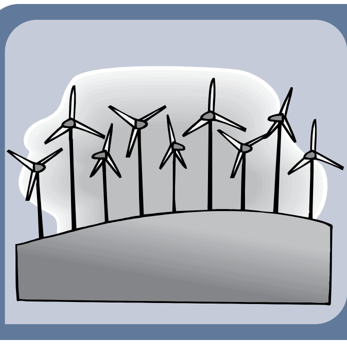


Waterwheels, Windmills and Turbines

Students construct simple turbines to investigate how the energy in wind and water can be harnessed to do work.

Grade Level: K–4 (5–8)

Subject Areas: English Language Arts, Science, Social Studies

Setting: Classroom

Time:
Preparation: 50 minutes
Activity: 50 minutes

Vocabulary: Dam, Generator, Hydroelectric power, Kinetic energy, Mechanical energy, Potential energy, Turbine

Major Concept Areas:

- Natural laws that govern energy
- Development of energy resources

Getting Ready:

Construct a turbine prior to the class and use this as a model. This turbine can also serve as the pinwheel used in the **Orientation**.

Young hands may lack the dexterity to make these turbines. Consider making a class set for these students. Students can make a simple pinwheel to demonstrate wind energy.

To prepare for Part C in the **Waterwheels, Windmills, and Turbines** activity sheet, cover the spout of an electric kettle with a piece of aluminum foil and secure with tape. Poke a pencil hole in the foil near the tip of the spout.

Objectives

Students will be able to:

- demonstrate how wind and water can move a simple turbine; and
- recount the role of turbines in electricity generation.

Rationale

Understanding how turbines operate helps students explain how humans have developed technology to further their ability to use energy resources.

Materials

- A pinwheel (see **Getting Ready**)
- Tea kettle (electric or with a heat source such as a hot plate)
- Aluminum foil
- Masking tape
- Photographs of windmills and waterwheels (optional)
- Each group will need a copy of and materials listed on the ***Waterwheels, Windmills and Turbines*** activity sheet
- Find additional resources related to this activity on keepprogram.org > Curriculum & Resources

Background

See the following resources for background information:

- ***Facts about Hydropower***
- ***Facts about Wind Energy***
- ***Electricity from Falling Water***
- ***Electricity from Fossil Fuels***
- ***Electricity from Uranium***

The wind gently blows across the surface of a lake. This is a calming sight, but who would think that wind and water are both sources of energy that can power all the electrical appliances in our home?

Wind is a form of energy created in part by the sun. The heating and cooling of Earth's surface and Earth's rotation help form wind. The sun heats Earth's surfaces. This heat is then radiated, warming the surrounding air. About two percent of the sun's energy that reaches Earth is converted to wind energy.

Wind energy has been used for hundreds of years. Farmers and ranchers have used windmills to pump water to fields and livestock in remote locations. Today wind machines still use mechanical energy to pump water but more and more they are used to provide electricity for operating lights and appliances. Although only a small amount of electricity in Wisconsin is generated through wind power (less than one percent), electricity generated by wind energy is steadily growing in the state. Wind machines that generate electricity can be small or large scale systems. Wisconsin utilities operate 402 large wind turbines in ten sites in Wisconsin. The rotation diameter of these blades can be over 150 feet (46 meters)! Home-sized (small scale) systems have rotation diameters that range from 10 to 20 feet (3 to 6 meters).

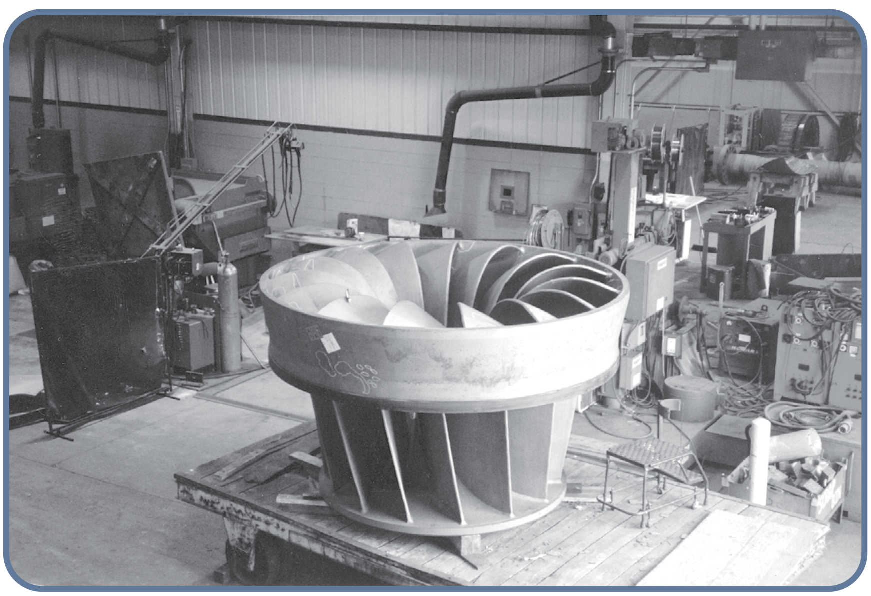
Similar to wind energy, water power has been used for many years to do work. Many people have seen grist mills located by streams. The flowing stream causes a waterwheel to rotate that turns gears within the grist mill to grind flour. Waterwheels also lift objects (including water) and power machinery.

Humans use flowing water to generate electricity (hydroelectricity). Dam operators regulate the flow of water through the dam (see ***Electricity from Falling Water***). There are around 150 hydroelectric sites in Wisconsin. These sites produce about 192 million kilowatt hours (kWh) of electricity.

Another form of water, steam, can be used to generate electricity as well. Burning fossil fuels (coal, oil, or natural gas) or the heat from nuclear fission converts water to steam. (see ***Electric Power from Fossil Fuels*** and ***Electricity from Uranium***).

Although there are variations in how wind, water, and steam generate electricity, all involve spinning blades. The blades spin a shaft that in turn causes a wire coil in a generator to spin. The generator converts the mechanical energy of the spinning coil into electrical energy. The spinning wire coil is surrounded by magnets that produce an electric current (see the activity "Electric Motors and Generators"). The electricity produced by the generator is transmitted through power lines to homes and businesses in the surrounding community. To make sure that enough water is available to spin the turbine, humans build dams to store water and release it as needed. The dams prevent the water from flowing down stream, creating a reservoir. The stored water behind the dam has a large amount of potential energy.

So, the next time you dip your toes in a babbling brook or feel a cool breeze on your face, remember: these resources also have the energy to generate electricity for appliances we use every day.



Water turbine for Unit #1 at Grandfather Falls Hydroelectric plant. Courtesy Wisconsin Public Service Corporation.

Procedure

Orientation

Show students a pinwheel and ask if they think it can do work. Remind them of the definition of work (applying a force—a push or a pull—that moves something a distance). Blow on the pinwheel to show students that it moves. Ask students to think of situations where a wheel similar to this can do work. Show students photographs or describe windmills and waterwheels.

Discuss what sources of energy make the windmills and waterwheels turn. Explain that the wheels are tools or simple machines that convert the kinetic energy in the wind or water to mechanical energy. Tell them that another word for this working wheel is a turbine, a wheel with blades joined to a shaft. Inform them they will make their own model turbine and experiment with different ways to make it turn.

Steps

1. Divide the class into small groups and provide each group with a copy of ***Waterwheels, Windmills and Turbines***. One student in the group can be responsible for getting materials, another student for reading directions and providing guidance, and another for constructing the turbine.

2. Have students read the Introduction and Making a Turbine sections of the activity sheet. Go over each step with students to make sure they understand the procedure. NOTE: For younger students, it might suffice to make simple pinwheels to demonstrate how wind energy spins the blades. Use the water resistant pie plate to illustrate how the flow of water or steam is used to spin the blades. **Caution: Warn students to be careful when using scissors and that the edges of the cut pie plate may be sharp.**

3. Tell students to make their model turbines. It is important to check to see that the shaft fits snugly in the hole in the pie plate. You may need to glue the shaft to the pie plate. The turbine should not rotate around the shaft.

4. When the students have finished their turbines, tell them to follow the instructions for conducting the experiments described in Using the Turbine, Parts A, B, and C on the ***Waterwheels, Windmills and Turbines*** and record answers to the questions on the activity sheet. **Caution: Supervise the kettle at all times to make sure no one gets burned.** Students will be able to answer most of the questions based on their observations.

Closure

When everyone has finished, discuss their answers to the questions posed in the ***Waterwheels, Windmills and Turbines***. Stress to students that the turbine caused a change in the direction of the energy of motion. The wind, water, and steam moved in a straight line until they hit the blades of the turbine. Then the turbine moved in a circle. Point out that because the turbine caused a change, we can call it an energy converter. Tell students that turbines are an important part of the machinery we use to make electricity. Discuss information about windmills, dams, and generators in power plants (see the **Background**).

Assessment

Formative

- Did students follow directions and successfully build model turbines?
- To what extent did students make careful observations and respond thoughtfully to the questions?
- Were students able to make the turbines spin using wind and water?

Summative

Have students build or sketch a simple power plant, including a turbine, and trace the flow of energy from the turbine to their homes.

Extension

Challenge students to design a different model for a waterwheel or turbine. For example, cut flaps in plastic jar and skewer the jar on a doweling rod.

Related KEEP Activities

This activity could be preceded with investigations found in K–5 Energy Sparks for Theme II: “Sunvestigations,” “Windy Wonders,” and “Water Fun.” Help students appreciate their dependence on electricity through K-5 Energy Sparks for Theme II: “Electricity in Our Lives.” Students identify energy sources used to generate electricity in “Fueling Around.” Have students learn more about electricity with the activity “Circuit Circus.”

Credits

Activity adapted from NMSU Cooperative Extension Service and the New Mexico Energy, Minerals, and

Natural Resources Department, Energy Conservation and Management Division. “Blowin and Flowin” pp. 11–17 in *Power Pack: Science and Energy SERIES* Supplement for New Mexico. Las Cruces, N. Mex.: New Mexico State University Cooperative Extension Service, n.d. Used with permission. All rights reserved.

Waterwheels, Windmills, and Turbines student page adapted from Society, Environment and Energy Development Studies Foundation. SEEDS 5: *The Energy Literacy Series Teacher’s Guide*. Edmonton, Alberta: Society, Environment and Energy Development Studies Foundation, 1981. Used with permission. All rights reserved.

Answers to Waterwheels, Windmills and Turbines Questions

Part A: The Windmill

1. The windmill spins gently when you blow on it lightly.
2. The windmill spins more quickly when you blow harder. You supply more energy when you blow harder.

Part B: The Waterwheel

1. The water has stored energy.
2. When the water strikes the blades of the turbine, the turbine spins.
3. To make the turbine turn the fastest, you should hold it as far from the cup as possible because the farther the water falls, the more kinetic energy it has and the more work it can do on the turbine.

Part C: The Steam Engine

1. Yes. The turbine turned as the steam hit it.
2. The steam was produced by boiling water in a kettle.

The Wisconsin K-12 Energy Education Program is supported through funding from

Wisconsin K-12 Energy Education Program (KEEP)
College of Natural Resources
University of Wisconsin-Stevens Point

Waterwheels, Windmills and Turbines

Introduction

Have you ever seen a windmill whirling in a breeze? Or a waterwheel slowly turning in a stream? Our ancestors joined the shafts of these bladed wheels to gears, levers, and different types of machines. They used these simple machines to mill grain, lift heavy materials, and pump water. In the early nineteenth century, many factories used waterwheels to run machines that spun cotton and sawed lumber.

Today, modern turbine engines are used instead of waterwheels and windmills. Modern turbines are also bladed wheels with shafts that are joined to other machines. Modern turbines spin much faster and deliver more power than waterwheels or windmills. These turbines are mainly used to produce electricity.

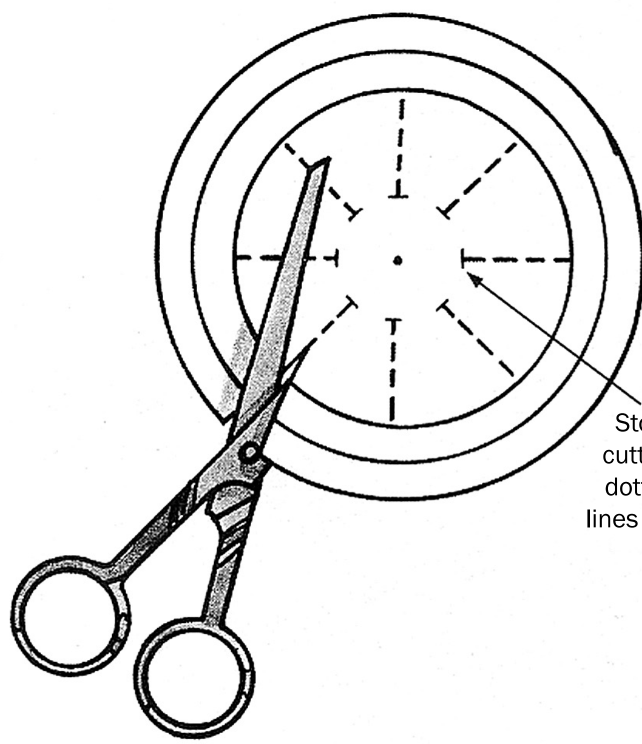
Making a Turbine

Each group will need:

- 1 pair of scissors
- 1 large paper clip (not the non-skid type)
- 1 pencil
- 1 plastic drinking straw
- 1 aluminum pie plate (at least 4 inches [10 cm] in diameter)
- 1 metal nail
- 1 foam cup
- Tray or pan to catch water
- Water
- Masking tape
- Glue

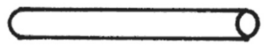
Instructions

1. Cut out the turbine pattern. Use four pieces of tape to secure the paper to the pie plate.
2. Remove the edge of the pie plate by cutting a circle on the pie plate. You may want to leave some space around the turbine pattern for now and cut more carefully around the edge later. Make sure that the turbine pattern stays taped to the pie plate.
3. Cut along each of the dotted lines. Cut from the edge toward the center of the circle.
4. Cut along the small solid lines (the dashes) on the turbine pattern.
5. Use the nail to make a hole in the center of the turbine.
6. Trim the pie plate by cutting along the outer edge of the turbine pattern. Remove the turbine pattern from the pie plate.



7. Twist each blade of the turbine slightly in the same direction.

8. To make the shaft, cut a piece of drinking straw so that it is the same length as the one shown.

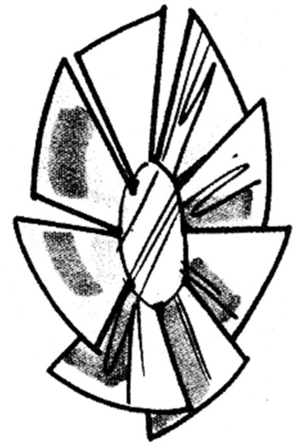


Straw length

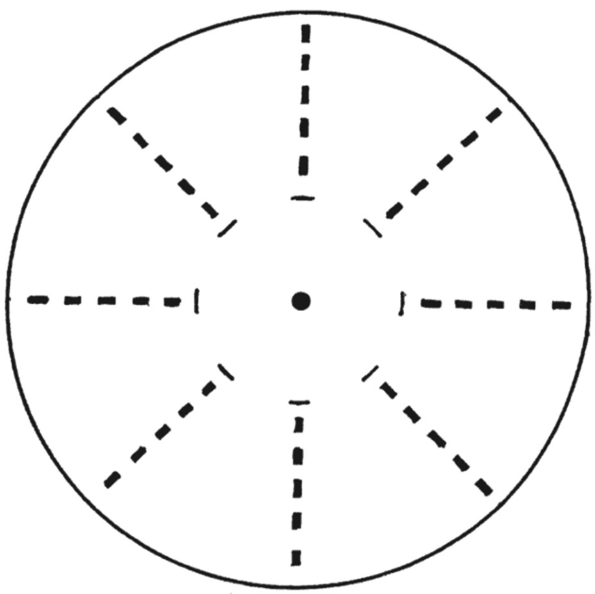
9. Carefully widen the hole in the turbine with a pencil point. Be sure you do not make the hole bigger than the straw. Put the piece of drinking straw through the hole. Make sure that the straw (shaft) fits snugly in the hole. Use glue if necessary. (Allow the glue to dry.)

10. Shape a paper clip into a long "L." Fit the shaft on the long end.

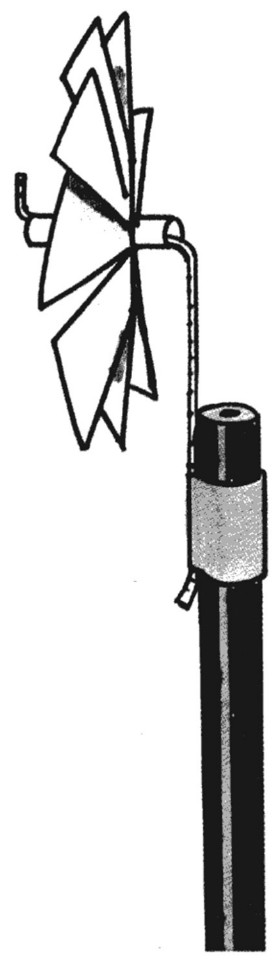
11. Bend the long end of the paper clip down as shown in the picture. Tape the pencil to the long end of the paper clip. Your turbine should now look like the drawing.



Twisted blades



Turbine pattern



Completed turbine

Using the Turbine

Part A: The Windmill

1. Blow lightly on the turbine from the side.

   Question: What happens?
   Our Answer:

2. Blow harder on the turbine.

   Question: What happens? Why?
   Our Answer:

Part B: The Waterwheel

1. Make a hole in the bottom of your foam cup with a nail. Widen the hole with your pencil. Then cover the hole with your finger and fill the cup with water. Hold the cup about six inches (15 cm) above the aluminum tray.

   Question: What kind of energy does the water in the cup have?
   Our Answer:

2. Let one group member hold the turbine just below the cup. Remove your finger from the cup.

   Question: What happens to the turbine?
   Our Answer:

Part C: The Steam Turbine

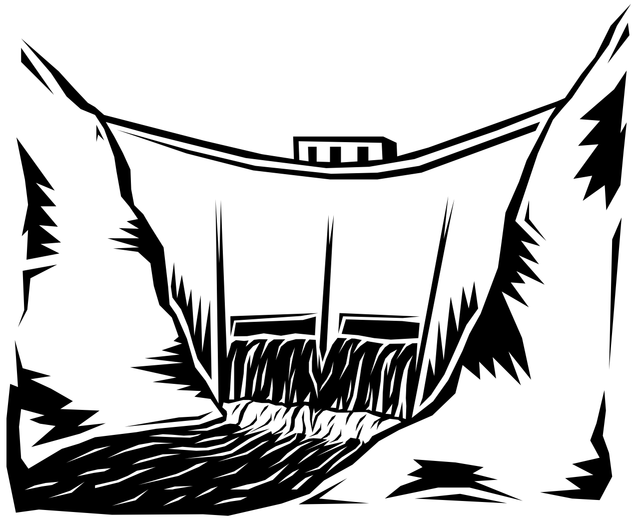
1. Hold your turbine over the hole in the spout of a boiling kettle of water.
   Caution: Make sure your fingers are not close to the spout; steam can burn!

   Question: Does Your turbine spin?
   Our Answer:

   Question: How was the steam made?
   Our Answer:

Facts about Hydropower

Introduction



Humans have used water as source of power for thousands of years. Civilization's earliest machines were waterwheels for grinding grain. The earliest reference to hydropower is in China between 202 BC and 9 AD. Later, waterwheels were adapted to drive sawmills, pumps, and bellows and to provide mechanical power for textile mills. Hydropower plants that produced electricity were developed in the late nineteenth century. Today, nearly all hydropower plants in the United States produce electricity. The term "hydroelectric power" is often used interchangeably with the term "hydropower."

A hydropower system converts the kinetic energy (energy of motion) in flowing water into other forms, such as electrical or mechanical energy. This conversion occurs when water flows past a waterwheel, propeller, or turbine. The farther the water falls the more kinetic energy it has. The kinetic energy of flowing water can be increased by building a dam across a river or stream.

Hydroelectric power is measured in kilowatt-hours, which is a measure of energy that calculates the power used over time. Kilowatt-hours is abbreviated as kWh. One kilowatt-hour of electrical energy is equal to 3,413 Btu (British thermal units). The power output of a hydroelectric power plant is measured in kilowatts (1,000 watts) or megawatts (1,000,000 watts).

Hydroelectric Power Plants

Hydroelectric power plants are generally located at places on rivers or streams that can be easily dammed to create a reservoir of water. Larger rivers with sufficient height for dams are ideal for providing electricity because the farther the water falls, the more kinetic energy there is to be harnessed. Penstocks channel flowing water into turbines which provide the mechanical energy to produce electricity in the generator. The amount of water released can be adjusted to meet the demand. Spillways divert excess water that builds up behind the dam. Most of the larger hydroelectric dams in the United States are on sizable rivers, such as the Colorado and Columbia in the West and those in the Tennessee Valley Authority region in the South.

One of the world's first hydroelectric power stations was built in Appleton, Wisconsin, in 1882, only three years after Thomas Edison's invention of the light bulb. This station's output was 12.5 kilowatts, which lit two paper mills and a house. The Wisconsin River, which runs the length of Wisconsin and spills into the Mississippi River, has been described as the "hardest working river in the nation." Most of the hydroelectric dams on the Wisconsin River are located on the upper two-thirds of the river. These dams have generating capacities between 700 kW and 29.5 MW (see ***Wisconsin Hydroelectric Sites***).

Electricity Production

In 2015, six percent of all electricity generated in the United States was generated using hydropower. Of the approximately 3,900 dams in Wisconsin, about 150 are used to generate hydroelectric power. These sites produced about 192,000 MWh (192,000,000 kWh) of electricity in 2015.

Facts about Hydropower

Hydroelectric power provided 16.6 percent of the world's electricity, or 3,900 terawatt-hours (TWh) in 2014. The world's three largest producers are China, Brazil, and Canada. The relatively small country of Norway generates about 95 percent of its electricity from hydropower.

Although most large-scale hydropower sites in Wisconsin and the U.S. have already been developed, some potential exists for small-scale, local hydropower plants. The amount of hydropower being generated today is nearly five times the worldwide potential amount estimated in 2011 at 946,182 MW. There are also immense undeveloped hydropower resources in northeastern Canada.

A number of industries in Wisconsin and the United States are located near large hydroelectric sites so they can use the cheap, reliable electricity these plants provide. Examples include the paper industry in Wisconsin and the aluminum smelting industry in the Pacific Northwest.

Effects

Hydropower offers several benefits. Hydroelectric power plants have no fuel costs and low operating and maintenance costs. They last two to ten times longer than coal and nuclear plants, emit no carbon dioxide or other air pollutants, and generate no waste. In addition, hydroelectric dams help control downstream flooding, provide water for crop irrigation, and create reservoirs that provide recreation and fishing.
Large reservoirs behind hydroelectric dams also flood vast areas, harm wildlife habitats, move human settlements, and decrease fertilization of farmlands and fish harvests below the dam. A concern currently being researched and mitigated is dam impediment to fish migration. Migrating fish such as salmon can be blocked by dams to traditional spawning sites and their population can be severely harmed. Fish ladders and passages have been implemented on a number of large and small dams across the globe to avoid this issue.

Outlook

Hydropower will continue to be an important energy resource in the United States and the world. However, it is unlikely that enough new hydroelectric plants will take the place of fossil- and nuclear-fueled electric power plants. Most available sites for large-scale hydroelectric power production in the United States have already been developed. On the other hand, the potential for further development of hydropower on smaller rivers and streams still exists. However, water shortages have decreased electricity produced by hydropower by 14 percent over the past two decades globally.

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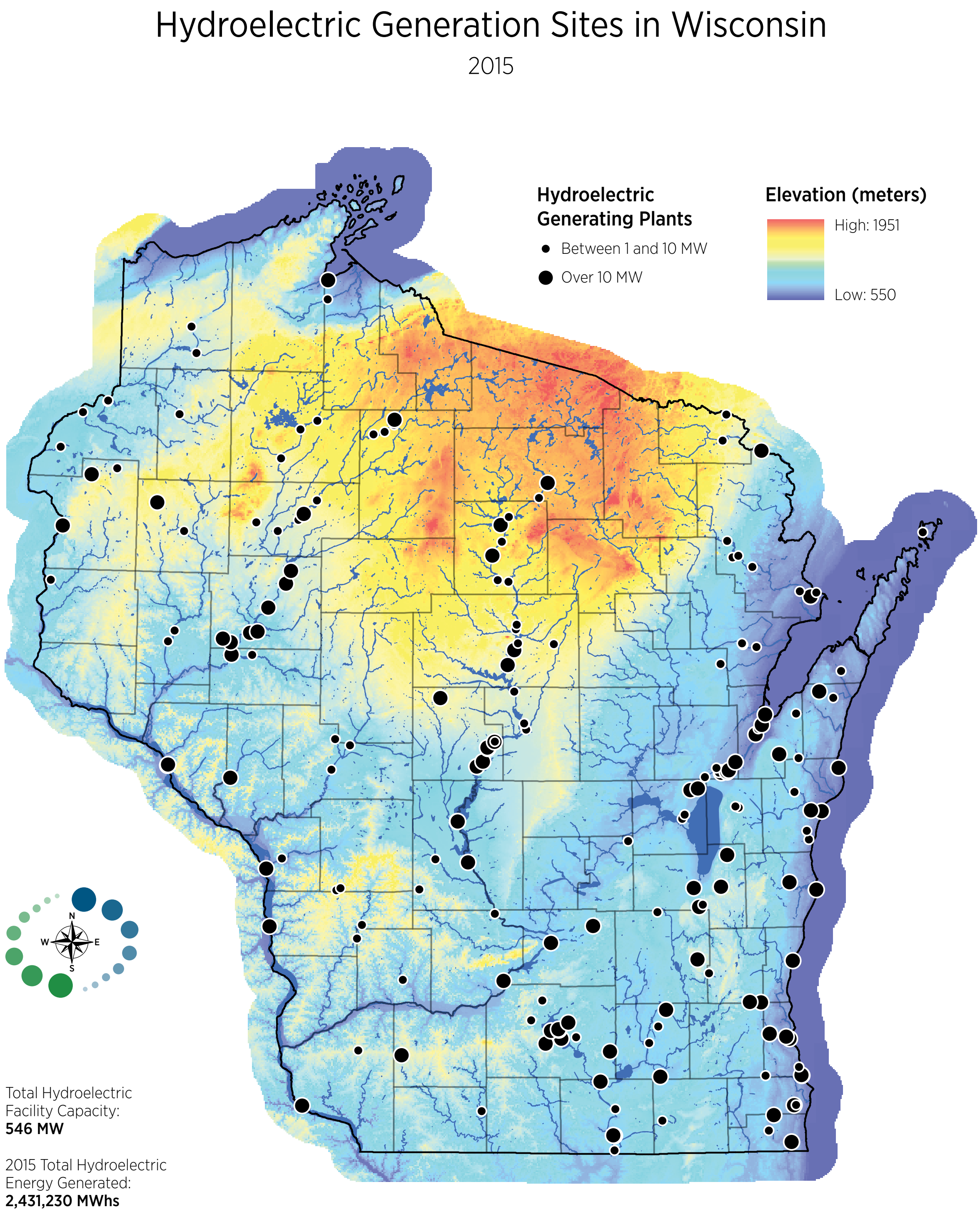
Wisconsin Hydroelectric Sites



(Capacity and energy generated include hydroelectric facilities owned by utilities, merchants, cooperatives, and other nonutilities.)

Source: Wisconsin Office of Energy Innovation. Wisconsin Energy Statistics Book.

Wisconsin Hydropower

Spillways at Wissota Hydro. Located on the Lower Chippewa River, this facility was completed in 1918 and produces 36.4 MW. Photo Courtesy of Xcel Energy.

Jim Falls Hydro auxiliary spillway adjacent to the power house. Located on the Lower Chippewa River, this facility was originally constructed in 1923. In 1984, a $92 million redevelopment project made it the largest hydro facility in the Midwest in terms of generating capacity (57.5 MW). Photo courtesy of Xcel Energy.

Facts about Wind Energy

Introduction

Wind energy, used by civilizations for thousands of years to grind grain and pump water using windmills, was reborn during the energy crisis of the 1970s when improvements in materials and technology made wind turbines more common. Today, wind-generated electricity is helping to provide for U.S. electrical needs.

Wind is created when solar energy heats the atmosphere. This heat produces differences in air pressure as cold air is denser than warm air. Air is made of gases and gases will naturally move from an area of high concentration to an area of low concentration to equalize pressure differences (reaching an equilibrium), creating wind as a result. In the process, energy from the sun is converted into kinetic energy (the energy in motion).

The output of a wind energy system is measured in kilowatts (1,000 watts) or megawatts (1,000,000 watts). Energy is power used over time and is calculated by multiplying power and time. Wind-generated electricity is measured in kilowatt-hours, a unit of energy. One kilowatt-hour of electrical energy equals 3,413 Btu (British thermal units).

Wind Potential

Wind resources are plentiful in the United States. With average, reliable wind speeds of 15 miles per hour or more, states in and around the Great Plains area of the United States possess the nation's greatest wind potential.

The best sites for wind potential in Wisconsin are found along Lake Michigan and Superior, where average wind speeds may reach 14 miles per hour (see ***Estimated Wind Power Energy Potential (at 70 meters) and Existing Wind Development Locations, 2015***). It is estimated that Wisconsin has an annual energy potential of 58 billion kilowatt hours, and it currently ranks 18th of the top 20 states for wind energy potential.

Electricity Produced Using Wind

The energy in wind is converted into electricity using wind turbines. A wind turbine is made up of an electrical generator mounted on a tower and connected to a propeller. The wind turns the blades of the propeller, causing the generator to spin and produced electricity. Rotor diameter and general sizes of turbines have increased and changed due to higher efficiency and more advanced technology (see **Average turbine nameplate capacity, rotor diameter, and hub height installed during period**).

Wind turbines can be used to provide electricity to single family homes, especially in rural areas. The electricity produced can be stored in batteries for use when wind speeds are low or when high winds could damage the turbine.

Electric utilities use larger wind turbines. Often the utility will place many wind turbines together in what is called a wind farm. The largest wind farm in the world is Gansu Wind Farm in China. Although it is not fully developed at this time, it had 10.73 GW installed at the end of 2014.

Facts about Wind Energy

Wind Electricity Production

Wind power supplies nearly five percent of our nation's electricity demand across 39 states. Worldwide, there are more than 268,000 wind turbines spinning to produce electricity. In 2014 installed wind capacity in Wisconsin was 648 MW with 417 turbines operating in utilities. Wind electricity production accounted for 2.5 percent of all in-state electricity production, enough to power 150,000 homes.

Other Uses

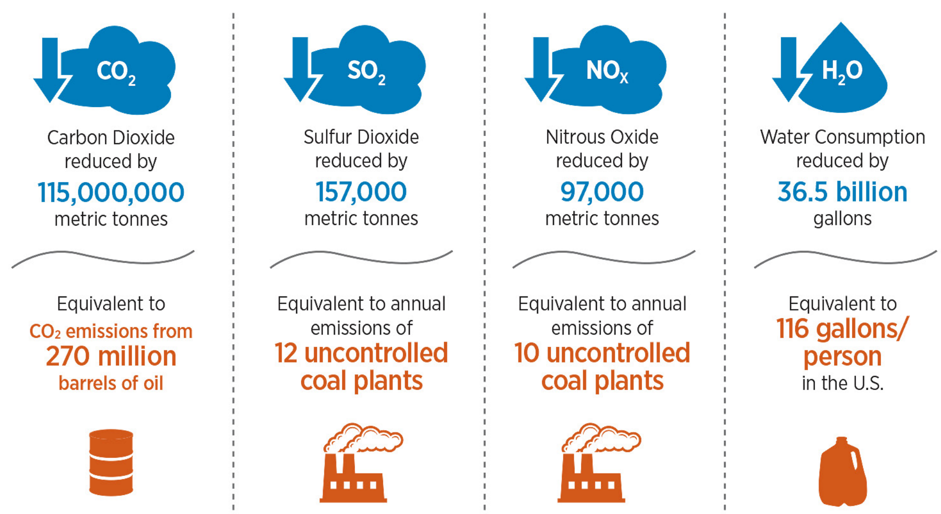
A modern wind turbine gets its design from windmills. Although windmills are not used as commonly anymore, they are still seen in rural parts of the U.S. and developing world to pump water or grind grain. A windmill is a device that has propeller blades connected to an axle with gears. The gears are connected to a vertical shaft that runs down the length of the tower and is connected to other mechanical equipment.

Effects

Wind energy has many benefits (see ***Wind generation in 2013 provided a range of environmental benefits***). Wind turbines have no fuel costs and low operating and maintenance costs. They produce virtually no air emissions or waste while in use. For example, the amount of electricity generated by the wind in one year in California avoided the production of 16 million pounds of air pollutants and 2.7 billion pounds of greenhouse gases. The wind plants also saved the equivalent of 4.8 million barrels of oil. In addition, wind energy creates jobs, is a 'homegrown' energy source, diversifies the national energy portfolio, can provide income for farmers, and can be deployed in all regions of the U.S.

However, wind energy is unreliable because the wind does not blow steadily in most places. Therefore, the electricity produced by home wind turbines needs to be stored in batteries, or a backup generator must be available, which increases the total cost of a wind energy system. On the other hand, a wind farm is

Wind generation in 2013 provided a range of environmental benefits.



Note: Emissions and water savings calculated using the EPA's Avoided Emissions and Generation Tool (AVERT). 'Uncontrolled coal plants' are those emissions control technology.

Source: Wind Vision: A New Era for Wind Power in the United States.

Facts about Wind Energy

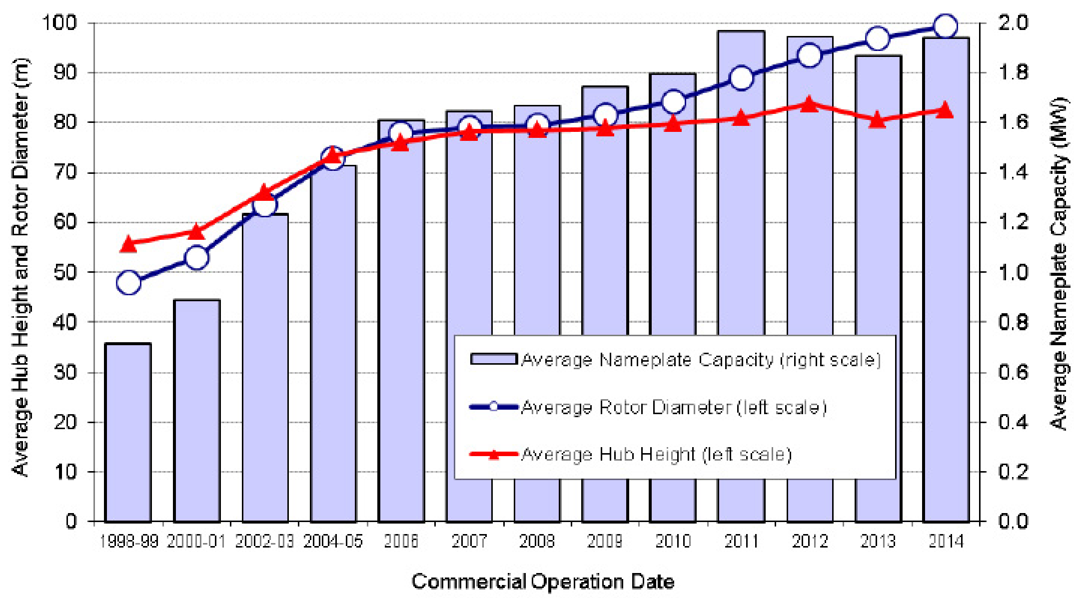
usually connected to a utility's power lines, so other power plants can supply electricity when the wind is not blowing. Some concerns about wind farms are aesthetic problems, propeller noise, and interference with birds' migratory patterns (although cell towers, electric lines, and domestic cats pose comparable threats to bird flight and populations). In addition, it is also important to assess the amount of waste and emissions produced by the manufacturing, transportation, and implementation processes of wind energy. Understanding these impacts and reducing environmental harms during the manufacturing processes will make wind energy even more appealing.

Outlook

After a lull, wind energy additions rebounded in 2014. Continued growth through 2017and beyond is expected and likely to become more mainstream. Texas continues to lead the nation in wind energy production, but other states such as Minnesota have implemented large-scale wind systems. Europe has aggressively developed wind power, and it has taken over hydropower as the third largest source of power generation in the EU. India, Brazil, China, Mexico, and Egypt also have sizable wind power projects underway.

Experts predict that by the year 2020 wind power could supply the U.S. with about 10 percent of the total electricity produced. No offshore wind energy plants are currently operating in the U.S. but progress is being made toward an offshore project in Rhode Island. The cost of wind-generated electricity has fallen and is becoming competitive with other ways of generating electricity. While wind energy is not expected to completely replace fossil- and nuclear-fueled electric power plants, its environmental advantages make it an attractive choice for the future.

Average turbine nameplate capacity, rotor diameter, and hub height installed during period (only turbines larger than 100kW)



Source: AWEA project database

Facts about Wind Energy

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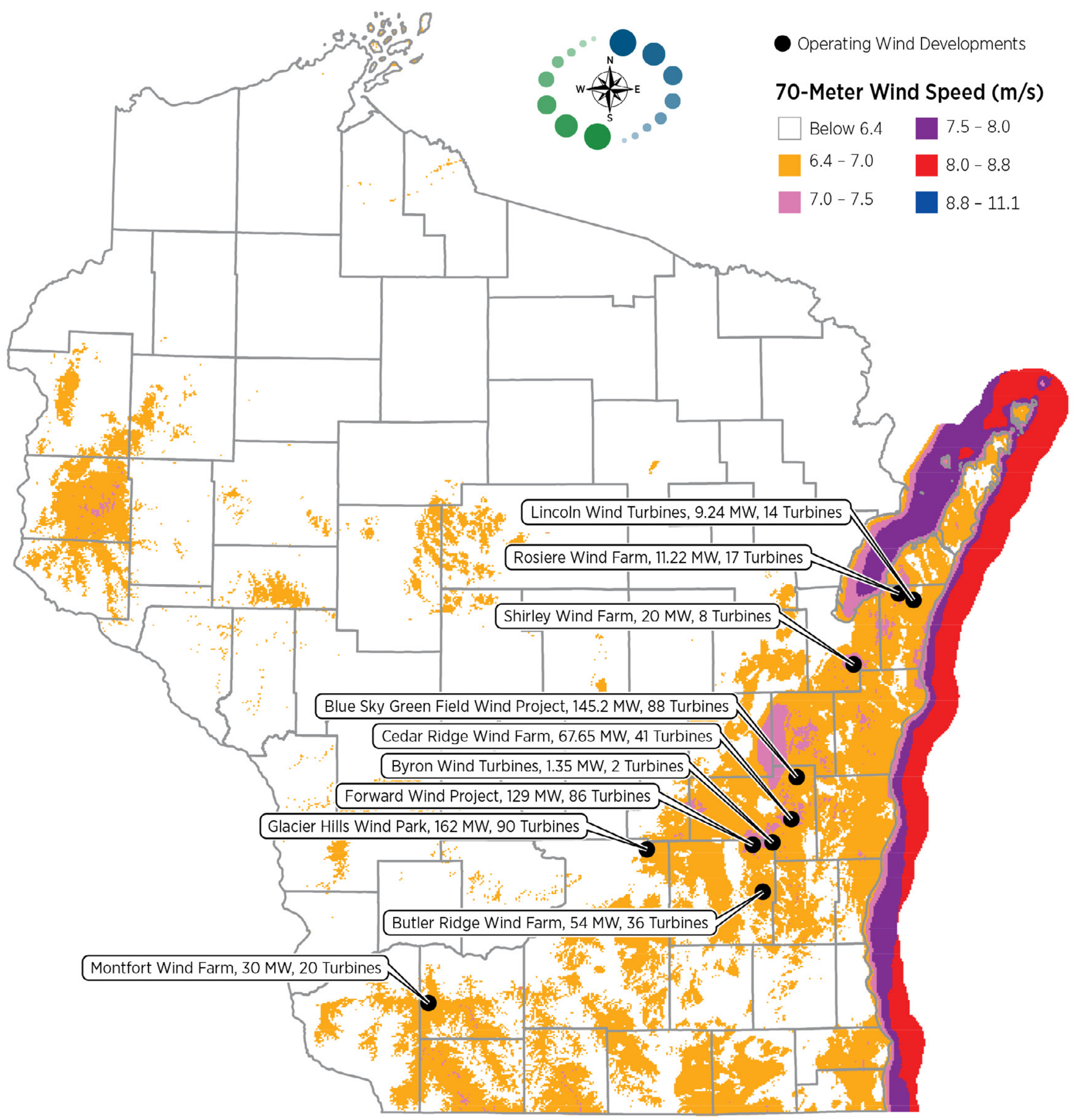
Facts about Wind Energy

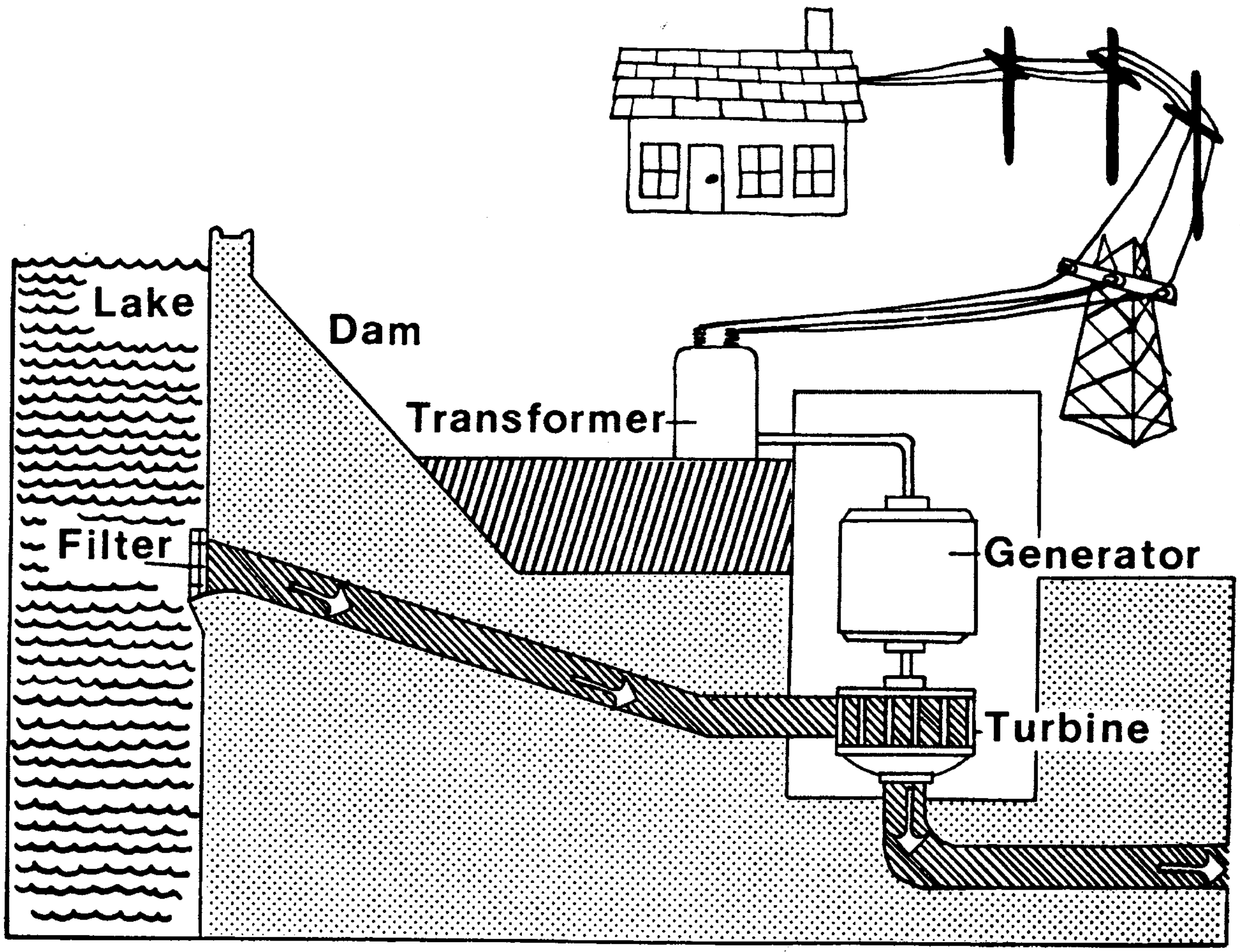
Estimated Wind Power Energy Potential (at 70 meters) and Existing Wind Development Locations

2015



Source: AWS Truewind (2008); Wisconsin Office of Energy Innovation. Wisconsin Energy Statistics Book: Wisconsin Energy Statistics 2018.

Electricity from Falling Water



Hydroelectric power is provided by the motion of falling water. When water that has been trapped in a lake behind a dam is released as needed, it can be made to flow through the turbines, which activate generators that make electricity.

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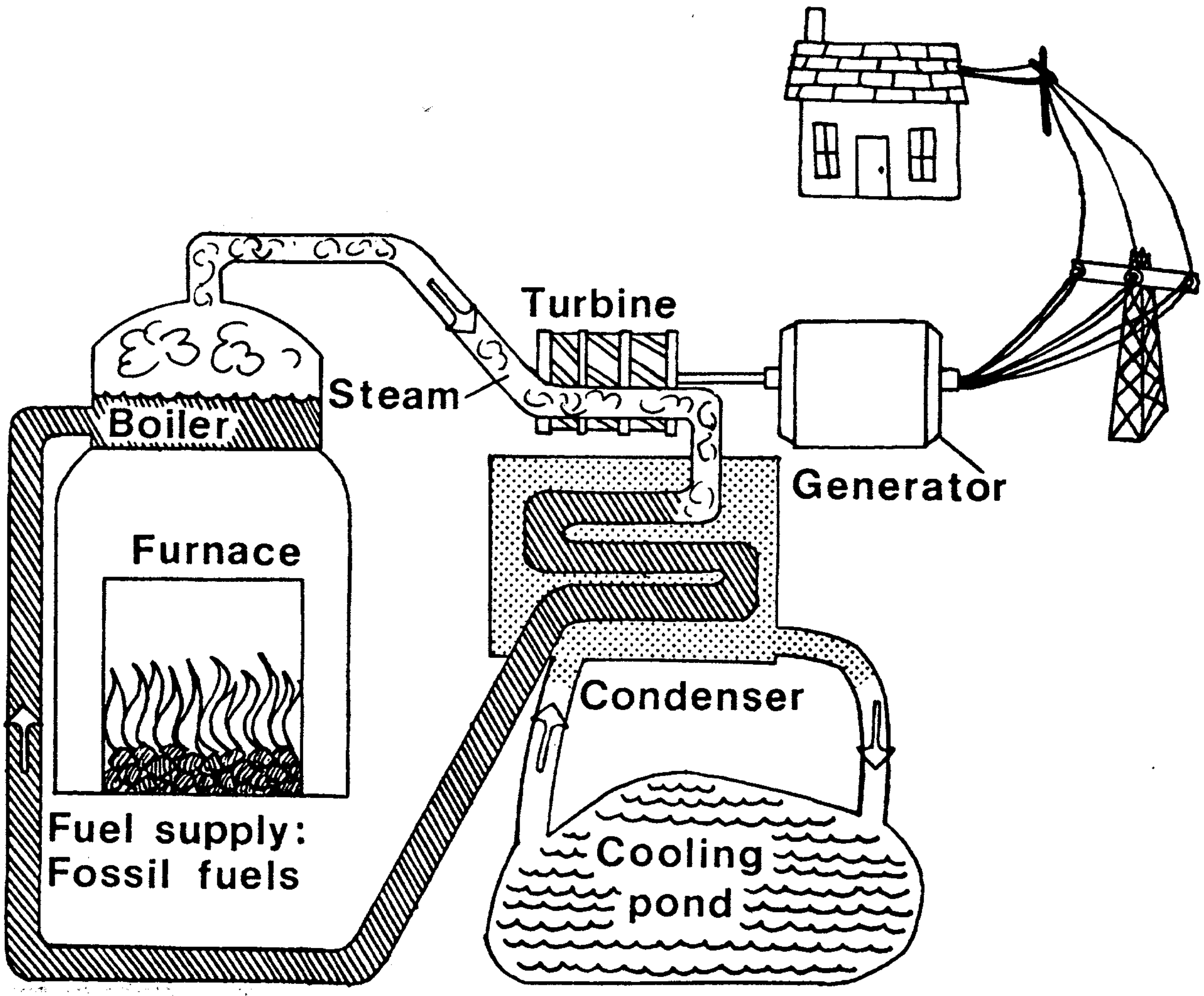
Alliant Energy, WPPI energy, We, WPS, Xcel Energy, MGE

Electricity from Fossil Fuels



Fossil fuels (oil, gas, coal) produce electrical power when they are burned in a furnace to heat boilers that make steam. The steam turns a turbine, drives a generator that makes electricity.

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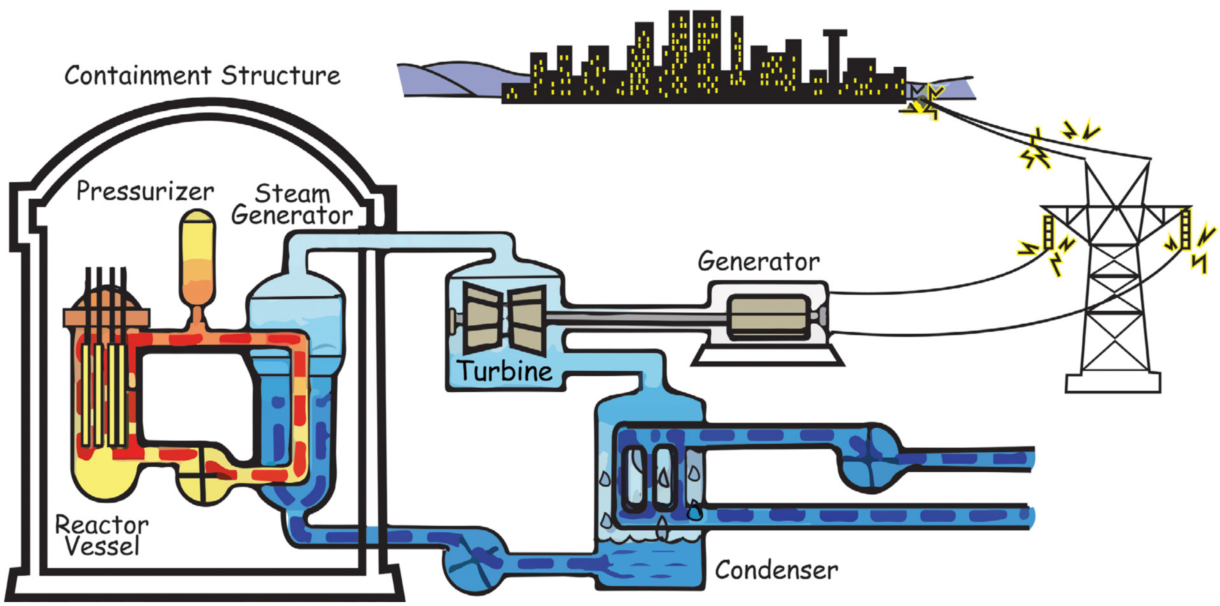
Electricity from Uranium

The Pressurized-Water Reactor (PWR)



Uranium is used in a nuclear reactor to produce electrical power. The uranium is split and gives off heat, which makes steam from water. The steam turns a turbine, which drives a generator. The generator makes electricity.

Source: U.S. NRC. What is Nuclear Energy?

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