**Educator Kit: Wind Energy**
**Materials List**

**2 PVC turbines**

**15 turbine hubs**

**75 dowel blades**

**2 sets of alligator clips**

**1 gearbox**

**2 multimeters**

**2 generators**

**2 protractors**

**1 wire stripper**

**4 books**
<u>Energy Island</u>
<u>Catch The Wind</u>
<u>Wind the Wold Over</u>
<u>The Boy Who Harnessed the Wind</u>

**Wind Energy Classroom Kit (Teacher Resource)**

Ages: grade 4 & up

**Transform wind energy into electricity!**
The electricity generated by the pvc wind turbine can be measured with a multimeter. The size, shape, and angle of the turbine blades can be modified to produce different amounts of electricity. Students will enjoy experimenting with different blade materials to explore their effect on generating electricity.

**Classroom Kit includes:** pvc parts to create two wind turbines, gearbox, generators, multimeters, and adequate supplies for small group blade design exploration

**Donated by the Center for the Advancement of Sustainable Energy**

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**How Does a Wind Turbine Work?**
https://www.youtube.com/watch?v=gHUJqTT3THU

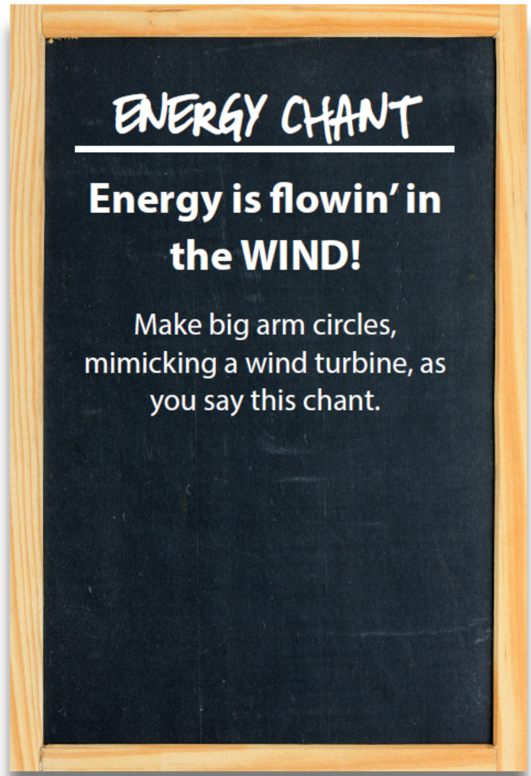
**How to build a pvc wind turbine?**
https://www.youtube.com/watch?v=cq6_0fIMHg8&t=471s

**KidWind Renewable Energy Challenge**
https://www.youtube.com/watch?v=n9rR9NH8l1Y

**Contact Information**

case@jmu.edu www.jmu.edu/case

# Wind Energy
## *TEACHER*




Wind is moving air. We can use the energy in wind to do work. Early Egyptians used the wind to sail ships on the Nile River. People still use wind to move them in sailboats. In the Netherlands, people used windmills to grind wheat. The Pilgrims used windmills to grind corn, pump water, and run sawmills. Today, we use wind to make electricity.

The energy in wind comes from the sun. When the sun shines, it heats the Earth. Some parts of the Earth get hotter than others. An area where land and water meets is a good example. Land usually absorbs and releases energy more quickly than water. The air over the land gets hotter than the air over the water. The warm air rises and cooler air rushes in to take its place. The moving air is wind.

As long as the sun shines, there will be winds on the Earth. We will never run out of wind energy. It is a **renewable** energy source. It is also free, since no one can own the sun or the air.

Some places have more wind than others. Areas near the water usually have a lot of wind. Flat land and mountain passes are good places for the wind, too. Today, we use big **wind turbines** to catch the wind. Sometimes, there are hundreds of wind turbines in one place. This is called a **wind farm**. Not all wind farms are on land; some countries have wind farms on the water. These are called **offshore wind farms**. The first offshore wind farm in the United States was built off the coast of Block Island, Rhode Island. The five-turbine wind farm began generating electricity for Block Island in 2016. Two new turbines were built in 2020 off of the coast of Virginia, with a large wind farm planned for 2024 in the same area. More wind farms will also be built on the Atlantic Ocean.

Many of the wind turbines on wind farms are very tall so they can catch the most wind. Some wind turbines are taller than a 20-story building or the Statue of Liberty! Not all wind turbines are that big, though. Some wind turbines might be only 30 feet tall. People can put these small turbines up in their backyards to generate electricity to use at home. Schools can put small wind turbines on their property to make electricity, too. Small wind turbines can even be put on sailboats so people have electricity when they are sailing on the water.

When the wind blows, it pushes against the blades of the wind turbines. The blades spin around. They turn a **generator** to make electricity. The wind turbines do not run all the time, though. Sometimes the wind does not blow at all. Sometimes the wind blows too hard. Most wind turbines operate 65 to 90 percent of the time.

Today, wind energy makes 9 percent of the electricity we use. Most of the big wind farms are in Texas, Oklahoma, Iowa, Kansas, and Illinois. More wind turbines and wind farms are popping up all over the country.

# What is Wind?

You can't see air, but it is all around us. You hear leaves rustling in the trees. You see clouds moving across the sky. You feel cool breezes on your skin. **Wind** is moving air.

## The Sun Makes the Wind Blow

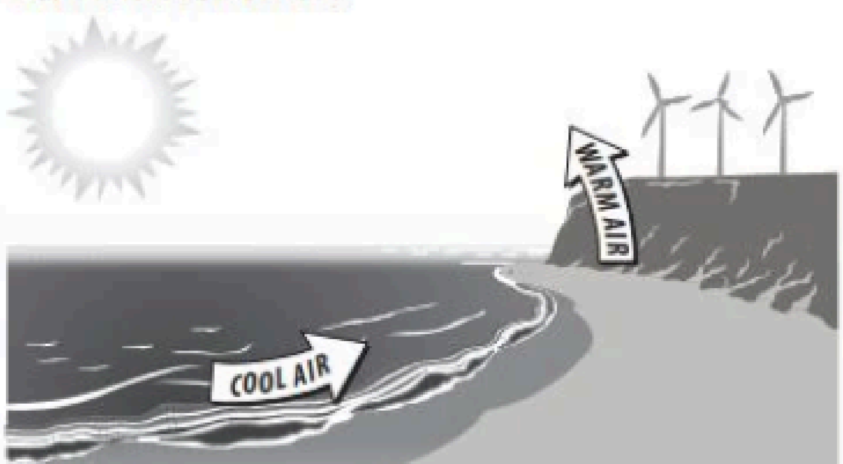
The energy in wind comes from the sun. When the sun shines, it heats the Earth's surface. The **Equator** gets more sunlight (**radiant energy**) than the North or South Poles. The Earth is not heated evenly.


Dark areas of land, like forests, **absorb** a lot of solar energy. Areas of water **reflect** solar energy. Light colored desert sand, snow, and ice reflect the sunlight, too.

As the Earth's surface absorbs the sun's energy, it turns the light into heat. The heat on the Earth's surface warms the air above it. The air over the Equator is warmer than the air over the **poles**. The air over land is warmer than air over water.

As air heats, it expands. Hot air rises. Cooler air rushes in to take its place. This moving air is wind. Wind is caused by the uneven heating of Earth's surface.

### How Wind is Formed




1. The sun shines on land and water.
2. Land heats up faster than water.
3. Warm air over the land rises.
4. Cool air over the water moves in.

**Cover Photo: 129MW Forward Wind Energy Center.**
**Photo by Ruth Baranowski, NREL 16411**

# Using a Multimeter "Cheat Sheet"


## Measuring Voltage:

- Voltage is the difference in electrical potential between two places in the circuit
- We therefore measure voltage **across** an element, meaning that we connect the multimeter in **parallel** with the element of interest
- To prevent the multimeter from changing the circuit, we want **very little current** to flow through the meter, so the meter needs to have a **very high resistance**


## Measuring Current:

- Current is the measure of how fast electrical charges move through a branch of the circuit
- We therefore need all of the current passing **through** an element to pass through the multimeter, meaning that we connect the multimeter in series with the element of interest
- To prevent the multimeter from changing the circuit, we want **as small a voltage drop** across the meter as possible, so the meter needs to have a **very low resistance**

## Setting the Dial:

- There are four settings on the multimeter. In general, we will be using DC voltage (V⎓) measured in "Volts" and DC current (A⎓) measured in "Amps," hence the "V" and "A" designations on the multimeter.
- The numbers along the dial represent **ranges of measurement**. For instance, the first range of measurement on the voltage side of the meter in the images above is from 200mV to 2V. If your expected reading is less than 200mV, you should set the dial to 200m. If it's greater than 200mV, but less than 2V, you should set the dial to 2, etc. The values get larger in the clockwise direction around the dial.

https://www.cebrightfutures.org/sites/default/files/multimeter-cheatsheet_0.pdf

**Kits available from**

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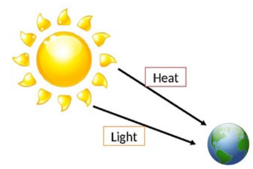
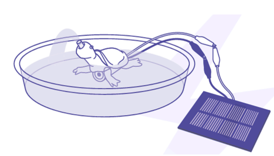
**Exploring Wind Energy**

**Exploring Solar Energy**



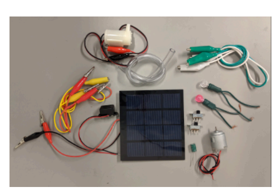

**Wind Powered Light (Firefly)**

**Solar Powered Water Fountain**



**Educator Kit: Wind Energy**

**Educator Kit: Solar Energy**



# WindWise Education

## *Wind Energy Activities for Students*

### *LESSON 10: WHICH BLADES ARE BEST?*






ISBN 978-1-4951-4354-0

# WHICH BLADES ARE BEST?

LESSON 10

## KEY CONCEPT

Students learn through experimentation how different blade designs are more efficient at harnessing the energy of the wind.

## TIME REQUIRED

1–2 class periods

## GRADES

6–8
9–12

## SUBJECTS

Physics
Technology/Engineering
Mathematics

KidWind PROJECT®

www.KidWind.org

## BACKGROUND

The blades of a wind turbine have the most important job of any wind turbine component; they must capture the wind and convert it into usable mechanical energy. Over time, engineers have experimented with many different shapes, designs, materials, and numbers of blades to find which work best. This lesson explores how engineers determine the optimal blade design.

## OBJECTIVES

At the end of the lesson, students will:

- understand how wind energy is converted to electricity
- know the process of scientific inquiry to test blade design variables
- be able to collect, evaluate, and present data to determine which blade design is best
- understand the engineering design process

## METHOD

Students will use wind turbine kits to test different variables in blade design and measure the power output of each. Each group of students will isolate one variable of wind turbine blade design, then collect and present data for that variable. If time allows, students can use their collected data to design an optimal set of wind turbine blades using the next lesson, "How Can I Design a Better Blade?"

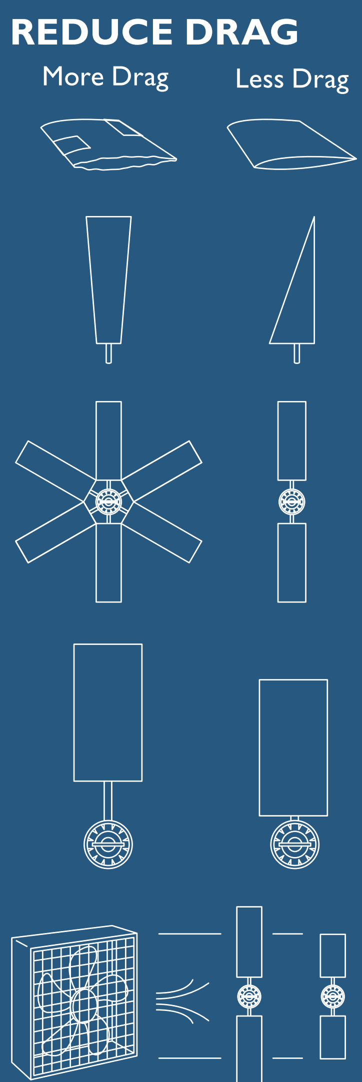
## MATERIALS

You will need one set of the following materials for each group:

- ❑ 1 model turbine on which blades can quickly be interchanged
- ❑ 1 multimeter or voltage/current data logger
- ❑ 1 box fan
- ❑ Milk cartons, PVC pipe, or paper towel rolls (optional)
- ❑ Ruler
- ❑ Pictures of wind turbine blades
- ❑ Sample blades of varying sizes, shapes, and materials
- ❑ Balsa wood, corrugated plastic, card stock, paper plates, etc.
- ❑ ¼" dowels
- ❑ Duct tape and/or hot glue
- ❑ Scissors
- ❑ Protractor for measuring blade pitch
- ❑ Safety glasses
- ❑ Poster-size graph paper (optional)
- ❑ Student reading passages and student worksheets*

*included with this activity

Additional Resources for every lesson can be found at http://learn.kidwind.org/windwise/. Resources include presentations, videos, extension activities, and other materials.




## GETTING READY

- Students should already have a basic understanding of wind energy, including the following:
  - what a wind turbine is
  - the fundamental parts of a wind turbine
  - how wind turbines transform energy from the wind
  - basic variables that impact turbine performance
- Most of this background was covered in the lesson "How Does a Windmill Work?" The additional resources listed at the end of this lesson also provide helpful information.
- The Blade Design PowerPoint found in the Additional Resources section will also be helpful for this lesson. This slideshow features descriptions of different blade designs and close-up pictures of wind turbine blades.
- Set up a safe testing area. Clear this area of debris and materials. Make sure the center of the fan is aligned with the center of the wind turbine. If you are working with multiple turbines, set them up so students will not be standing in the plane of rotation of a nearby turbine.
- Prepare three or four simple blade sets as samples for students to begin to see several variables and figure out how to build blades. Make sure the sample blade sets display different blade variables, such as length, material, and number of blades.
- Make copies of worksheets.

## ACTIVITY

**Step 1: Beginning questions for students**

- What do you think makes one turbine work better than another?
- What variables affect the amount of power a turbine can generate?
- Do some variables matter more than others? (For example, is turbine height more important than the number of blades?)
- What do modern wind turbine blades look like? Is this similar to those on older windmills? Why?
- How many blades do most wind turbines have? What do you think would happen with more or fewer blades?

**Step 2: Brainstorm blade variables**

Provide students with photos of different turbine designs, using the Blade Design PowerPoint or other photos found in the Additional Resources. Ask students to brainstorm some of the variables that affect how much energy the blades can capture while they are looking at the photos.

Variables may include:

- blade length
- number of blades
- weight/distribution of weight on blade
- blade pitch/angle
- blade shape
- blade material
- blade twist

**Step 3: Determining variables**
Organize students into small groups. Four students per group is optimal. Give each student a worksheet. Have each group select one variable to test. Length, number, pitch/angle, and shape are easy variables to test, but students can come up with additional variables as well. Before constructing blades, groups should determine what needs to be held constant in order to effectively test their variables.

If you are conducting this exercise as a demonstration, ask students which variable will perform better and why before testing it. Students will complete their worksheets while the teacher tests each variable. Students can take turns attaching blades or reading the multimeter.

**Step 4: Building blades**
Depending on the variable being tested, some groups will have to build multiple sets of blades, while other groups will only build one set. For example, the group testing blade material will have to build one set of identical blades with each material being tested. The group testing pitch/angle, however, will only build one set of blades and then test the angle of these blades on the turbine. Groups should collect their blade materials, then work together to construct blades.

**Step 5: Testing blades**
The group will attach each set of blades to the turbine and test it at both high and low wind speeds. The group can change wind speed by moving the turbine away from the fan or turning the fan lower. Wind coming from a fan is very turbulent and does not accurately represent the wind a turbine would experience outside. To clean up this turbulent wind, students can make a wind tunnel by building a honeycomb in front of the fan using milk cartons, PVC pipe, or paper towel rolls. This will slow the wind coming off the fan, but it will also straighten it out.

Be sure students understand what blade pitch (angle) is and how they will measure it or keep it constant. This concept was introduced in "How Does a Windmill Work?"

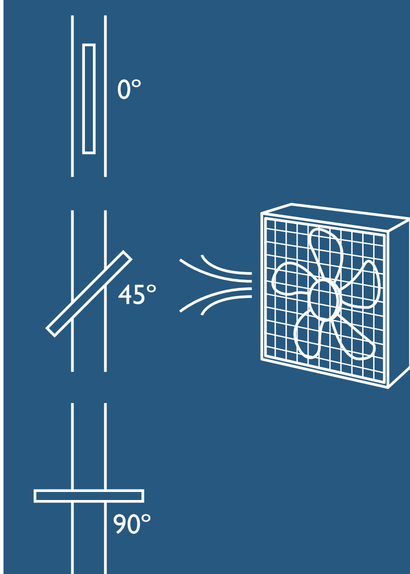
Make sure that students keep pitch constant while testing other variables or the results can be problematic.

Students will measure the voltage with a multimeter and record their data on the worksheet. If time permits, ask students to do three replications of each variable and average their results.

**Step 6: Analysis**
Once students have collected their data, tell them to answer the questions on the worksheet and make a graph of their data to present to the class. If poster-size graph paper is available for students, ask them to replicate the graph on this paper for their presentations.

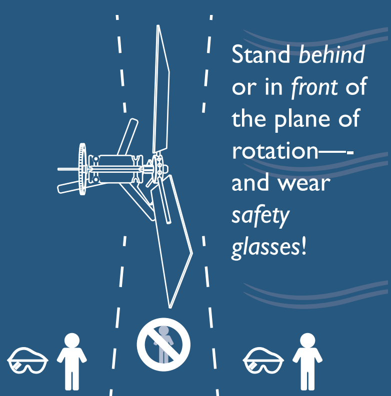
## BLADE PITCH

Blade pitch is the angle of the blades with respect to the plane of rotation. The pitch of the blades dramatically affects the amount of drag experienced by the blades. Efficient blades will provide maximum torque with minimum drag. Measure pitch with a protractor.




## ⚠ CAUTION!

- Do not stand in the plane of rotation of the rotor! You could be hit if your blade flies off during testing.
- The spinning rotor blades and metal rod can be dangerous. Make sure students work with caution.
- Be careful when working with the metal rod. Do not swing or play with the rod! The ends can be protected with tape, foam, cork, etc.
- Wear safety glasses when testing windmills. Safety glasses must be worn any time blades are spinning.




**Step 7: Presentation**

Each group will have five minutes to present its data to the class. Students should discuss their variables, how they designed the blades, and the results. Ask all the students to record the results from each group on their worksheets so they have all of the class results.

**Step 8: Wrap up**

Wrap up the lesson with some of the following questions:

- What variable has the greatest impact on power output?
- What type of blades worked best at low speeds? High speeds?
- What number of blades worked best?
- What shapes worked best?
- What length worked best?
- What problems did you encounter?
- Did longer blades bend backward in the wind? Was this a problem?
- What happened when the diameter of the turbine rotor was bigger than the diameter of the fan?

Ask students to analyze the class data and describe an optimal blade design. If time permits, this can be used as a starting point for the extension lesson: "How Can I Design a Better Blade?"

## EXTENSION

The following extension may be made for grades 9–12:

- Ask students to also collect amperage data and calculate power. Discuss voltage, amperage, and power and how they relate to one another.
- Ask students to determine the efficiency of their turbines. The efficiency of a turbine is a comparison between the theoretical power available in the wind and the actual power output of the turbine. To calculate the theoretical power in the wind, students can use this equation:

  $P = \frac{1}{2} \varrho (\pi r^2) V^3$
  
  P = total power available in the wind
  
  $\varrho$ = air density (1.23 kg/m$^3$ at sea level)
  
  $\pi$ = pi (3.14)
  
  r = rotor radius (length of one blade)
  
  V = velocity of the wind

Turbine efficiency is equal to the total power output of the turbine divided by the theoretical power available. Do not be surprised if your efficiency is under 5 percent. The maximum theoretical efficiency of a wind generator is 59 percent. Research Betz Limit to learn more about this.

## VOCABULARY

amperage – A measure of the rate of flow of electrical charges.

$$1 \text{ ampere} = \frac{1 \text{ volt}}{1 \text{ ohm}} = \frac{1 \text{ watt}}{1 \text{ volt}} \quad \text{or } 1 \text{ amp} = \frac{V}{R} = \frac{P}{V}$$

blade pitch – Angle of the blades with respect to the plane of rotation. (Blades perpendicular to the oncoming wind would be 0 degrees. Blades parallel to the wind would be 90 degrees).

drag – In a wind turbine, also called wind resistance. The friction of the blades against air molecules as they rotate. Drag works against the rotation of the blades, causing them to slow down.

lift – A force encountered by the blades that is perpendicular to the oncoming flow of air. Lift is a force working to speed up the rotation of the blades.

multimeter – An electronic instrument that can measure voltage, current, and resistance.

power – The rate at which energy changes form from one form to another, or the rate at which work is done

voltage – The electrical pressure or potential difference that drives the electric current. 1 volt = 1 amps × 1 ohm = 1 watts / 1 amps

wattage – the metric unit of power. In electricity, one watt of power is equal to one ampere of electric current being forced to move by one volt of potential difference. One watt is also equivalent to one joule of energy per second. 1 watt = 1 volt × 1 amp.

## RELATED ACTIVITIES

- Lesson 8: How Does a Windmill Work?
- Lesson 11: How Can I Design Better Blades?
- Advanced Blades Appendix

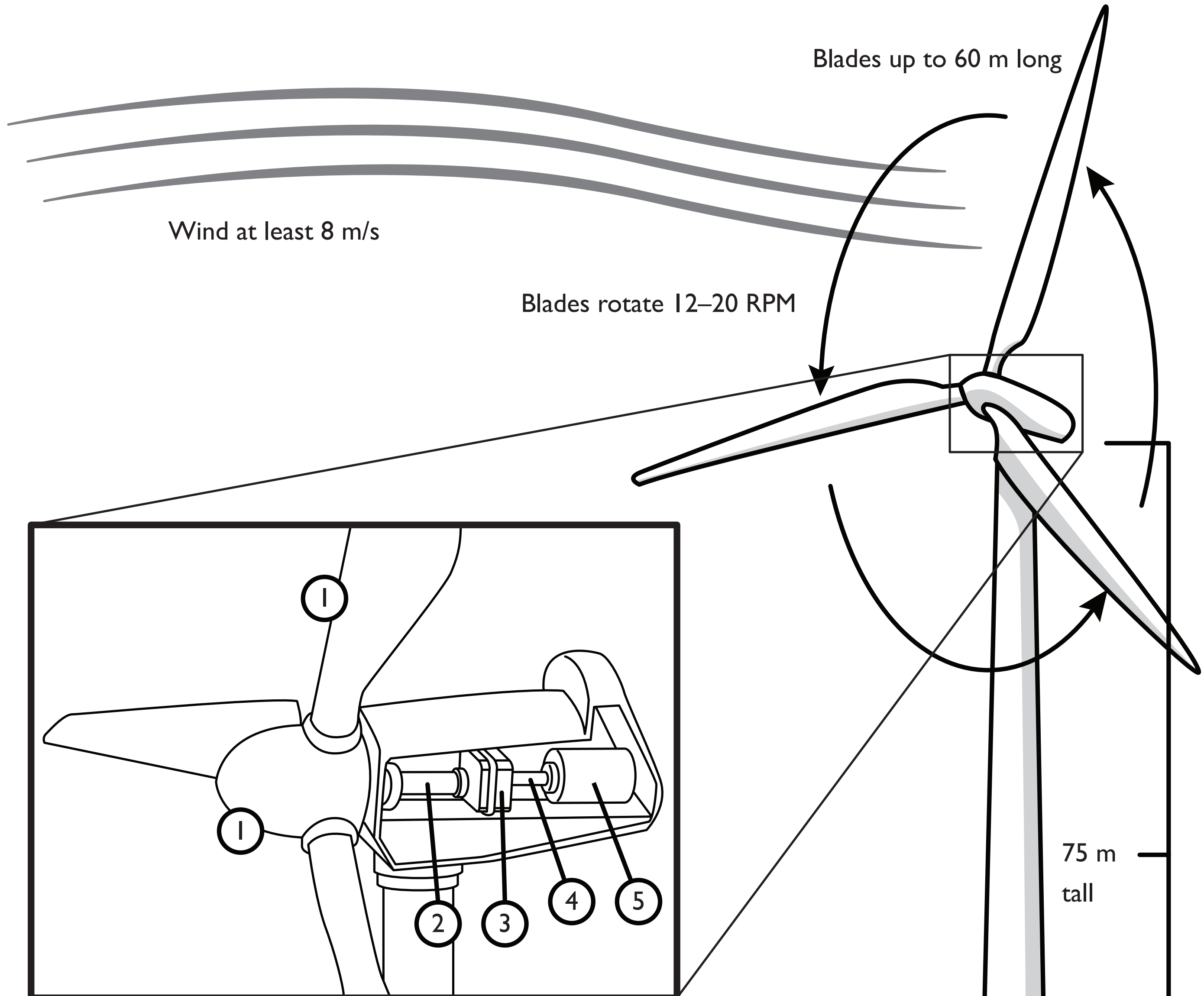
## USE A MULTIMETER WITH YOUR WIND TURBINE

Students need to know how to record voltage and amperage with a simple multimeter. Make sure you have done this yourself and can explain it to the students. It is important to ensure that the units are correct. If you multiply volts by milliamps, you will get a confusingly large and incorrect number for power. It is okay to just record voltage, which can make things easier.

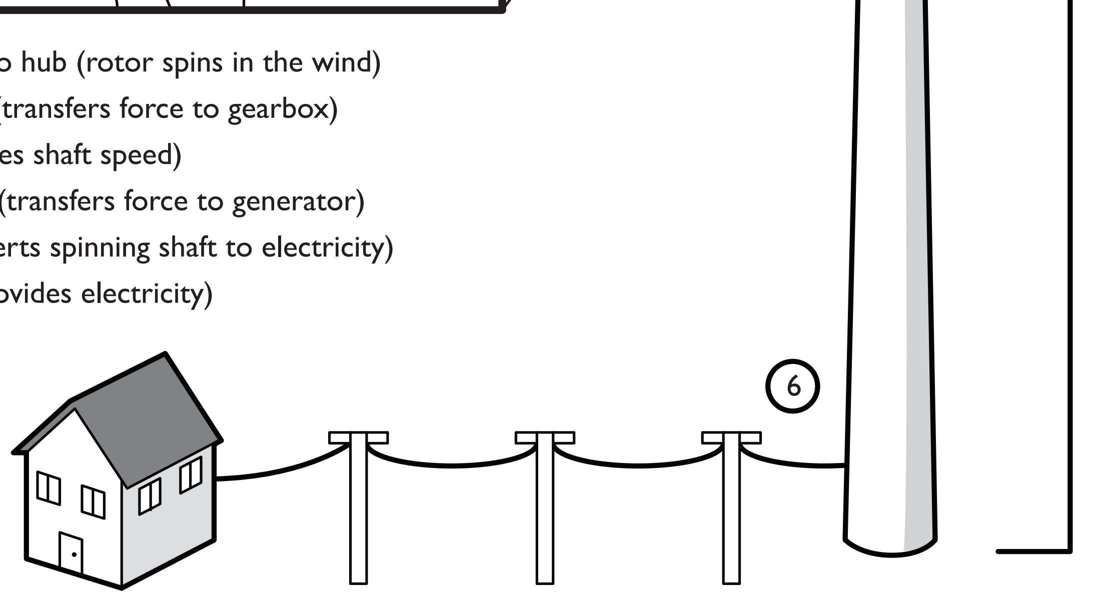
Small DC motors do not produce much power when spun slowly. A wind turbine without gears will not get more than 2 volts. On a wind turbine with gears, power output can be increased (2–8 volts) using gears to spin the shaft of the generator faster than the hub.

For videos on using a multimeter see additional resources at http://learn.kidwind.org/windwise

# ENERGY TRANSFERS AND CONVERSIONS IN A TURBINE




1. Blades attached to hub (rotor spins in the wind)
2. Spins drive shaft (transfers force to gearbox)
3. Gearbox (increases shaft speed)
4. High speed shaft (transfers force to generator)
5. Generator (converts spinning shaft to electricity)
6. Wires to grid (provides electricity)



Name______________________________________ Date________________ Class_________

**Variable**

What variable will you test for your experiment? _______________________________________

**Constants**

What variables do you have to keep the same (constant) as you perform this experiment?

**Experimental design**

Describe how you will perform this experiment.

1. What materials will you use?

2. How many times will you test your variable?

3. How long will you run the test?

4. How will you change your variable?

5. What will you use to measure your output?

**Hypothesis**

1. What do you think will happen?

2. Why do you think this will happen?

**Data tally sheet: grades 6–8**

| | LOW SPEED | HIGH SPEED |
|---|---|---|
| **VARIABLE** (e.g., length, in cm) | **VOLTAGE** (mV *or* V) | **VOLTAGE** (mV *or* V) |
| | | |
| | | |
| | | |
| | | |

**Graph your data**

Voltage output

Variable tested (length, number, etc.)

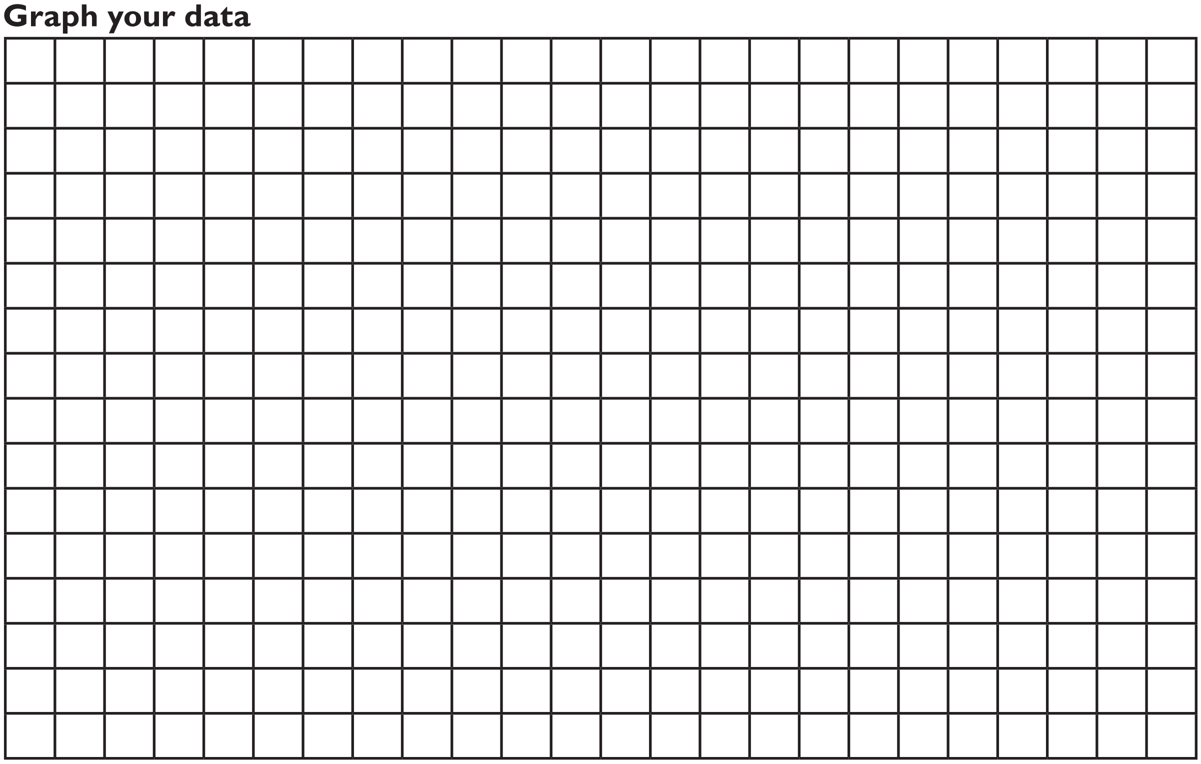
**Data tally sheet: grades 9–12**

| **LOW SPEED** | | | |
|---|---|---|---|
| **VARIABLE** (e.g., length, in cm) | **VOLTAGE** (mV *or* V) | **AMPERAGE** (mA *or* A) | **(V × A) = POWER** (mW *or* W) |
| | | | |
| | | | |
| | | | |
| | | | |

| **HIGH SPEED** | | | |
|---|---|---|---|
| **VARIABLE** (e.g., length, in cm) | **VOLTAGE** (mV *or* V) | **AMPERAGE** (mA *or* A) | **(V × A) = POWER** (mW *or* W) |
| | | | |
| | | | |
| | | | |
| | | | |

**Graph your data**

Voltage output



Variable tested (length, number, etc.)

Name______________________________________ Date________________ Class_________

**What happened?**

1. How did the voltage change as a result of manipulating the variable?

2. What was the optimal setting for the variable that you tested?

3. Do you think that the variable that you tested has a large or small effect on how much power the turbine can make?

4. What problems did you encounter as you performed your experiments? How could you fix these problems?

**Class results**

Record the results from the class experiments in the table below.

**Power = Voltage (V) × Current (A)**

Make sure you are recording volts and amps (not milliamps). 1 A=1,000 mA

| VARIABLE | VOLTAGE (V) | AMPERAGE | POWER OUTPUT |
|---|---|---|---|
| (e.g. length cm) | | (extension) (mA or A) | (optional) (mW or W) |
| 15 cm | 1.7 | **100 mA** | **0.17 W** |
| | | | |
| | | | |
| | | | |

1. If you were a lead design engineer, what would you recommend your company do to their turbine blades based on the class results? Why?

**Variable**

What variable will you test for your experiment?

*Answers will vary. Example variables: Blade pitch, blade shape/size, material of blades, number of blades, etc.*

**Constants**

What variables do you have to keep the same (constant) as you perform this experiment?

*Answers will vary. Example variables: Blade pitch, blade shape/size, material of blades, number of blades, etc.*

**Experimental design**

Describe how you will perform this experiment.

1. What materials will you use?
   *Answers will vary. Balsa, corrugated plastic, paper plates, cardboard, etc.*

2. How many times will you test your variable?
   *Variables should be tested at least twice.*

3. How long will you run the test?
   *Answers will vary. Trials should last at least 20 seconds.*

4. How will you change your variable?
   *Answers will vary.*

5. What will you use to measure your output?
   *Output should be recorded using a multimeter or other quantitative measurement.*

**Hypothesis**

1. What do you think will happen?
   *Students should hypothesize about how changing their chosen variable will affect the power output of the wind turbine.*
2. Why do you think this will happen?
   *Students should explain why they think changing the variable will affect power in this way.*

**What happened?**

1. How did the voltage change as a result of manipulating your variable?
   *Changing the variable should cause the voltage to increase or decrease.*

2. What was the optimal setting for the variable that you tested?
   *Which trial yielded the most voltage? For example, if the test variable is "blade pitch," students may answer "Blades pitched at 20 degrees produced the most voltage."*

3. Do you think that your variable has a large or small effect on how much power the turbine can make?
   *Answers will vary.*

4. What problems did you encounter as you performed your experiments? How could you fix these problems?

    *Answers will vary. One common problem is that it is hard to keep all other variables constant while testing one specific variable.*

**Class results**

Record the results from the class experiments in the table below.

**Power = Voltage (V) × Current (A)**

1. If you were a lead design engineer, what would you recommend your company do to their turbine blades based on the class results? Why?

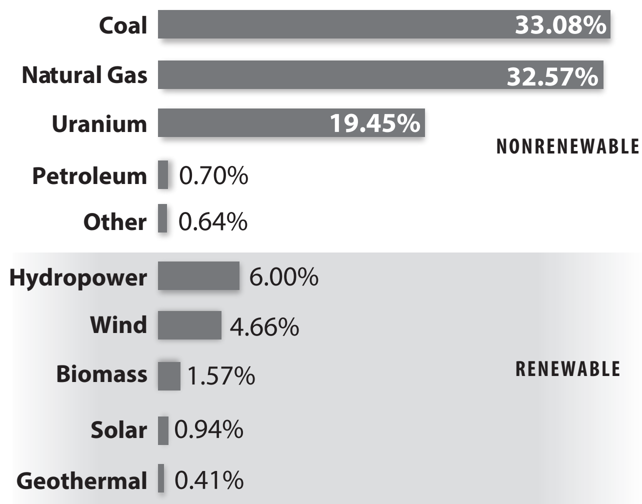
    *Students should describe the optimal blade design based on class results. This answer should discuss at least three variables—e.g., length of blades, number of blades, blade pitch, blade material, etc.*

# Electricity

**Electricity** is a **secondary energy source**. We use primary energy sources, including coal, natural gas, petroleum, uranium, solar, wind, biomass, and hydropower, to convert chemical, nuclear, radiant, and motion energy into electrical energy. In the United States, coal generates 33.08 percent of our electricity. Just over two decades ago, wind contributed less than one-tenth of a percent to the electricity portfolio. Wind is still a small percentage of electrical power generation; however, it is the fastest-growing source of electricity. Since 2010, wind energy capacity in the United States has grown by over 80 percent and capacity continues to increase.

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

## U.S. Electricity Net Generation, 2015



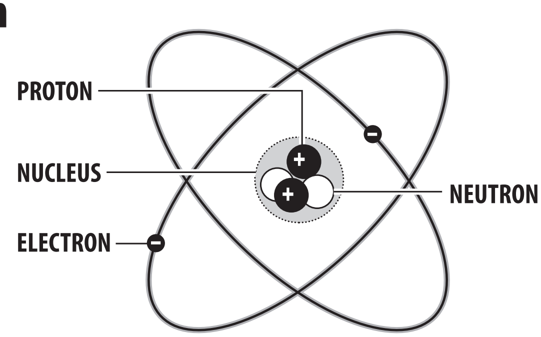

*Total does not equal 100% due to independent rounding.
** Other: non-biogenic waste, fossil fuel gases.
Data: Energy Information Administration

## Atomic Structure

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

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

## Atom




## Elements

An **element** is a substance in which all of the atoms are identical. The number of protons in an atom determines the kind of atom or which element it is. A **stable** atom of hydrogen, for example, usually contains one proton and one electron with no neutrons. Every stable atom of carbon has six protons, six electrons, and typically six neutrons.

## Electrons

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

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

## Magnets

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

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

## Electromagnetism

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

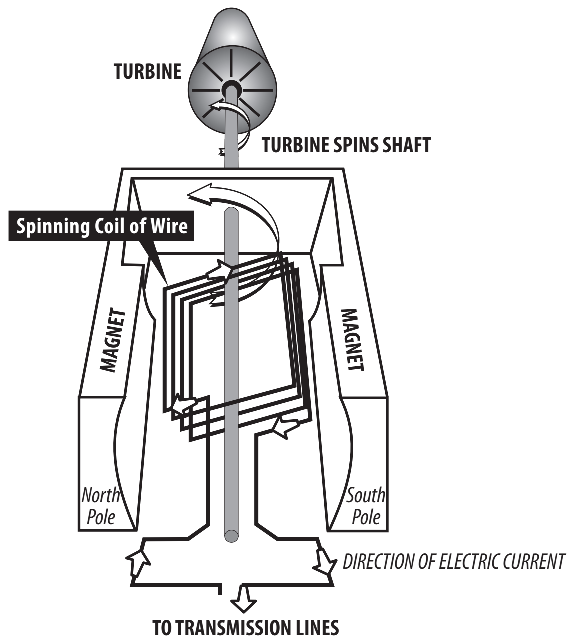
We can use this relationship to produce electricity. Some metals, like copper, have electrons that are loosely held. They can be pushed from their shells by moving magnets. If a coil of copper wire is moved in a magnetic field, or if magnets are moved around a coil of copper wire, an electric **current**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

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

## Producing Electricity

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

### Turbine Generator




**TURBINE GENERATOR**

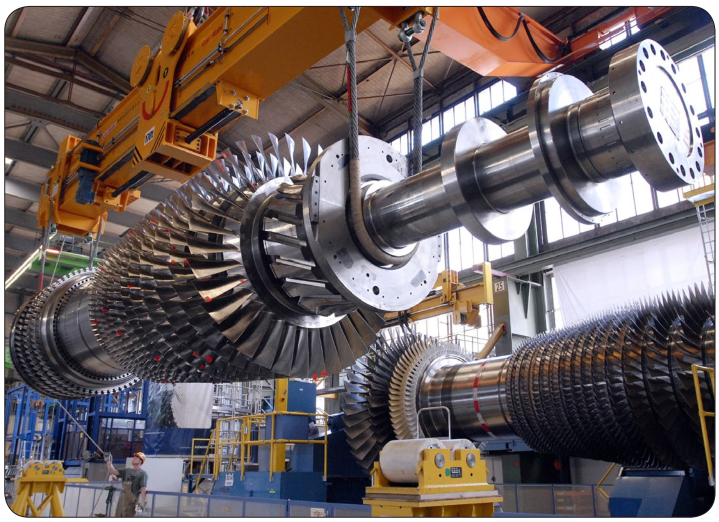


Image courtesy of Siemens

## The Grid

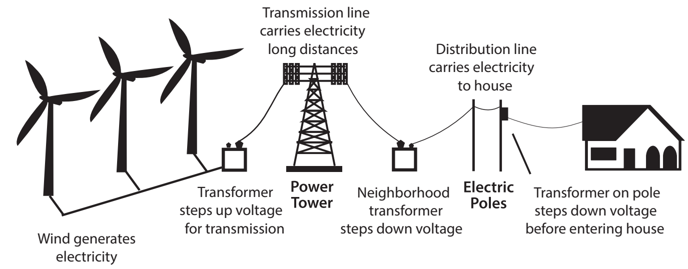
Once electricity is produced, it is distributed to consumers through the **electric grid**. The grid consists of power generators, powerlines that transmit electricity, and the components that make it all work, including substations, meters, homes, and businesses.

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

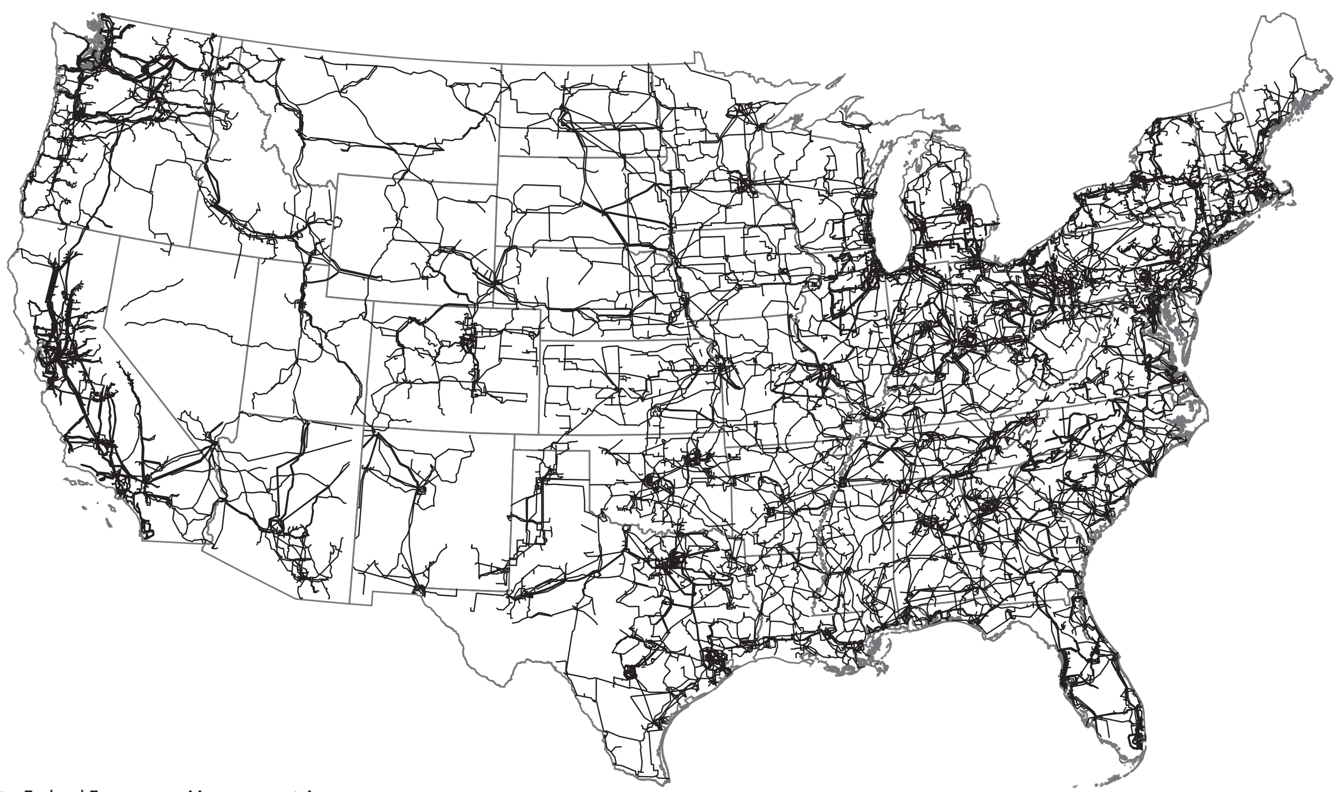
One challenge facing renewable energy sources, including wind, is that the most efficient spots for producing electricity are often in secluded or rural areas. Most traditional power plants are built near population centers and the fuel source is transported to the plant. This allows the electricity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

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

### Transporting Wind Energy




### High-Voltage Transmission Lines



Data: Federal Emergency Management Agency

# Harnessing the Wind's Energy

POSTMILL

SMOCKMILL

TOWER WINDMILL

DRAINAGE WINDMILL

## Evolution of the Windmill

Before we understood electricity, people were capturing the wind to do work. A mill is a machine used to shape materials or perform other mechanical operations. For many years, wind was the power source for mills of all kinds. The earliest European windmills, built in the 1200s, were called postmills. Their purpose was to grind grain between millstones. This is how windmills got their name. Millwrights built postmills out of wood. The entire windmill could be rotated when the wind changed directions. It was the miller's job to rotate the postmill.

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

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

Windmills were used for other work, too. Miners used windmills to blow fresh air into deep mine shafts. Windmills provided power to saw logs at sawmills and create paper at papermills. Wind power was an important part of the first Industrial Revolution in Europe.

## American Windmills

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

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

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

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

Wind power became less popular as power plants and transmission lines were built across America. By the 1940s, fossil fuels became an inexpensive source of power generation. Using wind power to generate electricity was almost abandoned. After the oil crisis of the 1970s, however, the use of wind power began to increase. Scientists and engineers designed new wind machines that could harness the energy in the wind more efficiently and economically than early models. Today, wind is one of the fastest growing sources of electricity in the world—increasing in capacity by 358 percent since 2008.

## Modern Wind Machines

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

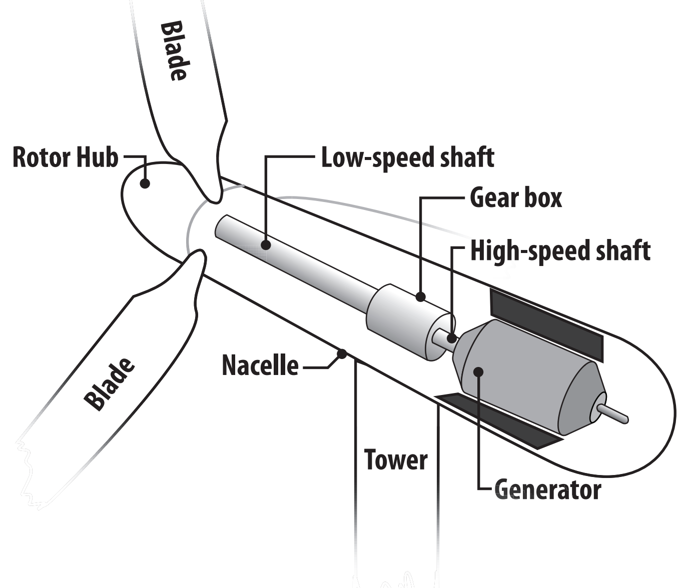
1. The moving air is caught by the blades and spins the rotor.
2. The rotor is connected to a low-speed shaft. When the rotor spins, the shaft turns.
3. The low-speed shaft is connected to a gear box. Inside the gear box, a large slow-moving gear turns a small gear quickly.
4. The small gear turns another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

Wind turbines are most efficient when they are built in an area where winds blow consistently at a minimum of 8-16 miles per hour (3.5-7 meters per second). Faster winds generate more electricity. High above ground, winds are stronger and steadier.

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

Wind turbines also come in different sizes, based on the amount of electric power they can generate. Small turbines may produce only enough electricity to power a few appliances in one home. Large turbines are often called utility-scale because they generate enough power for utilities, or electric companies, to sell. Most utility-scale turbines installed in the U.S. produce one to three **megawatts** of electricity, enough to power 300 to 900 homes. Large turbines are grouped together into wind farms, which provide bulk power to the electric grid.

### Wind Turbine Diagram




# Aerodynamics of Wind Turbine Blades

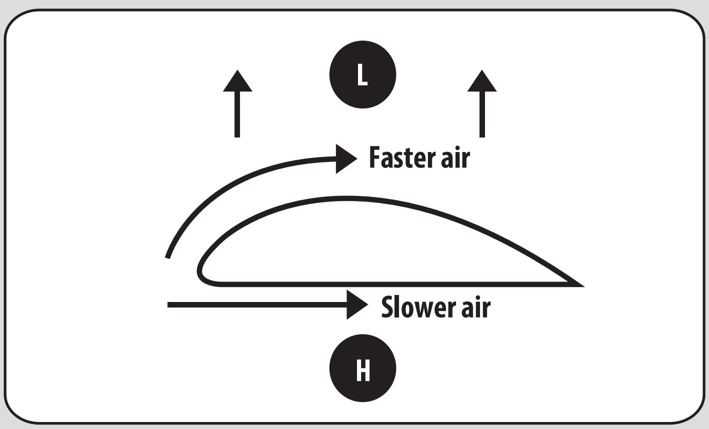
## Why Turbine Blades Move

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

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

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

**AIRFOIL SHAPE: A CROSS-SECTION**

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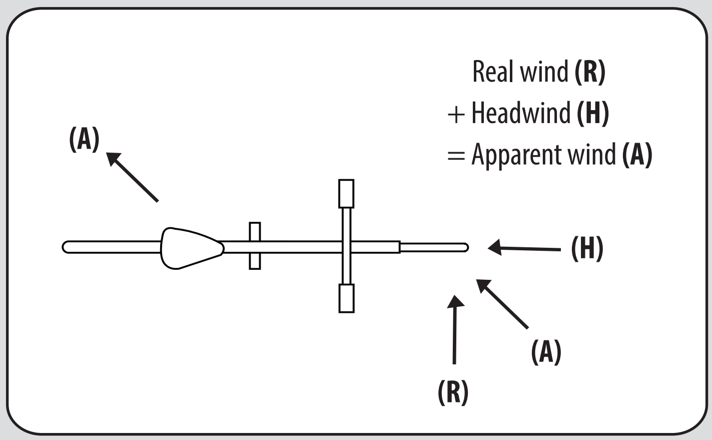
## Understanding Wind

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

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

**APPARENT WIND**




## Aerodynamics

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

## Drag

**Drag** is defined as the force on an object that resists its motion through a fluid. When the fluid is a gas such as air, the force is called aerodynamic drag, or air resistance. Drag is a force that is working against the blades, causing them to slow down. Drag is always important when an object moves rapidly through the air or water. Airplanes, race cars, rockets, submarines, and wind turbine blades are all designed to have as little drag as possible.

Imagine riding your bike down a big hill. To go faster, you might tuck your body to expose as little of it to the apparent wind as possible. This is a trick to reduce drag. Now imagine you have a big parachute strapped to your back when you ride down the hill. The parachute increases the drag significantly and this drag force slows you down.

Drag increases with the area facing the wind. A large truck has a lot more drag than a motorcycle moving at the same speed. Wind turbine blades have to be streamlined so they can efficiently pass through the air. Changing the angle of the blades will change the area facing the apparent wind. This is why blade pitch angles of 10-20 degrees tend to have much less drag than greater angles.

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

**Reducing Drag on Wind Turbine Blades:**

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

## Lift

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

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

## Shape

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

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

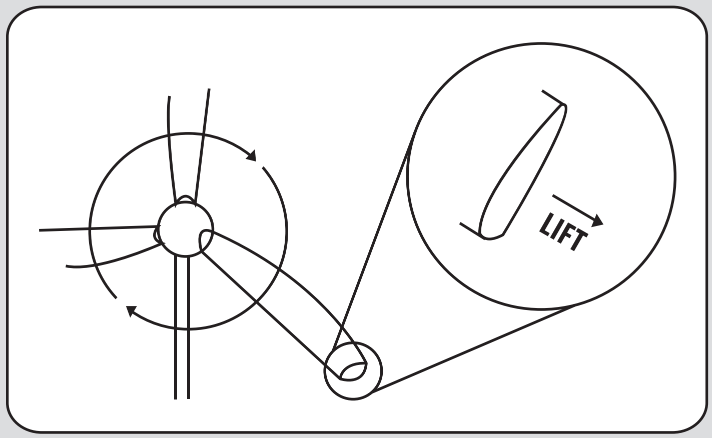
## Speed

Remember that the speed of air passing around the blade is a combination of the real wind and the headwind as the blade moves. The faster the blade is moving, the more drag/headwind it experiences, but the lift force will also increase as the blades move faster.

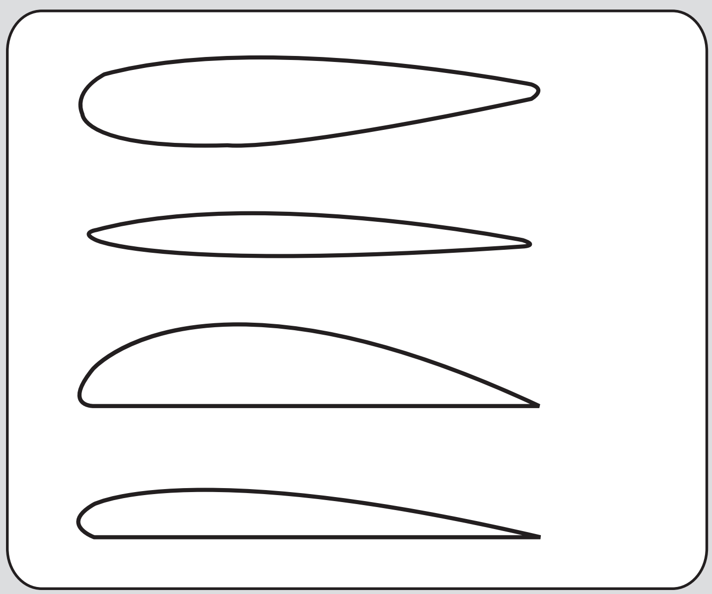
The tips of wind turbine blades travel much further with each rotation of the blades, and therefore move through the air much faster than the roots of the blades. Since they are traveling the furthest distance with each rotation (distance/time = speed), the tips of turbine blades experience more headwind. The roots, or base, of the blades do not experience as much headwind since they are passing through the air much more slowly.

The faster the air molecules are passing over a blade or wing, the more lift can be generated. So the tips of real turbine blades generate much more lift than the roots. Some large wind turbines have blade tip speeds over 322 km/h (200 mph).

**LIFT**




**AIRFOIL SHAPES**



## Angle

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

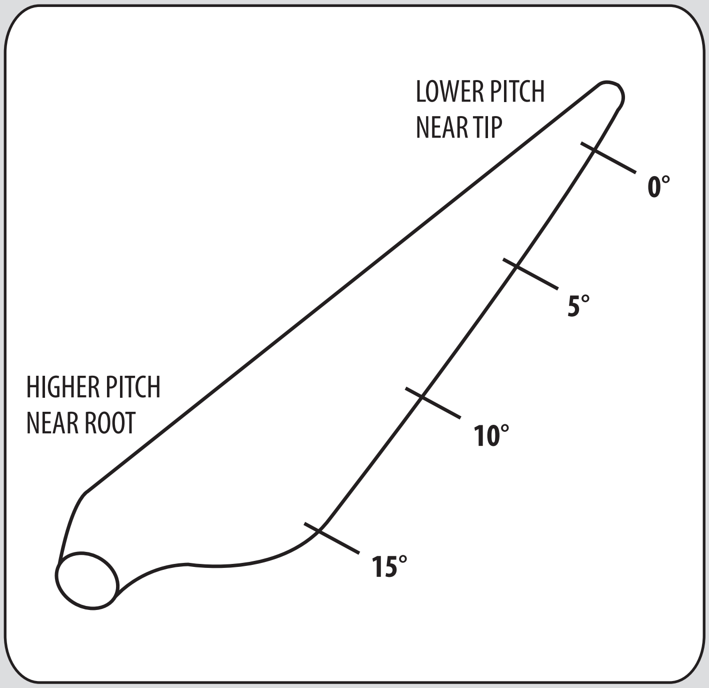
Real wind turbine blades typically have a twisted pitch — meaning the blade angle is steeper at the root of the blade and flatter further away from the hub. Once again, this is due to the fact that the tips move so much faster through the air. By twisting the pitch, the blades are able to take advantage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

## Torque

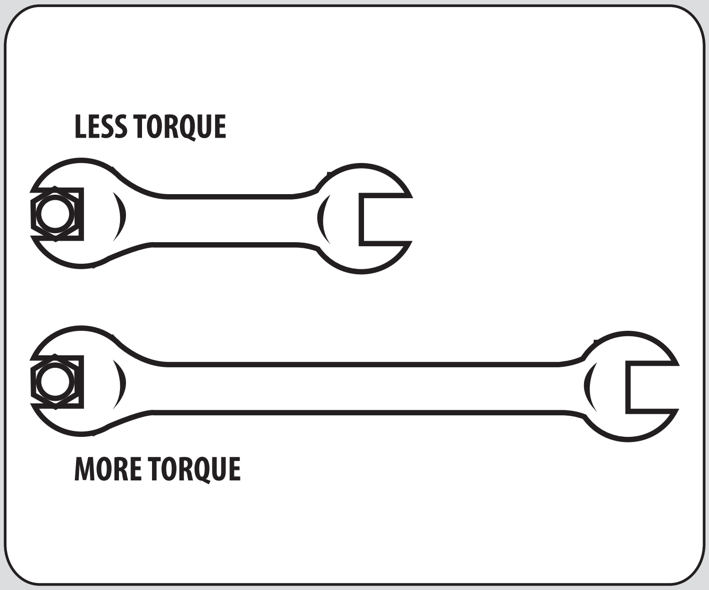
**Torque** is a force that turns or rotates something. When you use a wrench on a bolt or twist a screw loose with a screwdriver, you are generating torque. Torque is a lot like leverage. If you are trying to turn a wrench, sometimes you need a lot of leverage to loosen a tight bolt. Wind turbine blades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

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

**BLADE PITCH**




**TORQUE**

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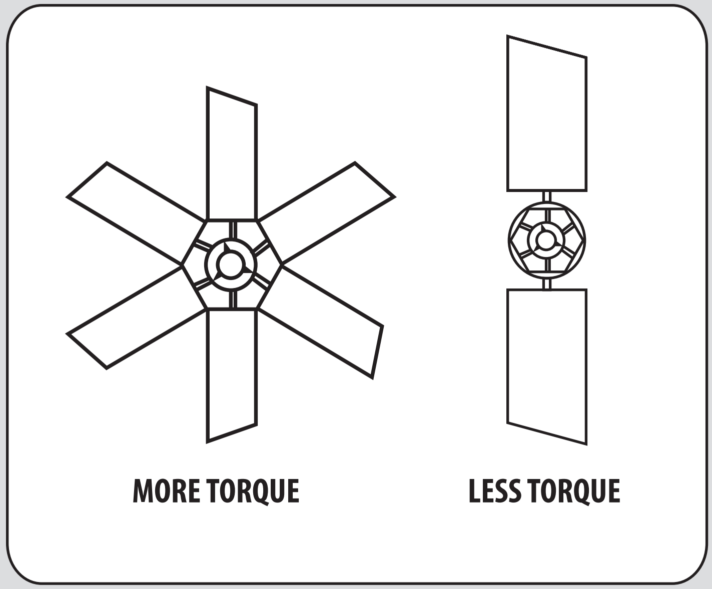
## Gearing Up For More Power

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

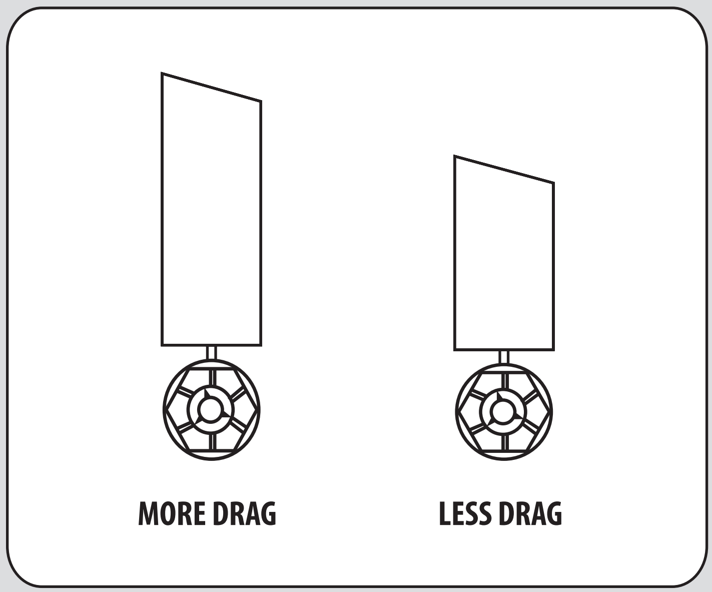
Power output is directly related to the speed of the spinning drive shaft (revolutions per minute or rpm) and how forcefully it turns. A large wind turbine has a rotor with blades, a gear box, and a generator. As the blades spin, the rotor rotates slowly with heavy torque. The generator has to spin much faster to generate power, but it cannot use all the turning force, or torque, that is on the main shaft. This is why a large wind turbine has a gear box.

Inside the gear box, there is at least one pair of gears, one large and one small. The large gear, attached to the main shaft, rotates at about 20 revolutions per minute with a lot of torque. This large gear spins a smaller gear, with less torque, at about 1,500 revolutions per minute. The small gear is attached to a small shaft that spins the generator at high speed, generating power. The relationship between the large and small gears is called the **gear ratio**. The gear ratio between a 1,500 rpm gear and a 20 rpm gear is 75:1.




## Putting It All Together

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



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGY EDUCATION AND WORKFORCE DEVELOPMENT

# Building the Basic PVC Wind Turbine

**Grades:** 5-8, 9-12

**Topic:** Wind Energy

**Owner:** Kidwind Project

This educational material is brought to you by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

# Building the Basic PVC Wind Turbine



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http://www.kidwind.org

The production of the kits and other materials related to wind energy have been generously supported by these agencies.

We would like to thank the *Wright Center for Science Education* at Tufts University for giving us the time and space to develop a nugget of an idea into something that has proven to be useful to hundreds of teachers.

We would also like to thank Trudy Forsyth at *National Wind Technology Center* and Richard Michaud at the *Boston Office of the Department of Energy* for having the vision and foresight to help to keep the Kidwind Project going! Lastly we would like to thank all the teachers for their keen insights and feedback on making these wind turbine kits and materials first rate!

## Basic PVC Wind Turbine Parts List

KidWind sells the *Basic PVC Wind Turbine* but it can easily be built with about $20 worth of parts. For a classroom of 25 kids we recommend having at least three turbines for blade testing. Below is a parts list for this wind turbine.

**PVC Pipe & Fittings & Dowels**

Head to your local hardware store for PVC pipe and fittings. KidWind also gets fittings from www.PlumbingStore.com. All pipe and fittings are 1”. This turbine has:

- ◊ *(5) 1” PVC 90° Fittings*
- ◊ *(3) 1” PVC T Fittings*
- ◊ *(5 ft) 1” PVC Pipe*
- ◊ *(1) 1” PVC Coupler*

**DC Motor, Wires & Clips**

A local electronics shop or *Radio Shack* will have wire, clips and multimeters. There are also a variety of online vendors—www.allelectronics.com. You can use any small DC motor as a generator. One DC motor that works well is the *Motor 500* by PITSCO. We also carry many different kinds at KidWind. You can easily test any motor/generator — spin it with your fingers and see if you get any measurable output if you do that is a good generator. This turbine has:

- ◊ *(1) Motor 500 (Pitsco) (KidWind also sells Wind Turbine Motors)*
- ◊ *(4 ft) 22 Gauge Hook Up Wire*
- ◊ *(2) Clips (Alligator or Banana)*
- ◊ *(1) Simple Multimeter to Record Power Output*

**Special Parts**

KidWind custom builds hubs for our turbines. For years we used to fashion your own hubs from Tinkertoys. If you want, head to your local toy shop or an online vendor to get yourself a barrel of Tinkertoys. A small junior barrel will run around $20 and has plenty of materials for 10 turbines. When you want something sturdy and tested come to Kidwind.

- ◊ *(1) Hub (Crimping Hub from Kidwind, Tinkertoy or a round piece of wood to attach blades)*

**Blade Materials**

You can make blades, out of a variety of materials— wood, cardboard, felt, fabric. Students have made blades out of ***styrofoam bowls, pie pans, paper and plastic cups***. Anything you find around the classroom can be made into blades!

- 4” dowels 3/8” dia. (or Tinkertoy rods)— attach blades that you make to this.

**Tools**

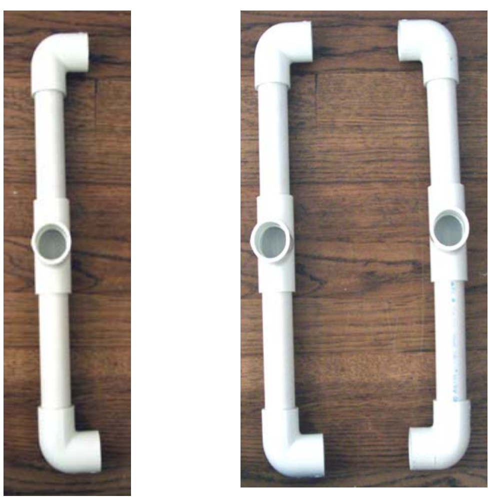
To build this turbine from scratch you’ll need at a minimum a drill, ruler, PVC cutter or hacksaw, wire strippers, soldering iron, solder, duct tape, glue.

# Building the Basic PVC Wind Turbine

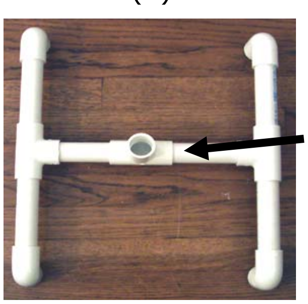
This is the first wind turbine developed at KidWind. The idea was adapted from a design we found at the www.otherpower.com website.

Rugged and cheap to build, this device will allow you to perform a variety of experiments and wind demonstrations quite easily.

These instructions will show you how to build this PVC turbine, how to make blades for your wind turbine, how to use a multimeter to record electrical data and some basic wind energy science.



(2) Identical Base Sides



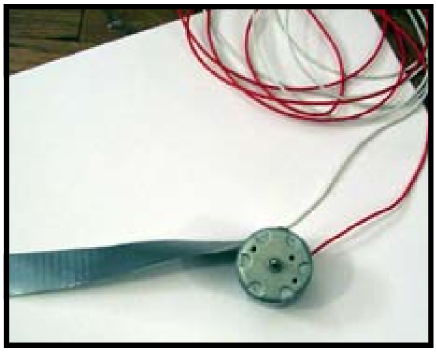
Sides joined together.

Make sure to drill a hole in this PVC tee so you can get the wires out!

## Building the PVC Tower Base

1. Using (4) 90° PVC fittings, (2) PVC tees and (4) 6" PVC pipe sections construct the two sides of the PVC turbine base. Make sure in this step to use the PVC tees that **DO NOT** have a hole drilled in them.
2. Fit the parts together without using glue (PVC glue is really nasty stuff). To make them fit snuggly tap them together with a hammer or bang them on the floor once assembled.
3. Next connect the two sides using the PVC Tee with the hole. The hole will allow you to snake the wires from the DC motor out.

## Building the Rotor & Hub

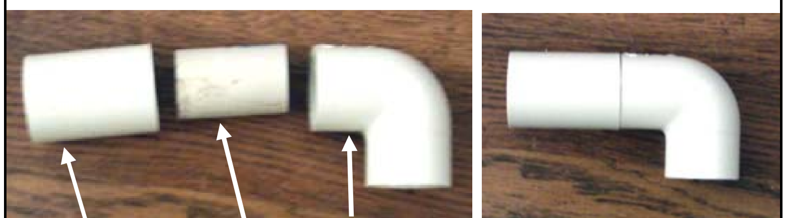


1. You will need to solder some wires (4′ long) to your DC motor. Wrap a piece of duct tape around the outside of the motor. This piece of tape should be about 1/2″ wide and 18″ long. This will help the motor fit securely into the PVC coupler.

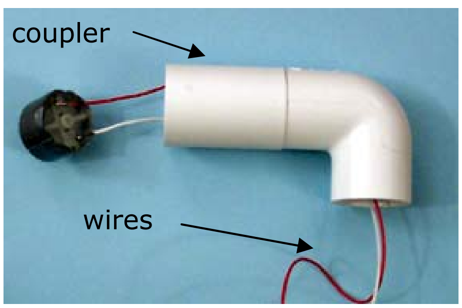
2. For this step use (1) PVC 90° fitting, (1) PVC coupler, (1) 3′′ piece of PVC pipe and the DC motor. The best DC motors will be close to 1″ in diameter so they fit tight in the coupler.

3. Arrange the pieces as they look in the image to the right. Push them together to form a solid piece. On a large wind turbine this is called a **nacelle** it holds the generator, gear boxes, and other equipment.

Nacelle Construction



coupler 3‟ piece 90° fitting




Make sure the wires come out the bottom!

4. Insert the wires attached to the DC motor through the nacelle. They should come out of the 90° PVC fitting. The motor will rest in the coupler.

Notice the motor is straight and not pushed all the way in!

5. Insert the motor into the coupler. It should fit **very** snuggly. If it is too loose or tight adjust by wrapping or unwrapping duct tape around the outside. As the motor is pushed on frequently by students, it must be TIGHT! You can glue this in to make it secure.

Motor secured into the coupler. STRAIGHT!

6. Insert the motor making sure that it is straight and not too far in. If it looks cockeyed straighten it out as it will cause your hub and blades to wobble while spinning.

7. Once the motor is secured attach the hub you have decided to use. Press the hub onto drive shaft. It should fit very snuggly.

Nacelle complete with Tinkertoy Hub!

*Crimping Hub sold by KidWind — FANTASTIC!!!*

## Attaching the Tower to the Base

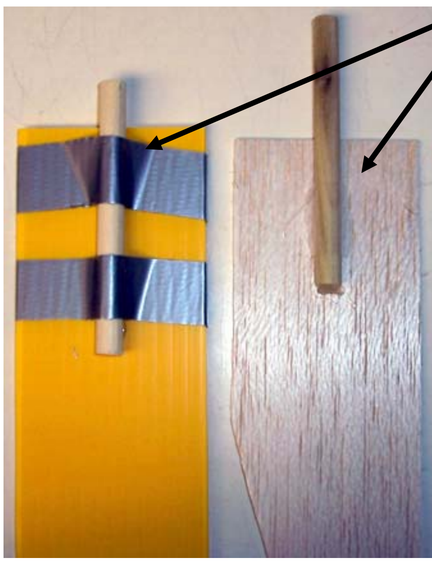
1. Snake the motor wires down the tower and through the hole in the PVC tee at the base of the wind turbine.
2. Attach the nacelle to the top of the tower.
3. Insert the bottom of the PVC tower into the tee at the center of the turbine base.
4. It should look just like the wind turbine to the right!
5. Assure that the PVC pipe is seated tightly into the fittings by tapping together with a hammer or by banging on the floor.
6. Do not to use any glue so that once finished you can take it apart and store it away for next year!
7. Attach alligator clips to the wires coming out of the turbine to help to hook your turbine up to a multimeter!

SUCCESS!!
Wind Turbine Completed!

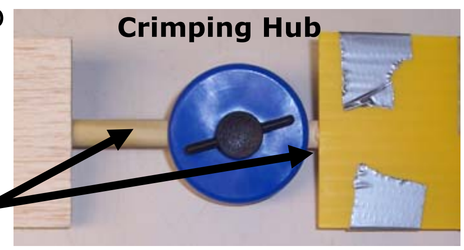
## Building & Attaching Blades

**Caution!!**

**Never make blades using metal or any sharp edged material as these could cause injury during testing. Blades tend to spin very fast (400-600 RPM) and they can easily cut people if they have sharp edges.**

1. To make blades, carve or cut different shapes and sizes out of a variety of materials (wood, cardboard, felt, fabric) and hot glue or tape them to the dowels. Students have made blades out of ***styrofoam bowls, pie pans, paper and plastic cups***. Anything you find around the house or classroom can be made into blades!
2. Before testing check that the blades are securely attached to the dowel. If not secured properly, they may detach or deform as you test your turbine in high winds. We recommend using a combination of tape and hot or regular glue.
3. Insert the dowels into holes on the crimping hub. It is important to tighten the hub when inserting the blades so that they do not come out at high speed.
4. When attaching the blades to the hub consider a few important questions;
   - How close is the root of your blade to the hub? What do you think is optimal?
   - Are your blades about the same size and weight? Blades that are not balanced will cause vibrations that can reduce the efficiency of your turbine..
   - Are the blades equally distributed around the hub? If not you can also have a set up that is out of balance.
   - Have you secured the hub after you inserted the blades? If not they can fly out at high speed!
   - Want to know how fast your blades are spinning then get one of these—*Hangar 9 Micro Tachometer*.




Pie plate used to catch the wind. As the crimping hub can be separated into two parts you can try different creative ways to attach blades to the hub. One of the best blades we ever saw was made from a pizza pie box!

Again, **DO NOT USE** sharp metal or very hard plastic to make blades as blades can spin at very high speed (500RPM) and could cause injury.

## SAFETY & BLADE TESTING AREA

- **It is important to wear safety goggles when constructing and testing blades.**
- **NEVER make blades using metal or any sharp edged material as these could cause injury while spinning fast during testing.**

### SETUP FOR TESTING

Safely set up your testing area like the picture below. It is important to clear this area of debris and materials.

Stand In Front or Behind Turbine

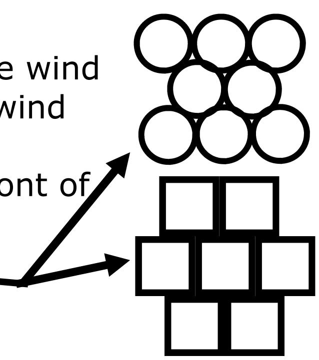
Make sure the center of the fan matches up with the center of the wind turbine. You may need to raise your fan with some books or a container.

Some things to note about fan wind that reduces the efficiency. Fans create;

- *Highly Turbulent & Rotational Wind*— Blades may spin better one direction than another
- *Highly Variable Wind Speed* - Wind speed is about 10-13 MPH on high for a $20 circular fan. Wind speeds near the middle will be much different than the edges.
- *Limited Diameter*— Blades bigger than fan will not "catch" more wind—they will just add drag and slow down your blades.

### How to Clean Up Wind?

Want some more "professional wind"? You can try to build a simple wind tunnel. Lots of plans can be found online (search term:classroom wind tunnel) and at www.kidwind.org. One simple way to make more laminar—smooth, straightened—flow is to build a honeycomb in front of your fan using milk cartons, 2" PVC pipe or some other material.



### Going Outside?

While you can use your wind turbine outside, you must make sure that you face it into the into wind. This is because this turbine is not designed to YAW (or rotate) to face the wind. If the wind shifts, and the turbine cannot rotate, winds will hit the blades from the sides causing stress and inefficiency.

For a wind turbine that can yaw check out the Kidwind Yawing PVC turbine on our website (http://www.kidwind.org).

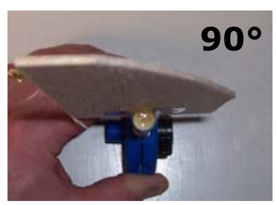
## Some Blade Building Tips

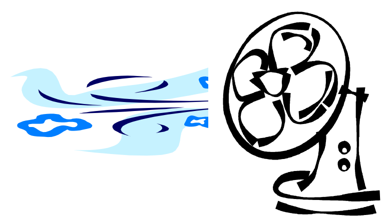
KidWind model wind turbines are designed for use in science classes, or as a hobby or science fair project. Their purpose is to give students an affordable way to perform various blade design experiments quickly. **Efficient blades are a key part of generating power from a wind turbine. Sloppy or poorly-made blades will never make enough energy to do anything. It takes time and thought to make good blades!**

An important concept to keep in mind when making turbine blades is drag. Ask yourself, **"Are my blades creating too much DRAG?"**. Your blades are probably catching the wind and helping to spin the hub and motor drive shaft, but consider the ways that their shape or design might be slowing the blades down as well. If they are adding **DRAG** to your system it will slow down and in most cases low RPM means less power output.

**Some tips on improving blades:**

- **SHORTEN THE BLADES** - Wind turbines with longer blades do make more power. While this is also true on our small turbines it is often difficult for students (and teachers) to make large, long blades that don't add lots of drag and inefficiency. See what happens when you shorten them a few centimeters.
- **CHANGE THE PITCH** - Students commonly set the angle of the blades to around 45° the first time they try to use the turbine. Try making the blades flatter towards the fan (0° - 5°) . Pitch dramatically affects power output, so play with it a bit and see what happens. Finding a way to **TWIST** the blades (0° near the tips and around 10° - 20° near the root) can really improve performance.





- **USE FEWER BLADES** - To reduce drag try using 2, 3 or 4 blades.
- **USE LIGHTER MATERIAL** - To reduce the weight of the blades use less material or lighter material.
- **SMOOTH SURFACES** - Smooth blade surfaces create less drag. Try removing excess tape or smoothing rough edges to reduce drag.
- **FIND MORE WIND** - Make sure you are using a decently sized box or room fan with a diameter of at least 14"-18".
- **BLADES VS. FAN** - Are your blades bigger than your fan? If the tips of your blades are wider than the fan you're using, then they're not catching any wind– they are just adding drag!
- **BLADE SHAPE** - Are the tips of your blade thin and narrow or wide and heavy? The tips travel much faster than the root and can travel faster if they are light and small, which means that if you have wide or heavy tips you may be adding lots of drag.

## What can you do with your turbine?

### Factors that Affect Power Output

How much power is your wind turbine producing? The weightlifter turbine uses simple machines (pulleys, wheels) to transform the energy in the wind to lift heavy objects. There are two factors that determine how much power your turbine is producing: (1) How much weight it can lift, and (2) How fast the weight is lifted. Look at the next page to learn more about power in the wind and how to get the most out of your turbine. Once you have read through the materials, start experimenting! What factors can you change to increase the power output of your turbine?

Here are a few ideas for starters.

- *Wind Speed*
- *Blades*
- *Diameter of driveshaft, adding gears, etc.*

Wind speed is an easy one. Take your turbine and place it in front of a fan at three different distances. How does the power output change? Why does it change? Make a graph and discuss. Think about this in relation to the Power in the Wind equation.

### Blade Design

An entertaining group of experiments involves blade design. The blades on modern turbines "capture" the wind and use it to rotate the shaft of a generator. The spinning shaft of the generator spins magnets near wires and generates electricity. The WeightLifter turbine does not produce electricity, but works in much the same way to convert wind into power. How well you design and orient your blades can greatly impact how much power your turbine produces.

The ideal blade setup for the weightlifter turbine may be different than the ideal blade setup for an electricity producing turbine. When producing electricity, the goal is to make the rotor spin as fast as possible to spin the generator faster. When lifting weights, however, your blades need to provide lots of torque (muscle) not just speed. It can really pay off to experiment with your blades until you find a setup that provides lots of torque and speed.

Experiments with blades can be simple or very complicated, it depends on how deep you want to explore. Some variables you can test with blades include:

- *Blade Length*
- *Blade Number*
- *Blade Pitch*
- *Blade Shape*
- *Blade Materials*
- *Blade Weight*

If you are doing this for a science fair or project you should focus on just one these variables at a time as your results can get confusing quite quickly.

See page 10 for some great ideas for experimenting with your WeightLifter wind turbine.

## Power in the Wind — A simple look

If a large truck or a 250lb linebacker was moving towards you at a high rate of speed you would move out of the way right?

Why do you move? You move because in your mind you know that this moving object has a great deal of ENERGY as a result of its **mass** and its **motion**. And you do not want to be on the receiving end of that energy.

Just as those large moving objects have energy so does the wind. Wind is the movement of air from one place on earth to another. That's the motion part.

What is air though? Air is a mixture of gas molecules. It turns out that if you get lots of them (and I mean lots of them) together in a gang and they start moving pretty fast they can definitely give you, a sailboat or a windmill a serious push. Just think about hurricanes, tornadoes or a very windy day!

Why aren't we scared of light winds while we stay inside during a hurricane or wind storm? The velocity of those gangs of gas molecules have a dramatic impact on whether or not we will be able to stay standing on our feet. In fact, in just a 30 mph gust you can feel those gas molecules pushing you around.

Humans have been taking advantage of the energy in the wind for ages. Sailboats, ancient wind mills and their newer cousins the electrical wind turbines, have all captured the energy in the wind with varying degrees of effectiveness. What they all do is use a device such as a sail, blade or fabric to "catch" the wind. Sailboats use energy to propel them through the water. Wind mills use this energy to turn a rod or shaft.

A simple equation for the ***Power in the Wind*** is described below. This equation describes a the power found in a column of wind of a specific size moving at a particular velocity.

**P = Power in the Wind (watts)**
**ρ = Density of the Air (kg/m3)**
**r = Radius of your swept area (m2)**
**V = Wind Velocity (m/s)**
**Π = 3.14**

$$P = 1/2\ \rho\ \Pi\ r^2\ V^3$$

From this formula you can see that the size of your turbine and the velocity of the wind are very strong drivers when it comes to power production. If we increase the velocity of the wind or the area of our blades we increase power output.

The density of the air has some impact as well. Cold air is more dense than warm air so you can produce more energy in colder climates (as long as the air is not too thin!).

The sample equation to the right shows how much power there is in a column of wind coming out of your average household box fan.

**How much power is there coming off a regular circular house fan?**

**V** = 5 m/s (meters per second)
**ρ** = 1.0 kg/m3 (kilograms per cubic meter)
**R** = .2 m
**A** = .125 m2 ($A = \Pi r^2$)

**Power in the Wind = $\frac{1}{2}\rho A V^3$**

Power = (.5)(1.0)(.125)(5)3
= 7.85 Watts

There are 7.85 watts coming out typical house fan. Can our little turbines capture all of this power?

# How to use the Multimeter

Small DC motors  like the one you're using do not produce much power when spun slowly (see power output sheet).  As a result, our electrical output will be limited and even a great set of blades in high winds might only be able to light an LED.  To accurately measure our production you should use a multimeter.  If you are interested in lighting bulbs and creating more electricity you may want to check out the *Geared Turbine* at the Kidwind Website (http://www.kidwind.org).

Power (Watts) = Voltage (V) x Current (A)   <—- **Watch Your Units**

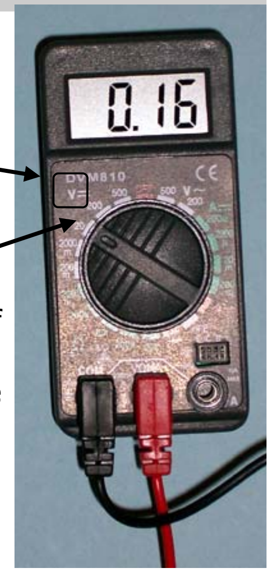
**Make sure you are recording volts and amps (not milli or microvolts unless you want to!) If your readings are higher than 1— 2 watts you have done something wrong!**


**<u>Voltage</u>**

1.  Attach the wires from the generator to the multimeter.

2.  To check the voltage select DC Volt (V) and choose a the whole number setting at 20 volts.

Set at 20 DC Volts




3.  Place your turbine out in the wind or in front of a fan and let it run up to speed.  It is normal for the readings to fluctuate.  Power output is often unsteady because the wind is inconstant or your blades are not balanced.

4.  A set of very well designed blades may make around 1 –2 volts Typical blades will be in the 0.4 - 0.8 volt range.

5.  When measuring voltage you are calculating how fast the DC generator is spinning.  The faster it spins the higher the voltage.  As there is no load on the generator it has very little resistance so it can spin very fast.  If you look closely when you attach a load (bulb, pump) the RPM may drop as will your voltage.

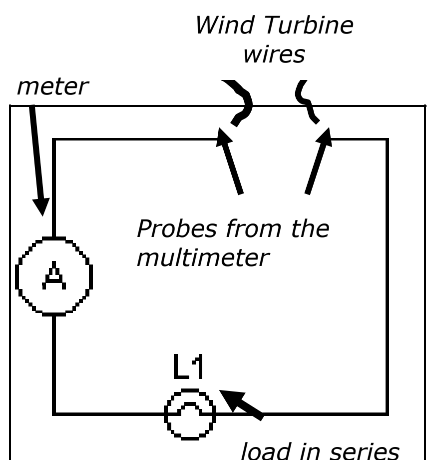
**<u>Amperage</u>**

1. To get a more accurate picture of the power output of your turbine measure amperage as well.  To accurately measure the amperage you must hook up your multimeter differently.

2. Place a load (a resistive object - small bulb, resistor, pump etc.) in series with the meter so that the generator is "loaded" and has to do work.

3. A set of very well designed blades will make around 0.1 amps (100 milliamps) with this motor.  Typical blades will be in the .02-.05 amp (20 – 50 milliamp) range.   This will vary based on your resistive load.

4. When measuring amperage you are gauging how many electrons are being pushed through the wire by the turbine. This relates to the torque your blades are generating.




*To accurately record current you need to put a load in series.  In this picture you can see the load (bulb) between the connection with the meter and the turbine.*

**DON'T FORGET  TO TURN OFF THE METER WHEN YOUR ARE DONE OR THE BATTERY WILL DIE!!**

# PVC Wind Turbine FAQ

**Why are the dowels flying out of the hub?**
*You need to get a Crimping Hub from Kidwind or secure them better to the hub.*

**Why won't the rotor spin when I put my turbine in front of the fan?**
*Check the orientation of the blades. Are your blades oriented in the same direction? Are they flat? Are they hitting the tower? Look at some pictures of old and new windmills to get some ideas about how to orient your blades.*

**Why does the turbine slow down when I attach it to load (pump, bulb, motor)?**
*Loading the generator forces it to do work. This makes it harder to push electrons through the circuit. The more load you add the harder it is for the generator to turn and the more torque you must generate from the blades. The only way to do this is to make bigger blades or relocate your wind turbine to a place with higher wind speeds.*

**Why are the readings on my multimeter all over the place?**
*Your readings may be fluctuating because the wind coming out of your fan is fluctuating. This can also be caused by your blades not spinning smoothly or changing shape as they spin. Additionally, if your blades are not balanced, evenly distributed, or are producing unequal amounts of drag your readings will be irregular.*

**What are the best blades?**
*That is for you to figure out! Lots of testing and playing will get you closer to your answer.*

**Is a fan a good wind source to test with?**
*Well, it is the best we've got, unless you have a wind tunnel handy! The wind that comes out of a fan has a great deal of rotation and turbulence. It isn't very smooth. While it will still make your turbine spin it is not exactly like the wind outside. To see this turbulence, hold a short piece of thread in front of a fan and move it from the center out. It should head out straight all the time...does it?*

**Can I take my turbine outside? Can I leave it there?**
*You can certainly take, use and test your wind turbine outside. But unless you have a yawing turbine it will not track the wind and may not perform optimally. To make it work well you will have to continually face it into the wind. It is not a good idea to leave your turbine outside for too long. It is designed for basic lab tests and not to endure the rigors of the outdoor environment!*

**Based on the power in the wind equation it seems that longer blades should make more power. On my turbine this is not true!! WHY??**
*The blades on your turbine may be bigger than the diameter of the fan. If that is the case, the extra part is only adding drag so your blades will slow down. Additionally if you design large blades poorly they will have lots of drag near the tips and slow down. This will negate any positive effect of the added length. Also short blades spin faster than long ones, so if you are just recording voltage they will seem better. Try short blades with a load in series and see if they have enough torque to spin. Many cases they do not!*