling the length of the blades quadruples the blade-swept area |
| **tip speed** or **rotor tip speed** | the speed of the tip of a rotor blade as it travels along the circumference of the rotor-swept area |
| **tip speed ratio** | the ratio of the speed of the tip of a rotating blade to the speed of the wind |
| **torque** | moment force; the tendency of a force to rotate or twist an object on its axis |
| **tower** | devices, some as tall as 120 feet, which lift wind turbine blades high above the ground to catch stronger wind currents |
| **trade winds** | warm, steady easterly breeze flowing towards the Equator in tropical latitudes |
| **transformer** | a device that converts the generator's low-voltage electricity to higher-voltage levels for transmission to the load center, such as a city or factory |
| **transmission (electric)** | the movement or transfer of electrical energy over an interconnected group of lines and associated equipment between points of supply and points at which it is transformed for delivery to consumers or is delivered to other electric systems; transmission is considered to end when the energy is transformed for distribution to the consumer |
| **transmission line** | a set of conductors, insulators, supporting structures, and associated equipment used to move large quantities of power at high voltage, usually over long distances between a generating or receiving point and major substations or delivery points |

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| **transmission system (electric)** | an interconnected group of electric transmission lines and associated equipment for moving or transferring electrical energy in bulk between points of supply and points at which it is transformed for delivery over the distribution system lines to consumers or is delivered to other electric systems |
| **tunnel effect** | when air becomes compressed in narrow spaces and its speed increases |
| **turbine** | a device with blades, which is turned by a force, e.g. that of wind, water, or high pressure steam; the motion energy of the spinning turbine is converted into electricity by a generator |
| **turbulence** | disturbance or chaotic change in the speed or direction of the wind |
| **upwind turbine** | a turbine that faces into the wind, requires a wind vane and yaw drive in order to maintain proper orientation in relation to the wind |
| **utility generation** | generation by electrical systems engaged in selling electrical energy to the public |
| **valley wind** | a wind that blows up the slope of a mountain allowing cooler air to sweep into the valley |
| **volt (V)** | the International System of Units (SI) measure of electric potential or electromotive force; a potential of one volt appears across a resistance of one ohm when a current of one ampere flows through that resistance |
| **voltage** | the difference in electrical potential between any two conductors or between a conductor and the ground; a measure of the electrical energy per electron that electrons can acquire and/or give up as they move between the two conductors |
| **watt (W)** | a metric unit of power, usually used in electric measurements, which gives the rate at which work is done or energy used |
| **wind** | the term given to any natural movement of air in the atmosphere; a renewable source of energy used to turn turbines to generate electricity |
| **wind farm** | one or more wind turbines operating within a contiguous area for the purpose of generating electricity |
| **wind machine** | device powered by the wind that produces motion or electric power (wind turbine) |
| **wind resource areas (WRAS)** | areas where wind energy is available for use based on historical wind data, topographic features, and other parameters |
| **wind shadow** | the area behind an obstacle where air movement is not capable of moving material |
| **wind shear** | the change, sometimes severe, in wind direction caused primarily by geographic features and obstructions near the land surface |
| **wind turbine** | a system that converts motion energy from the wind into electrical energy |
| **wind vane** | wind direction measurement device; can be used to send data to the yaw drive |
| **windward** | into, or facing the direction of the wind; opposite of leeward |
| **windward slopes** | those slopes facing into the wind |
| **yaw** | side-to-side movement; for wind turbines, it refers to the angle between the axis of the rotor shaft and the wind direction; as this angle increases, the turbine's ability to capture the wind's energy decreases |
| **yaw drive** | device used to keep the rotor facing into the wind as wind direction changes |