E³A ACTIVITY GUIDE

The E³A (Exploring Energy Efficiency and Alternatives Youth Energy Activity Guide) is designed to help guide youth in their exploration of energy and energy technology. The guide includes hands-on experiential learning activities as well as information and resources to help lead the learning process.

Targeted Ages

While activities can be modified to meet the needs of K-12 youth, this guide targets ages 9 to 13. More specific age recommendations are provided on each activity. Teen leaders can also be engaged to lead younger youth in the activities.

Using the Guide

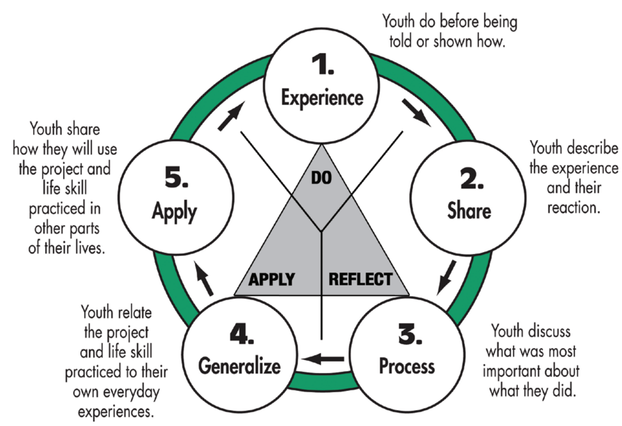
This guide is intended as a supplement to project leadership in topics like electricity and wind power. It is designed to provide activities and experiments for use in group meetings or camp settings to introduce key energy concepts. You may opt to use only one or two activities, or you can combine a series of activities to explore a topic in-depth.

The guide has been divided into key subject areas (wind power, solar electricity, solar thermal, etc.) Within each subject, activities are provided to teach key concepts. For some topics, multiple activities are suggested that utilize the same lesson plan—this allows you to find an activity that will work best for your group and location, as well as for available supplies.

NOTE: Many of these activities are designed to be conducted outdoors. In the event the weather does not cooperate, plan alternatives means of completing the activities.

The Learning Model

Each lesson is built on two complimentary learning models—the Experiential Learning Model (Do, Reflect, Apply) of 4-H, and the 5E Constructivist model for science education. In these lessons, youth are involved in an activity, look back at it critically, determine what was useful or important to remember and use this information to perform another activity or modify the activity to be more successful. The lessons provide learning objectives as well as science curriculum standards addressed by each activity. Reflect and apply questions are asked in each section.



Do-Reflect-Apply model combined with 5E model.
5E model: Pfeiffer, J.W., & Jones, J.E., "Reference Guide to Handbooks and Annuals"
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The 5E Lesson Plan

Engage: Each lesson begins with a brief activity to introduce the concept and get youth involved in learning. Based on their observations or experience, youth can develop a hypothesis—an assumption they will test with their experiment/activity.

Explore: Youth will explore an energy concept through an activity. Observations during the activity will help youth to test assumptions (hypothesis) and explore the concept in greater depth.

Explain: Through guided discussion, youth share their explorations and develop an understanding of

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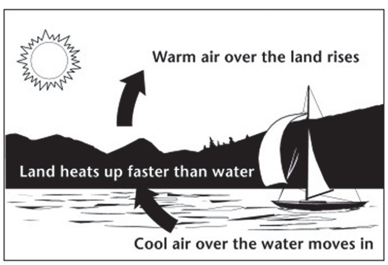
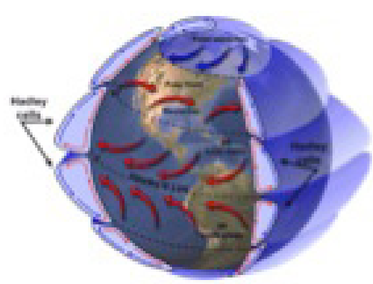
the concept. Learners explore common themes and relate the key learning objectives to their experiences.
Extend: In the "extend" phase of the lesson, learners are asked to further test their assumptions and to apply the information in different ways.
Evaluate: The lesson closes with an evaluation of the concept that was explored, the activity conducted, and what was learned.

What is Wind?

Wind is air in motion—it is also a form of energy. Let's break that down. The air moves because of the uneven heating and cooling of the Earth's surface. During the day, air over land heats up more quickly than air over water. As the warm air over land expands and rises, the cooler air rushes in to take its place and creates wind. The opposite happens at night as the land cools more quickly than water. We can feel this type of wind when we stand in a valley or near a lake, but it also takes place on a global level—where, for example, the land and water near the Equator are heated more than at the North and South Poles.

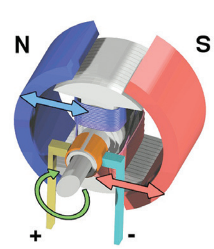


Source: EIA National Energy Development Project



Wind is Energy?

To have kinetic energy, we must have mass and motion (velocity). Air has mass because it is made up of molecules (carbon dioxide, oxygen, nitrogen, etc.) and it is moving—so it is kinetic energy! Wind turbines, boat sails, and wind mills for pumping water are all technologies that we use to capture this energy and convert it into a form of energy that we can use.



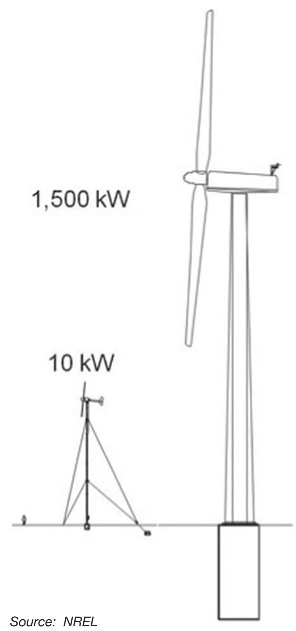
Source: Wikimedia Commons

Using Wind Energy

People have been using the wind's energy for centuries. Boat sails have carried people over water since early times. Wind was used to grind corn and grains as early as 200 B.C. Many farms and ranches in the West still have working windmills, which they use to pump water for animals. But the most common application today is the use of wind turbines to generate electricity.

How Does a Wind Turbine Generate Electricity?

Wind turbines use a simple electrical motor. Like most electrical motors, an electrical current is created when copper windings spin between two magnetic poles (North and South). When the wind turns the turbine blades, the shaft that holds the copper windings rotates and electrical current is generated. That current is transmitted through the turbine components, down the tower, and along a power line where we can then use the electricity.



Source: NREL

What's a Watt?

Electricity is used each time you turn on an appliance, light, or other electrical device. Most devices use power in "watts." A "watt" is a term for power and a "watt-hour" is a term for energy. A light bulb with a 100-watt power rating will use the energy of 100-watt-hours if it is turned on for one hour.

A kilowatt is 1,000 watts. In most homes, electricity comes from an electrical utility. The amount of energy used by a customer of the utility is tracked on an electrical meter (also called a kilowatt-hour meter). It records the energy (kilowatt hours, kWh) used during a billing period and the customer is billed for that amount. An average home uses about 10,000 kilowatt-hours per year. A megawatt is one million watts.

Wind Generation Comes in Different Sizes

Wind can be used to generate electricity in a cabin or electronics on a boat. These systems are very small (measured in watts). Wind turbines that make electricity for a home range in size from (typically) 1 kilowatt to 10 kilowatts. Large commercial wind farms use much larger equipment! These turbines are usually at least 1.5 megawatts. In Europe and in off-shore wind (wind turbines installed in the ocean) turbines can be as large as 5-6 megawatts. Bigger turbines are a bit more complex than the small systems we find on homes, but the basic mechanics are the same.

How Do People Use Electricity from the Wind?

There are three primary ways that people use electricity from the wind. One is as a direct source–the wind turbine is hooked directly to the house, cabin, or water pump. Depending on the application, these systems may need batteries to store electricity when the wind is not blowing. Another way is called net metering—there is no battery and the electrical utility provides power when the wind is not blowing. In net metering, the kilowatt-hour meter rolls backward when the wind turbine makes electricity, and rolls forward when the utility provides the power. Big wind farms generate power for the utility grid. That electricity may be used locally, or may be sold to a utility many states away.

Making Wind Work

The amount of power produced by a wind turbine is dependent on three primary factors:

1. Air density
2. The speed of the wind
3. The swept area of the turbine blades (swept area is the circle of air "swept" by blades as they turn).

A formula for calculating the kinetic energy of the wind is:

$$P = \frac{1}{2}\rho v^3 \Pi r^2$$

ENERGY*=(½) x (Air density) x (Velocity)^3 x (Swept area of rotor)^2*

Why is the power production formula so important?

Wind turbines are all about producing energy. The formula says that doubling the swept area creates four times the energy (because it is a ***squared*** function). Increasing velocity, or wind speed, by two times will result in eight times the amount of energy because it is a ***cubic*** function (2x2x2). On the other hand, if wind speed is cut in half there is only one-eighth the amount of energy production.

Understanding Wind

The formula tells us that to understand wind energy we need to focus on three key elements. First, we need to measure and observe the wind—how fast does it move (velocity) and how does it behave in our location? Second, we need to understand how wind turbine design influences the amount of wind captured, and third, we need to consider where to locate a turbine to get the maximum amount of power output.

This activity guide is divided into four areas—measuring, observing wind, siting, and wind turbine design— to help youth understand some of the critical factors in achieving power generation with the wind. You can find more in-depth information on wind energy at www.e3a4u.info.

MEASURING AND OBSERVING WIND SERIES

Why Does Measuring the Wind Matter?

Three primary factors affect the amount of energy generated by a wind turbine: air density, the swept area of the turbine blades, and the velocity (speed) of the wind. But to correctly site (locate) a wind turbine, we also need to know the characteristics of the wind–like wind direction, wind speed, wind shear, and turbulence. In large-scale wind (for utilities), whole industries are dedicated to measuring and evaluating the wind. Learn more about the wind in your area using the activities in this series.

How is Wind Measured?

There are many ways that the wind is observed and measured. **Weather vanes** have been used for centuries to indicate wind direction. In your community, **anemometers** (devices that measure wind speed) measure the wind every day. Weather stations, AgriMet stations, and your local airport all have anemometers to measure the wind speed and direction.

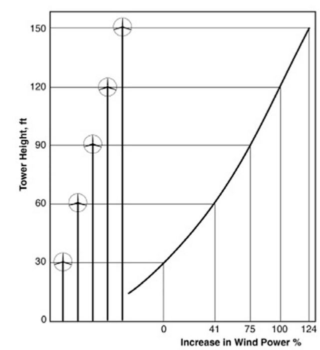
People installing wind turbines measure wind in many ways. Wind for small turbines may be assessed using local wind data sources or wind mapping information (See www.e3a4u.info for links to online sources of wind mapping data). You can also find mapping information on page 35. A minimum wind speed of 10 miles per hour is considered a threshold for making small wind work on a site.

In utility-scale wind, the data collection is much more precise. Anemometers installed on meteorological towers (**met tower**) as high as 60 meters (200 feet) collect data for at least one year. Wind developers need to know about the wind at 80 meters or more—the hub height of commercial wind turbines. Structures taller than 200 feet require special permitting by the Federal Aviation Administration, so wind profiling experts use **SODAR** (Sonic Detection and Ranging) to better understand the wind above 60 meters. SODAR is a meteorological instrument that sends sound waves into the atmosphere and then measures the amount of "scattering" of those sound waves to calculate wind speed and turbulence. SODAR is like radar, except that sound waves are used instead of radio waves.

LIDAR (Light Detection and Ranging) is another technology used to measure horizontal winds. LIDAR uses light (usually pulses from a laser) to measure the oncoming wind. LIDAR may be installed on commercial wind turbine blades to help increase the energy output from wind turbines. LIDAR installed on a turbine rotor can predict the wind before it hits the turbine. It will prompt the turbine to proactively adjust the blades in advance of changes in the wind to increase the power output.

Characteristics of Wind

Wind Shear



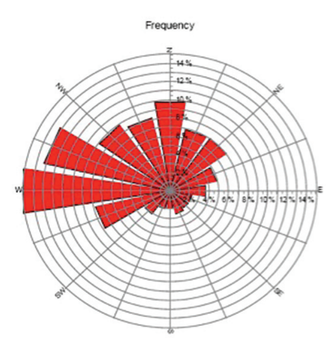
Source: KidWind

The change in wind velocity with elevation above ground is known as wind shear. Increasing energy production of a wind turbine is achieved primarily through increasing tower height, as taller towers are able to access higher wind speeds. Because wind power output has a cubic relationship to wind velocity, taller towers magnify the energy generation potential. For small wind turbines (under 10 kilowatts), a tower height of at least 30 feet (including the blades) above the tallest obstacle within 500 feet of the wind turbine is typically recommended to maximize energy generation.

Wind Distribution

Wind varies by time of day, season, height above ground, and topography of the site. Wind speeds, in most of the world, are modeled using a statistical analysis called Weibull Distribution. This is important in discussions of wind, but not a concept addressed in the youth guide.

Wind Rose

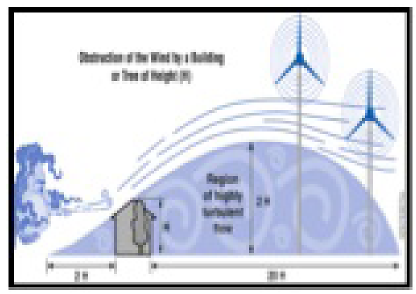


A wind rose can be extremely useful when analyzing wind. In addition to the frequency of the wind, it is useful to know what direction the prevailing wind resource comes from. Turbines should be installed to access the strongest prevailing winds, and should be sited upwind of any obstacles to maximize production. Wind roses from locations around the West are provided at www.wrcc.dri.edu/wraws/nidwmtF.html.

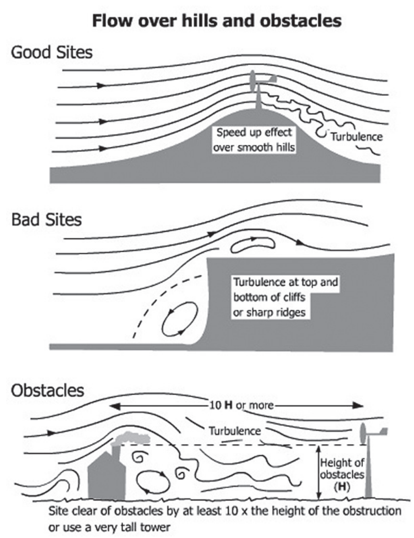
Turbulence and Obstruction

Turbulence is significant in wind generation. It decreases power output from the turbine and causes additional stress on the equipment. Trees, buildings, grain silos and other obstacles can cause turbulence. The region of turbulence downwind of an obstacle is twice the height of that obstacle and quite long. For example, a 30-ft tall house creates a region of turbulence that is 60 ft high and 600 ft long.

Turbulence may also be related to topography. The image below shows characteristics of "good" sites for energy generation versus sites with high levels of turbulent air flow.



Source: NREL



Source: NREL

Sheltering

In hilly terrain, the wind will follow channels, such as canyons. Placing your wind turbine on the leeward side of a hill or sheltering the turbine from the dominant wind will impact energy output.

Air Density

Air density varies by temperature and elevation. In Montana, changes in air temperature mean that air density in winter months is typically better for wind energy power generation than summer months. However, a factor often overlooked in wind resource assessments is changes in air density given elevation. As elevation rises, air density declines such that (given other factors are constant) annual energy production of a turbine sited at 7,000 feet could be 20 percent lower than a similar turbine sited at sea level.

Building a Wind Gauge

This lesson provides four ALTERNATIVE METHODS for building a gauge to measure and observe the wind. The lesson is similar for all of the methods, but the alternatives provide you the opportunity to adapt the lesson based on age, time, and available resources. You may also opt to have learners make different types of gauges and compare/contrast results as part of the lesson.

Life Skills

Critical thinking, problem solving, observation

Lesson Overview/Objective

This unit is designed for ages 9 - 12. Specific age recommendations are provided on each activity. The lesson provides an introduction to the basic concept of measuring wind direction and velocity.

Montana Science Standards

Learners will measure wind velocity and evaluate changes in wind as a result of obstruction, elevation, and direction. This addresses Science Content Standard 1.2 (select and use appropriate tools to make measurements, gather, process and analyze data from scientific investigations), 2.3 (describe energy and compare and contrast energy transformations and characteristics …of motion), 5.2 (apply scientific knowledge and process skills to understand issues and everyday events)

Essential Learning Expectations

Identify wind velocity and understand factors influencing turbulence

Success Indicators

Learner's ability to successfully make a completed wind gauge and learner's ability to successfully make observations, ask questions, and communicate understanding in a science notebook will be assessed. An informal assessment will be utilized to ascertain content knowledge.

Learner Goals

Learners will construct a wind gauge to determine direction and relative speeds of wind. Observations regarding wind behavior in various outdoor locations will indicate the influence of obstruction on air flows.

Vocabulary

Weather vane, anemometer, wind velocity, wind direction, turbulence, wind shear, wind rose

Learners can provide examples of:

- Using the wind gauge to record wind velocity
- Using the wind gauge to determine wind direction
- Identifying a location where the wind has been impacted by turbulence

Learners can:

- Complete all activities in the lesson
- Explain the phrase: Obstacles reduce wind velocity by creating turbulent air flow.

Things to love about this lesson

- Can be adapted for several ages
- Simple and few materials required
- Can be used to record wind direction and relative velocity over several days or meeting times

Considerations for Success

- Learners need to be outside in at least a light breeze
- There will be better observation on sites that are larger and have a variety of obstacles and spaces: trees, buildings, open spaces, etc.

5E Building a Wind Gauge Lesson Plan

Engage

When and where have you experienced interaction with wind?

- Ask learners to evaluate an area outside and record evidence in their notebooks of the wind blowing. (If available, use a kite to help students visually assess the wind behavior in different locations.)
- How does the wind behave around buildings or trees? Up high (in treetops or at tops of buildings)? Ask them to record observations.
- What might we hypothesize about the wind based on our observations?

Explore

Provide learners with directions to design ONE of the FOUR possible gauges:

- Show learners how to read the amount of wind for their gauge.
- Outside, learners record the wind velocity and observations in notebooks.
- Have learners move around the area—do their results change near obstacles like buildings or trees? Record observations in their notebooks.

Explain

Begin the explanation phase by having learners share their observations, questions and reflections of the EXPLORE activities. Proceed as follows:

- Write observations on a flip chart as they are discussed (for informal settings, this can be done with discussion only)
- Compare strongest and weakest wind velocity measures from their gauges. Where did they find the highest wind velocities? Lowest?
- What do our observations tell us about how wind behaves?
- Explain that air flow around obstacles creates turbulence. What evidence of turbulence was observed?
- Ask learners to pretend that they have been hired to find the best site to locate a wind turbine on the property. The turbine needs the highest wind velocity and no turbulence. Where might they want to locate the wind turbine?

Extend

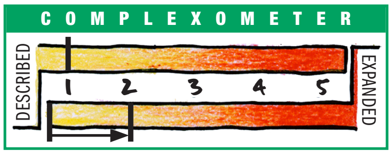
Use the following:

- Place the wind gauge on a yardstick and extend it upward. Does the wind change as the height above ground is increased? What might we predict about the wind at 100 feet?
- Use a compass to determine which direction the wind is coming from. Plot the direction on the wind rose chart (pg 18). Why would this information matter if we were going to install a wind turbine?
- If the gauges are used over several days or at different times of the day, compare wind direction and the weather. What correlations are observed between wind direction and weather? Wind and time of day?
- Have students select a different type of gauge to build. Compare/contrast results.
- Have students draw a diagram of their home including things around the home such as trees, shrubs, and other things that might block the wind. Label the north, east, west, and south sides of the diagram. Have them use the gauge to record the wind at various spots around their home and mark those recordings on their diagram. Share findings at the next meeting.

Evaluate

- Assess gauge design and observations
- What similarities & differences do you notice between the different gauges?
- How and where do you see wind playing a role in your life?
- In what ways might you be interested in learning more about wind?
- Can you identify how you might change the design elements to make it work better?
- How does wind impact your life?
- How is wind currently used for energy in your area?
- How can you help younger children design pinwheels and learn how they work?
- Create a short lesson for children in your neighborhood.

1.1 Simple Cardboard Wind Gauge



Materials

- Paper
- Pencil
- Flip chart & markers
- Scissors
- Thread or string
- Compass (optional)
- Light cardboard
- Yard stick
- Tape
- Notebook or Paper

Safety Reminders

Monitor use of scissors

Activity Time

15-30 Minutes

Notes on this Gauge

This is a very simple gauge for youth ages 9 – 11. The construction takes roughly 10 minutes. Observations and the lesson can range from 10 minutes to 20 minutes, depending on the amount of EXTEND activities you include.

Construction Instructions

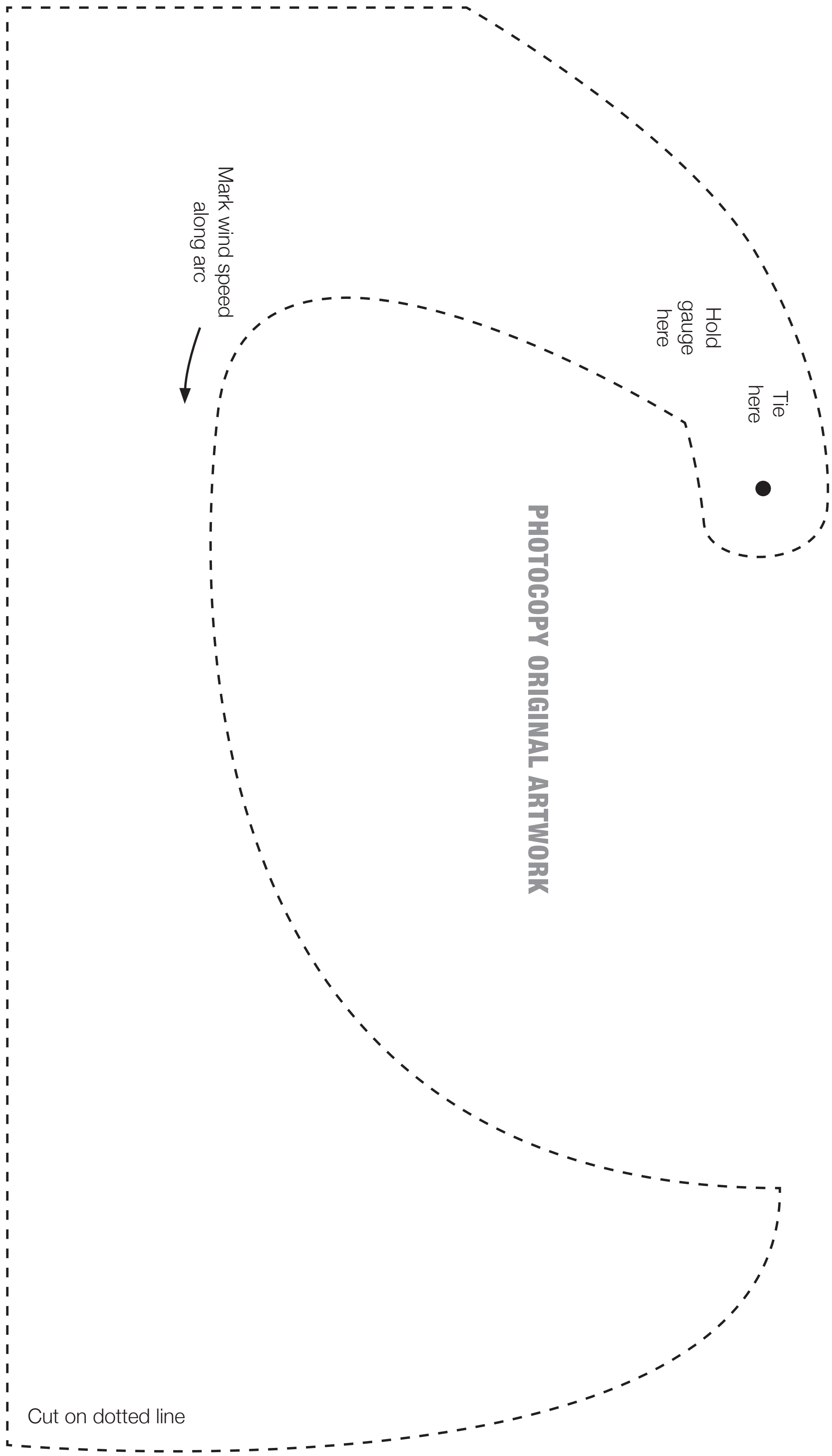
- Trace the pattern onto light-weight cardboard.
- Cut out the cardboard wind gauge.
- Cut 2 feet of thread or string.
- Punch a small hole in the ‘tie here’ dot, and tie a single strand of thread or string through the hole.
- Once outside, hold the gauge where the string is tied.
- Move the gauge until the thread is blowing toward the arc of the gauge.
- Make marks with a pencil along the arc to show how hard the wind is blowing.

Discussion

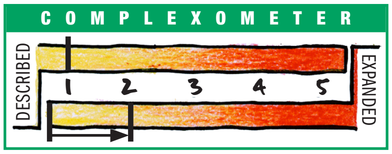
1. How could you improve the design of your wind gauge?
2. Why do we want to measure the wind?
3. How does the wind speed differ at different locations?
4. What projects could you do to teach others to gauge wind speed?
5. How can you share information about wind energy potential in your state with members of your community?
6. Why would this information be important to share?

This activity was adapted from: www.energyquest.ca.gov/projects/windmeasure.html

SIMPLE WIND GAUGE TEMPLATE



1.2 Pencil and String Gauge



Materials

- Pencils with erasers
- Notebook or paper
- Thumbtacks
- Flip chart & markers
- Thread or string (25 cm per participant)
- Compass (optional)
- Tape
- Protractor
- Rulers

Safety Reminders

Monitor use of sharp thumbtacks

Activity Time

15-30 Minutes

Notes on this Gauge

This is a very simple gauge. The construction takes roughly 10 minutes. Observations and the lesson can range from 10 to 20 minutes, depending on the amount of EXTEND activities you include. The use of the protractor to read the gauge can be challenging. You may wish to pair learners so that one can hold the gauge while the other reads the protractor.

Conversion Chart

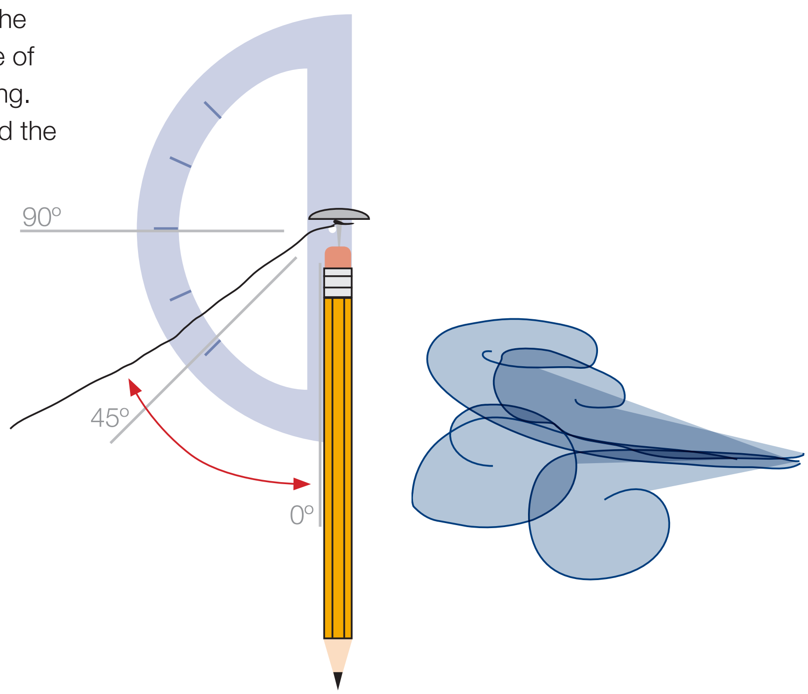
String Angle (degrees)	Wind Speed (mph)
20	0
30	8
40	12
50	15
60	18
70	21
80	26
90	33

Construction Instructions

- Push the thumbtack into the pencil eraser
- Tie the thread around the base of the thumbtack.
- Hold the protractor sideways, along the side of the pencil. *(see below)*
- Measure the power of the wind by holding the device in the air and observing the wind blowing the thread. Record the angle of the thread with a protractor–the larger the angle, the higher the wind energy at the location.
- Record the observations.

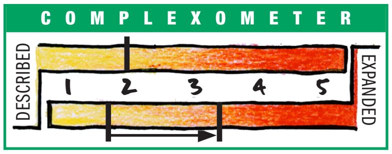
Discussion

1. How could you improve the design of your wind gauge?
2. Why do we want to measure the wind?
3. How does the wind speed differ at different locations?
4. What projects could you do to teach others to gauge wind speed?
5. How can you share information about wind energy potential in your state with members of your community?
6. Why would this information be important to share?



This activity was adapted from 4-H Energy Project "Energy Explorer" 1986 "Wonders of the Wind" Chapter. Montana State University Extension.

1.3 Pinwheel Wind Gauge



Materials

- Construction paper (1 sheet per participant)
- Notebook or paper
- Straight pins
- Flip chart & markers
- Pencil with eraser
- Compass (optional)
- ¼" piece of straw
- Scissors
- Needle-nose pliers

Safety Reminders

Monitor use of scissors and straight pins

Activity Time

15-30 Minutes

Notes on this Gauge

The construction takes roughly 15 minutes. Observations and the lesson can range from 10 to 20 minutes depending on the amount of EXTEND activities you include.

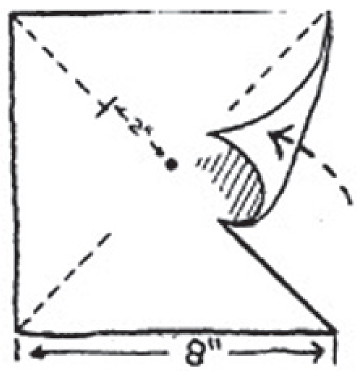
Construction Instructions

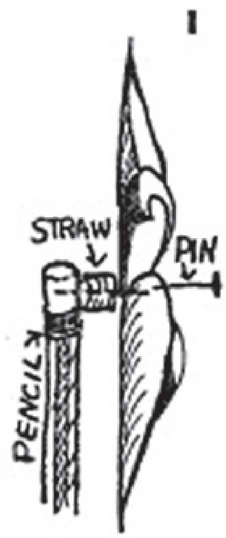
- Cut the construction paper into an 8-inch square.
- Find the center of the paper by drawing lines from the bottom corners to the opposite top corners. Cut on the lines, stopping about 3/4-way to the center. Do not cut through the center point.
- Fold in every other corner to the center of the square. Glue or tape the corners down.
- A piece of straw pinned between the backside of the pinwheel and eraser will help the pinwheel turn.
- Pin the pinwheel-with straw on the pin-to the eraser end of a pencil.
- The instructor can use the needle-nose pliers to bend the straight pin into the eraser for safety.
- Blow straight on the front of pinwheel to see it turn.

Students can design their own pinwheel instead of using the template. They can make more or fewer blades and different shapes such as a hexagon, octagon or polygon. Experiment with different types of paper, shape of the blade or depth of the cut compared to the center circle design.

Discussion

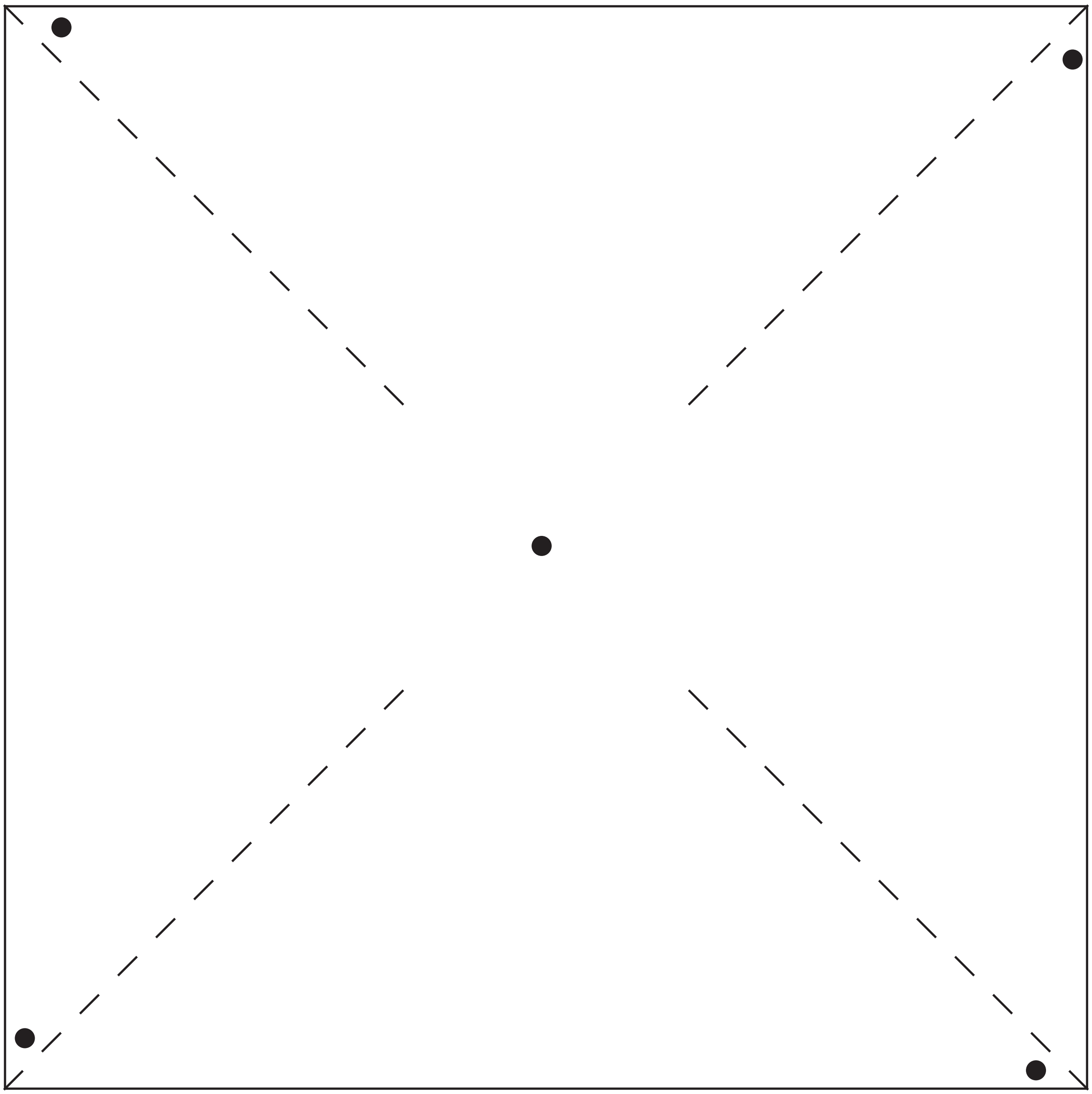
1. How could the pinwheel use the power of the wind?
2. What are some advantages that exist in using wind energy?
3. What are some disadvantages?
4. Think about the materials used in this experiment. What new materials could you develop to further explain the process of wind energy being used for work?
5. Can you think of some way to make wind a reliable source of energy?
6. What adjustments can you make in the design to make your pinwheel turn better?





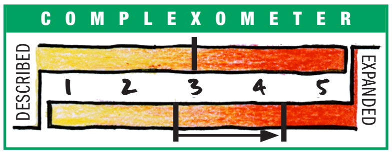
This activity was adapted from 4-H Energy Project "Energy Voyagerr" 1986 "Wind Watchers" Chapter. Montana State University Extension and www.4-H.org/curriculum/wind

Pinwheel Template



PHOTOCOPY ORIGINAL ARTWORK

1.4 ANEMOMETER



Materials

- Five 3 oz. paper cups
- Two plastic soda straws
- One pencil (with unused eraser)
- Single-hole paper punch
- Scissors
- Tape
- One push-pin
- Permanent marker
- Stopwatch
- Box fan (optional)

Safety Reminders

Monitor use of scissors and pins

Activity Time

15-30 Minutes

Notes on this Gauge

The construction takes roughly 15 minutes. For youth ages 9 - 13. Observations and the lesson can range from 10 minutes to 20 minutes, depending on the amount of EXTEND activities you include.

Construction Instructions

- Take four cups and punch one hole in the side of each, about ½ inch (1.5cm) below the rim, and big enough for a straw to fit.
- Take the fifth cup and punch two holes in it, big enough for a straw to fit, directly opposite from each other and about ½ inch (1.5cm) below the rim. Now punch two more holes in the cup, each ¼ inch (1cm) below the rim that are equally-spaced between the first two holes (see picture).
- Using the push-pin and a very sharp pencil, make a hole in the center of the bottom of the cup with four holes in it. The hole should be large enough that the pencil can fit easily through it.
- Slide straws through the hole in one of the cups that has only one hole in it. Bend the tip of the straw that is inside the cup at about ½ inch (1.5cm) and tape it down to the inside of the cup.
- Place the other end of the straw through the two holes across from each other in the fifth cup and then through the single hole in one of the other cups. Tape the end of the straw to the inside of the second cup as you did earlier, making sure that the openings of the two cups face the opposite direction.
- Repeat steps 4 & 5 with the remaining two cups, sliding the straw through the remaining two holes in the fifth cup. Make sure the opening of each cup faces the bottom of the cup next to it (no two openings should be facing each other). Each of the four cups should be facing sideways.
- Insert the pencil with the eraser facing up through the bottom of the fifth cup. Carefully push the pin through the two straws inside the top of cup and into the eraser on the pencil.
- Take the permanent marker and draw a large X or ☺ on the bottom of one of the cups.

Your anemometer is now ready to use! Take it outside and hold it in front of you in an open area where the wind is blowing. If wind is not blowing, use the box fan as a wind source.

Look at the bottom of the marked cup as it spins around. Count the number of times it spins around (revolutions) in 10 seconds. Use the table of revolutions per 10 seconds to estimate wind speed.

Chart with Revolutions per 10 Seconds and Miles Per Hour

Revolutions in 10 Seconds	Wind Speed in Miles per Hour	Wind Speed in Kilometers
2–4	1	2
5–7	2	3
8–9	3	5
10–12	4	6
13 – 15	5	8
16 – 18	6	10
19 – 21	7	11
22 – 23	8	13
24 – 26	9	14
27 – 29	10	16
30 – 32	11	18
33 – 35	12	19
36 – 37	13	21
38 – 40	14	23
41 – 43	15	24
44 – 46	16	26
47 – 49	17	27
50 – 51	18	29
52 – 54	19	31
55 – 57	20	32

Discussion

1. Why is wind speed important?
2. How could you improve the design of your anemometer to make it more efficient?
3. What members of your community need to know the speed of the wind?
4. How can you share information about wind energy potential in your state with members of your community?
5. Why would this information be important to share?

This activity adapted from www.doi.gov/csc/southeast/index.cfm

Observation to Measure the Wind

This lesson uses Beaufort Scale observations to measure the wind.

Life Skills

Critical thinking, problem solving, observation

Lesson Overview/Objective

This unit is designed for youth ages 9 - 13. The lesson provides an introduction to the basic concept of measuring wind direction and velocity.

Montana Science Standards

Learners will measure wind velocity and evaluate changes in wind as a result of obstruction, elevation, and direction. This addresses Science Content Standard 1.2 (select and use appropriate tools to make measurements, gather, process and analyze data from scientific investigations), 2.3 (describe energy and compare and contrast energy transformations and characteristics …of motion), 5.2 (apply scientific knowledge and process skills to understand issues and everyday events).

Essential Learning Expectations

Identify the affects of wind on the natural environment and measure wind velocity using physical indicators.

Success Indicators

Learner's ability to successfully make observations, ask questions, and communicate understanding in a science notebook will be assessed. An informal assessment will be utilized to ascertain content knowledge.

Learner Goals

Learners will observe the natural affects of wind and translate their observations into measurements of average wind speed. Observations regarding wind behavior in various outdoor locations will indicate the influence of obstruction and sheltering on wind speed.

Vocabulary

Weather vane, anemometer, wind velocity, wind direction, turbulence, sheltering, wind shear, wind rose

Learners can provide examples of:

Identifying natural affects of wind on the landscape

Using the Beaufort Scale to calculate wind speed

Identifying a location where the wind impact has been influenced by obstruction or sheltering

Learners can:

- Complete all activities in the lesson
- Explain the phrase: Observation of the natural environment can indicate whether a site is suited for wind turbine energy generation.

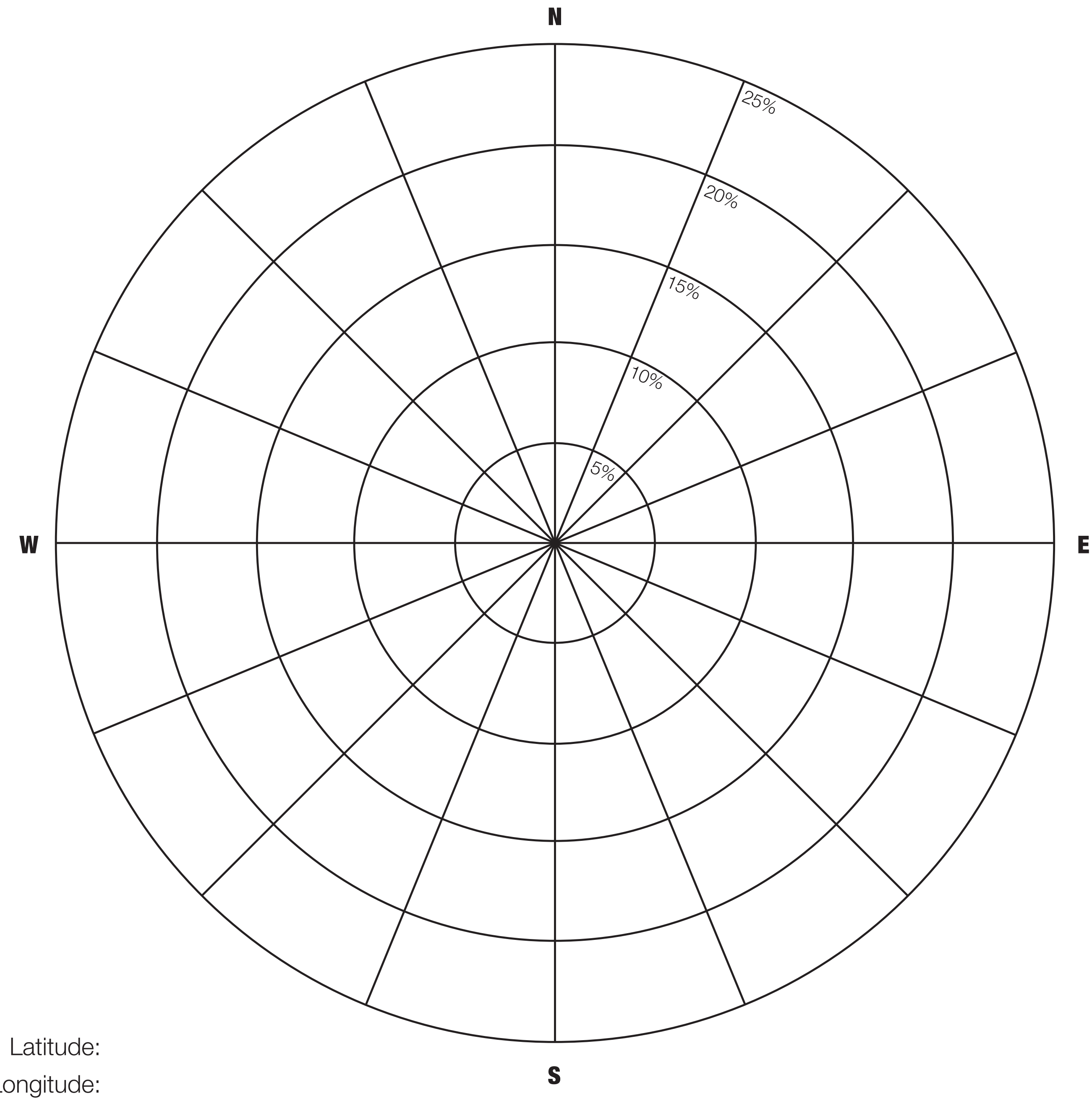
Things to love about this lesson:

- Can be adapted for several ages
- Simple and few materials required
- Can be used to record wind direction and relative velocity over several days or meeting times.

Considerations for Success:

- Learners need to be outside in at least a light breeze.
- There will be better observation on sites that are larger and have a variety of obstacles and spaces: trees, buildings, open spaces, etc.

WIND ROSE GRAPH



Latitude:
Longitude:

PHOTOCOPY ORIGINAL ARTWORK

5E Beaufort Scale Wind Observation Lesson Plan

Engage

- Ask learners to evaluate an area outside and record evidence of the wind in their notebooks.
- How do we know that the wind is blowing? How do we know if wind is common in this location? Ask them to record observations.
- What might we hypothesize about the wind based on our observations?

Explore

Provide learners with the Wind Observation Worksheet and the Beaufort Scale Handout:

- Show learners how to use the Beaufort Scale.
- Outside, learners record wind observations in notebooks.
- Have learners move around the area—do their observations change near obstacles like buildings or trees? Record observations in their notebooks.

Explain

Begin the explanation phase by having learners share their observations, questions and reflections of the EXPLORE activities. Proceed as follows:

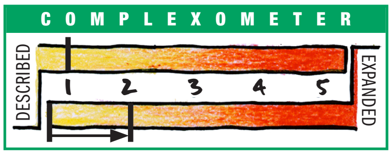
- Write observations on a flip chart as they are discussed (for informal settings, this can be done with discussion only)
- Ask learners to compare the locations with the strongest and weakest wind velocities based on their observations.
- Once all observations are on the chart, ask, “What do our observations tell us about how wind behaves?”
- Explain that air flow around obstacles creates turbulence. Objects also create a pocket of “shelter” from the wind. What evidences of turbulence and/or sheltering were observed?
- Ask learners to pretend that they have been hired to find the best site to locate a wind turbine on the property. The turbine needs the highest wind velocity and no turbulence or sheltering. Where might they want to locate the wind turbine?

Extend

Use the following:

- If possible, take learners to a higher elevation. Does the wind change as the height above ground is increased? What does this tell us about wind shear? What might we predict about the wind at 100 feet?
- Use a compass to determine which direction the wind is coming from. Can we tell the wind direction without a compass using the natural environment? Why would this information matter if we were going to install a wind turbine?
- If the observations are made over several days or at different times of the day, have learners compare wind direction and the weather. What correlations are observed between wind direction and weather? Wind and time of day?
- What members of your community need to know the speed of wind?
- Investigate other tools for measuring wind.

1.5 Beaufort Scale Wind Observation



Materials

- Observation chart
- Notebook or paper
- Beaufort Scale handout
- Flip chart & markers
- Compass (optional)
- Pencils

Safety Reminders

If working with a large group, you may wish to have several adults monitor youth while they are taking observations outside.

Activity Time

15-30 Minutes

Notes on this Activity

Observations and the lesson can range from 15 to 30 minutes, depending on the amount of EXTEND activities you include. For youth ages 9 - 13. You can pair this activity with the Anemometer activity in this series to compare observed wind speeds and measured wind speeds. You can also find weather station readings from local sources to compare observed and measured wind speeds.

Instructions

- Go outside and observe the wind. Using the Beaufort Scale, record your observations onto paper.

Discussion

1. What indicators of wind speed did you observe today?
2. Is today a good day to fly a kite? How do you know?
3. What do your other senses tell you about the wind?
4. How do your observations compare with the official weather information?
5. How can you teach others to observe the speed of the wind?
6. What projects could you do to observe the wind and gauge its speed?

This activity was adapted from 4-H Energy Project "Energy Voyager" 1986 "Wind Watchers" Chapter. Montana State University Extension

History of Beaufort

In 1805, Royal Navy officer Francis Beaufort had a problem. When sailing the seas, naval officers made regular weather observations, but there was no standard scale. One man's "stiff breeze" might be another man's "strong wind." No gauges to measure the wind at sea had been invented. Beaufort devised a scale that used observations of the sails and environment to describe the wind speed. This scale soon became the standard for ship's log entries in the Royal Navy. In the 1850s the scale was adapted to include cup anemometer rotations using an anemometer like in Activity 1.4. In 1916, the descriptions were changed from the sails of the sea, and land observation descriptions were added. Many severe weather warnings today use approximately the same scale that Beaufort devised, for example a hurricane force wind might be described as a Beaufort scale 12.

Beaufort Wind Scale

Developed in 1805 by Sir Francis Beaufort

Force	Wind Speed (miles per hour)	Classification	Appearance of Wind Affects on Land
0	Less than 1	Calm	Calm, smoke rises straight up
1	1-3	Light Air	Smoke moves in the direction of the wind, wind vanes don't move
2	4-7	Light Breeze	Leaves rustle, wind can be felt on face, wind vanes begin to move, flags stir
3	8-12	Gentle Breeze	Leaves and small twigs are constantly moving, light flags blow out
4	13-18	Moderate Breeze	Dust, leaves, and loose paper lifts off ground, small tree branches move, flags flap
5	19-24	Fresh Breeze	Small trees in leaf begin to sway, flags ripple
6	25-31	Strong Breeze	Larger tree branches move, umbrellas are hard to use, flags beat
7	32-38	Near Gale	Whole trees moving, hard to walk against the wind, flags extended
8	39-46	Gale	Twigs break off trees, walking is very difficult
9	47-54	Strong Gale	Slight structural damage occurs, shingles blow off roofs
10	55-63	Whole Gale	Whole trees are uprooted, severe damage to buildings
11	64-73	Violent Storm	Widespread damage
12	74+	Hurricane	Violent destruction

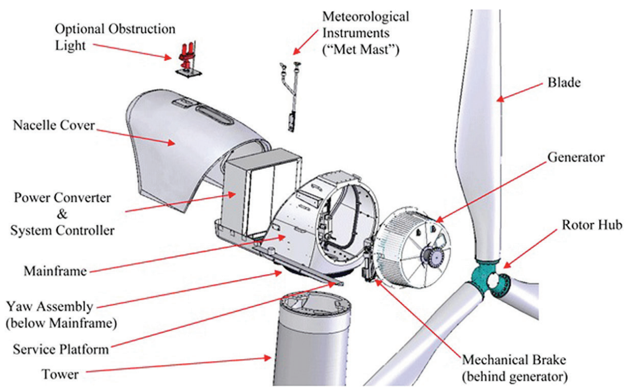
Beaufort Wind Scale					Anemometer Readings	
Date	Time	Location	Appearance of Wind Affects on the Landscape	Wind Speed in Miles Per Hour	Revolutions in 10 Seconds	Wind Speed in Miles Per Hour

WIND TURBINE DESIGN

There are four main parts of a small wind system: 1) the rotor, 2) the generator, 3) the tower, and 4) the control system.

Rotor

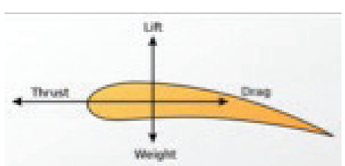
The rotor includes the blades and the hub of a conventional horizontal-axis small wind system. The blades are designed to capture the energy in the wind and turn it into rotational torque. Rotational torque is the force that rotates the central shaft. The rotor hub connects to a central shaft, which drives a generator.



Source: MSU Wind Application Center

Turbine blades can be made of many different materials. Most blades are made of composites (fiberglass is common), because they are strong, lightweight, and cost less than other materials.

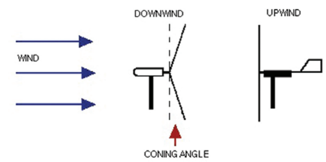
Blades are airfoil-shaped, like airplane wings. Airfoils are shapes which cause a force, or "lift," just because of their shape.



Source: Wikimedia Commons

Lift is caused by air flowing around the airfoil shape. "Drag" is caused by air pushing against the blade. In "lift" machines, the blade is shaped to maximize the force of lift. The amount of lift depends on the angle at which the blade hits the wind. By angling the blade, the lift force can be raised and lowered, and the turbine speed can be regulated. All commercially-successful wind turbines are "lift" machines. Some turbines (including the historic 'windmills' common on farms and ranches decades ago) are "drag" machines. These turbines rely on drag forces to create rotary motion. Drag machine blades may be cupped or use a flap plate, which uses the wind's energy to push, rather than lift the blade.

Turbines may be either "upwind" or "downwind" machines. Upwind machines use a tail fin or vane to place the blades into the wind upwind of the tower, whereas in a downwind turbine, the blades are downwind of the tower. Each type has certain advantages and disadvantages.



Source: NREL

Blades are designed with twist and taper along the length of the blade. These design characteristics are needed to keep stresses uniform along the length of the blade: As the rotor turns, the tip moves at a faster speed than the base of the blade and requires a shallower angle and smaller blade cross-section to produce the desired lifting force. Some small wind turbine's blades "pitch," so the blade changes angle as the wind speed increases. "Pitching" is standard on large, utility-scale wind turbines, but is less common for small wind turbines.

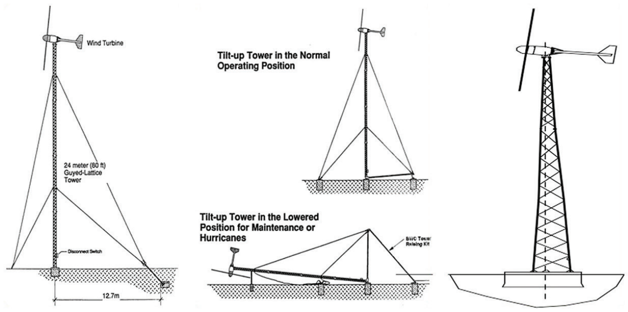
Source: MSU Wind Application Center

Generator

Most small wind turbines are permanent magnet, direct-drive systems. Permanent magnet generators make electrical power using copper wire coils and magnets. This is described in "What is Wind" on page 4 of this guide.

Tower

There are three basic types of towers: guyed towers, monopole, or latticed towers. Guyed towers are the least expensive. Tilt-up guyed towers are designed so that they can be laid down to perform maintenance, or if severe storms are expected. Tilt-up guyed towers are usually more expensive than conventional guyed towers. Monopole or latticed (or free-standing framework) towers are available in permanent free-standing or tilt-up designs. The towers are of a more robust design so they do not



Guyed, monopole, and latticed towers. Source: NREL

require guy wires, and there is an increased cost associated with this design.

Is a Tower Necessary?

Yes. Wind speed is greater as the height above ground increases and turbulent airflows are reduced– both are key factors in wind power production. A taller tower will enable the wind turbine to produce more electricity, but taller towers are also more expensive. For home energy, tower heights range from 30-120 feet. Commercial wind turbine heights are at least 200 feet.

Control System

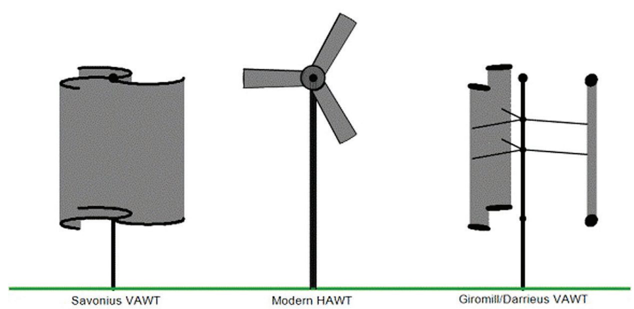
To account for changing wind directions, turbines must be able to "yaw" – that is, turn to face the wind. Most small wind turbine systems use a passive yaw control system, unlike the larger commercial-scale units that rely on active yaw control systems that utilize an electric motor to change the direction of the turbine. Passive control systems are designed to cause the rotor to spin more slowly when the wind speed exceeds a certain level.

Types of Turbines

There are two primary types of turbines—Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT).

In HAWTs, the nacelle (the outer casing for the generator and other operational components) sits on top of the tower parallel to the ground. They are the most common type of turbine and most are upwind, lift machines. HAWTs are usually two- or three-blade designs. Over years of testing, the three-blade designs have had the highest power output. There are some two-blade designs on the market today, but these machines often experience "yaw chatter," or vibration caused when yawing. Blade designs vary by manufacturer, ranging from curved blades and blades with weighted tips to blades with unique cuts and designs.

There are usually three designs of VAWT machines: Darrieus, Savonius, and Giromill. They are mounted with the turbine components perpendicular to the ground. VAWTs have struggled to gain commercial acceptance due to various design, performance, and reliability issues. VAWT rotors are often near the ground where there is lower wind speed and a more turbulent wind resource. VAWT units tend to have poor self-starting abilities, and in some models, the entire rotor must be removed to replace parts. There has not been a commercially-successful VAWT in the United States.



Source: Wikimedia Commons

Wind Turbine Design Series

This lesson provides three ALTERNATIVE METHODS for building a wind-powered machine. The lesson is similar for all of the methods, but the alternatives provide an opportunity to adapt the lesson based on age, time, and available resources. You may also opt to have learners make different designs and compare/contrast results as part of the lesson.

Life Skills

Critical thinking, problem solving, observation

Lesson Overview/Objective

This unit is designed for ages 9 to 12. The lesson provides an introduction to the basic concepts of wind turbine design.

Montana Science Standards

Learners will develop hypotheses related to wind turbine design. They will create machines and evaluate machine performance to test hypotheses. This addresses Science Content Standard 1.1 (identify a question, determine relevant variables and a control, formulate a testable hypothesis, plan and predict the outcome of an investigation, safely conduct scientific investigation, and compare and analyze data), 1.2 (select and use appropriate tools to make measurements, gather, process and analyze data from scientific investigations), 1.3 (review, communicate and defend results of investigations, including considering alternative explanations), 1.5 (identify strengths and weakness in an investigation design), 2.6 (identify, build, describe, measure, and analyze mechanical systems and describe the forces acting within those systems), and 5.2 (apply scientific knowledge and process skills to understand issues and everyday events).

Essential Learning Expectations

Identify the attributes of wind turbine design that affect power production.

Success Indicators

Learner's ability to successfully make observations, ask questions, and communicate understanding in a science notebook will be assessed. An informal assessment will be utilized to ascertain content knowledge.

Learner Goals

Learners will hypothesize anticipated outcomes based on wind turbine design. Learners will test their hypotheses, observe outcomes, and identify opportunities to improve system performance.

Vocabulary

Rotor, generator, tower, airfoil, twist, taper, upwind, downwind, HAWT, VAWT

Learners can provide examples of:

- Identifying attributes of wind turbines that impact performance
- Using different materials and designs to change system output
- Testing a hypothesis and communicating whether their findings confirm or reject the hypothesis

Learners can:

- Complete all activities in the lesson
- Explain the phrase: The design of the sail or blade influences the amount of energy we can capture from the wind.

Things to love about this lesson:

- Can be adapted for several ages
- Can be used to discuss many elements of turbine design

Considerations for Success:

- Some activities require materials that take time to acquire
- Some activities require assembly of testing environment prior to the activity being conducted

5E Wind Turbine Design Lesson Plan

Engage

- Ask learners to consider wind machines (sails, wind turbines, weather vanes) and form a hypothesis about the characteristics that make a design effective in capturing the wind.
  - What factors of design might influence the amount of wind energy captured by the machine?
- Have learners write a hypothesis they would like to test with a wind machine.

Explore

Provide learners with directions to design ONE of the three possible wind machines:

- Show learners how to read the amount of wind power they have captured (based on the activity).
- Have learners test different machine designs and record results in their notebooks. This can be done as a contest between groups or individuals.

Explain

Begin the explanation phase by having learners share their observations, questions and reflections of the EXPLORE activities. Proceed as follows:

- Write observations on a flip chart as they are discussed (for informal settings, this can be done with discussion only).
- Ask learners to compare results of different designs.
- Once all observations are on the chart, ask; "What do our observations tell us about wind machine design?"
- Explain that air flowing around an airfoil can create lift and drag. They can further explain how changing the blade design or pitch can impact lift and drag.
- Discuss factors that impact the performance of the wind machine—how does turbulent air flow change performance? What does this tell us about the need for towers?

Extend

Use the following:

- Compare and contrast machine designs to test the hypothesis.
- Place an obstacle between the machine and the fan to create turbulence (object does not have to be large). What was the effect?
- Discuss the design of the wind machine:
  - How fast was it?
  - Does weight affect performance?
  - What happens if the shape of the blade (or sail) is changed?
  - What happens if the angle of the blade is changed (or the sail is attached differently)?
  - What other design changes could you make that might change the performance?
- Test designs and then allow learners to modify their designs and re-test their assumptions.
- If doing the activity comparing types of wind turbines —What can we learn about HAWTs and VAWTs? What are advantages or disadvantages of each?
- Discuss how their results prove or disprove their hypotheses.

Evaluate

- Assess wind machine design and observations
- How do you think the information gathered in this activity applies to a large wind farm?
- In what ways might you be interested in learning more about wind?
- Can you identify how you might change the design elements to make it work better?

USING MULTIMETERS AND VOLTMETERS

Several of the activities in this section suggest measuring turbine output using a multimeter or voltmeter. The multimeter is a tool used to measure current and resistance, and it displays the reading numerically. The voltmeter only measures voltage, but it displays a visual reading where more lights are illuminated as the electrical output increases.

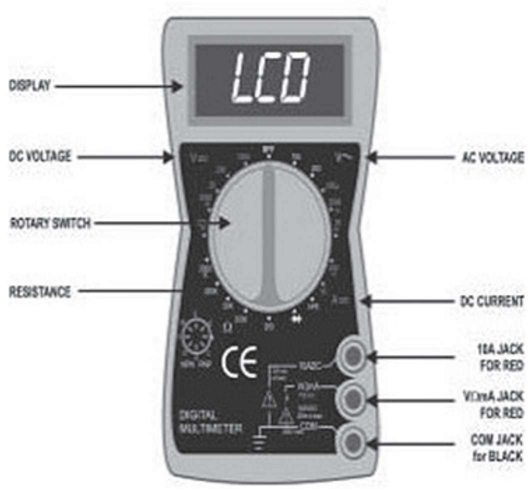
It is important to note that when using either tool to measure electricity, some measurements will never stay the same at a single repeatable value. You will find that the values continuously change depending on the situation in which you are using the tool. It is important to discuss as a class the variability of measurement and let them come up with a standard for collecting their data, whether it's going with the highest reading, lowest reading, or the reading that appears the most frequently in a given time period.

Digital Multimeter

Before using the multimeter, read the operator's instruction manual that is included in the box for the safety and operating instructions.

To use a multimeter reading DC voltage:

- Connect RED lead to VΩmA connector and BLACK to COM.
- Set switch to 20 on DC VOLTAGE scale (1000).
- Adjust switch to lower settings until you are satisfied with the reading.



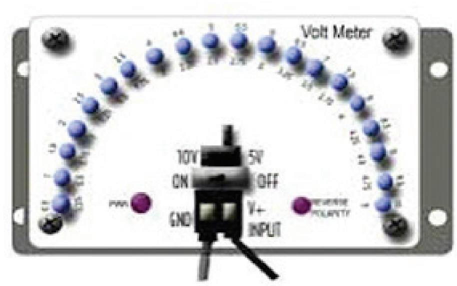
To use a digital voltmeter reading DC current:

- Connect RED lead to VΩmA connector and Black to COM.
- Set switch to highest setting on DC CURRENT scale (200m).
- Connect leads to wires.
- Adjust switch to lower settings until you are satisfied with the reading.

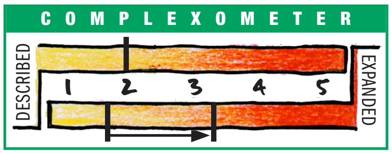
Visual Voltmeter

To Use the Visual Voltmeter:

- Switch the tab over to 5V.
- Press down on the "GND" button. Insert one wire from the turbine into the hole on the bottom. Release the button to secure the wire in place. Repeat this with the other wire on the "V+Input" side.
- Turn the voltmeter on.
- Place the turbine in front of the fan. The lights on the volt meter will light up indicating how much electricity is being generated.
- If the Reverse Polarity light flashes, then switch the wires in the "GND" and "V+Input" locations.



1.6 Wind Powered "Boat"



Materials

- Flexible straws
- Cardboard or index cards
- Tape
- Tape measure
- Straight pins
- Scissors
- Flat, smooth surface of at least 75 cm (29.5 in)
- Paper plates
- Box fan
- Small styrofoam tray (part of an egg carton or a supermarket tray)

Optional Materials

- Pencils
- String
- Paper cups
- Stop watch with second hand
- Paper clips
- Pennies
- Misc. hardware/office supplies

Safety Reminders

Monitor use of scissors, pins and fans

Activity Time

30-60 Minutes

Notes on this Wind Powered "Boat"

The construction takes roughly 20 minutes. Observations and the lesson can range from 20 to 60 minutes depending on the amount of EXTEND activities you include. For youth ages 9 - 13.

Construction Instructions

- Ask students to design and build a "sailboat" that will travel in a straight line a minimum of 75 cm (29.5 in) on a smooth surface.
- Students are to use a Styrofoam tray for the body and attach a mast with a sail to the tray.
- Simulate the wind using a fan. Position the fan on the floor or a table top.
- Mark a starting line about 30 cm from the base of the fan.
- Fasten a tape measure to the table or floor.
- Place "boats" at the starting line with the fan on low.

Discussion

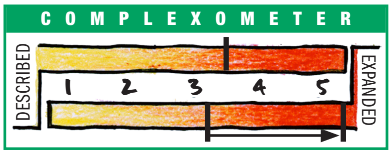
1. What forces influence your boat? Did the location of the post impact your boat?
2. What other design changes could you make that might change the speed?
3. How do you learn from the designs of others?
4. How can you use your new ideas to improve your design?
5. In what other situations might you need to balance choices and trade-offs?

Brief History of Sails

Early sailboats had square sails. These sails were pushed by the wind. The sailboat had to go in the direction of the wind's push. Sails with larger areas were able to use more wind power. Later triangular sails became popular. These sails were able to use the wind to push or pull the boat. Modern sailboats use different shapes and combinations of sails to maximize the force of the wind. Some of the first wind powered machines for pumping water used cloth sails to catch the wind. Some of these are still in use today on the island of Crete.

This activity was adapted from The Power of Wind www.4-H.org/curriculum/wind

1.7 Comparing Types of Wind Turbines



VERTICAL AXIS WIND TURBINE

Materials

- Empty 16 oz. plastic bottle
- Pencil
- ¼” Dowel or coat hanger (at least 9” long)
- Scissors/utility knife
- Tape
- Marker
- Wooden spools
- Hole punch
- Cardboard/ cardstock
- Hot glue gun/glue
- Fan (optional)

Safety Reminders

Monitor use of scissors, utility knives, hot glue gun

Activity Time

20 - 45 Minutes

Notes on this Activity

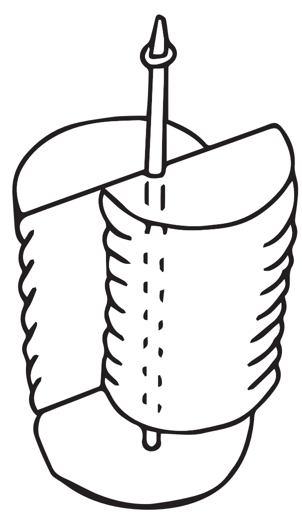
The purpose of this activity is to compare and contrast two types of small wind turbines, Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). You may wish to assign half of the group to make a VAWT while the other half makes a HAWT so that you can compare and contrast the performance. More information on HAWT and VAWT turbines is provided on page 23. For the VAWT turbine, the construction roughly takes 20 minutes. Observations and lesson can range from 15 minutes to 45 minutes, depending on the amount of EXTEND activities you include.

Construction Instructions

In a Vertical Axis Wind Turbine (VAWT), the rotor is composed of two, offset, semi-cylindrical elements rotating about a vertical axis. The Savonius turbine is one of the simplest turbines. Aerodynamically, it is a drag-type device, consisting of two or three scoops. Looking down on the rotor from above, a two-scoop machine would look like an “S” shape in cross section.

- Peel the label off an empty bottle.
- Cut the plastic bottle in half lengthwise and cut off the tapered top section.
- Offset the halves with the center of one half facing the sidewall of the opposite half, and tape together—see photo.
- Trace onto cardboard the pattern of the rotor—it will similar to a figure-8 split in half.
- Punch holes in both halves of the cardboard top and bottom where they come together
- Glue the plastic rotors onto the cardboard
- Insert a small dowel or coat hanger into the holes
- Add spools to the dowels outside of the rotor
- Paint a stripe of color with magic marker onto one side of the rotor

Your VAWT rotor is now ready to use! Take it outside and hold it in front of you in an open area where the wind is blowing or use a fan. Compare it to the HAWT turbine.



This activity was adapted from a 1980’s MSU Extension Energy Program: Energy Voyager, Wonders of the Wind and twww.energyeducation.tx.gov/pdf/54inv.pdf

HORIZONTAL AXIS WIND TURBINE

Materials

- One 2-liter plastic bottle
- 500 ml sand
- 2 wooden dowels (30 cm x 5mm)
- Jumbo paperclips
- 2 corks (2 cm)
- Metal washers- all sizes
- Single hole punch
- Fan
- Stop watch
- Cardboard, paper
- Hot glue gun
- Rulers, markers
- Protractor
- String
- Scissors

Safety Reminders

Monitor use of scissors, hot glue gun and fan

Activity Time

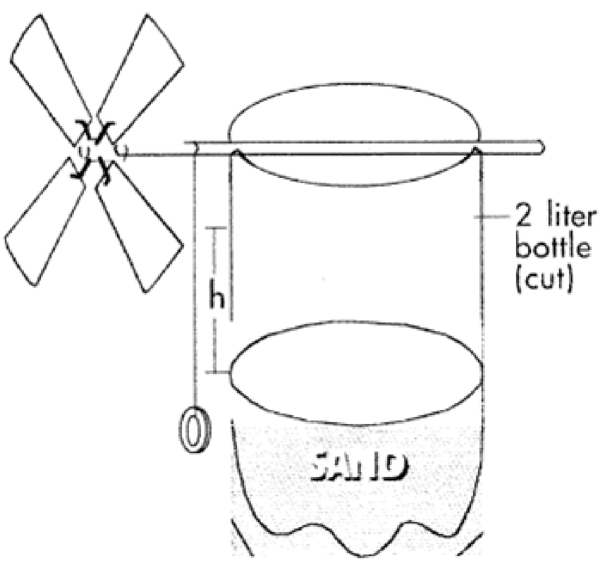
20 - 45 minutes

Notes on this Activity

The construction takes roughly 20 minutes. Observations and lesson can range from 15 minutes to 45 minutes depending on the amount of EXTEND activities you include.

Construction Instructions

HAWT is the most commonly used wind turbine to generate electricity. HAWT has blades with an aerodynamic design that produces lift force which turns the rotor. This rotates the generator shaft and drives the generator, producing electricity.



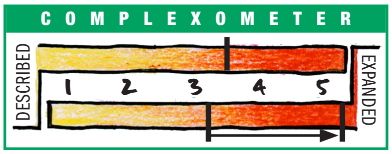
- Cut off the top of the 2-liter bottle. Use a single hole punch to cut half-circle notches in the top edge you just cut to hold the dowel in place
- Fill the bottom of the bottle with sand.
- Design a set of rotor blades from cardboard or paper or (other materials)
- Straighten out one end of a jumbo paperclip for each blade.
- Glue the rounded end of the paper clip to each blade. Allow 1 cm of the straightened paperclip to extend beyond the blade.
- Insert the paperclip blades into a cork. Make sure the blades are spaced evenly.
- Using a protractor, twist each blade to a 45 degree angle.
- Glue the cork to the end of the dowel.
- Insert the dowel into the notches

Take it outside and set it in an open area where the wind is blowing or use a fan on low speed. Compare it to the VAWT turbine.

Discussion Questions

1. What differences or similarities do you find between the HAWT and VAWT turbines?
2. How could you improve the design of your rotor to make it more efficient?
3. Think about the materials used in this experiment. What new materials could you develop to further explain the process of wind energy being used for work?
4. Given what you know about wind resource assessment, would siting be different for the turbine types?

1.8 Design Efficient Turbine Blades



Materials

This activity can also be done using a kit from KidWind.com. All PVC pipe parts should be 1" diameter.

- 2-3 box fans
- 1 – 24" length PVC pipe
- 1 – 2" length PVC pipe
- 6 – 6" length PVC pipe
- 2 – PVC tees
- 1 – PVC tee with a hole drilled in the bottom
- 5 – PVC elbows (90°)
- 1 – PVC coupler
- 1 – wind turbine generator
- 4 ft – 22 gauge (awg) hook-up wire, solid
- 1 – 12-hole crimping hub (more than 1 if testing multiple designs)
- 2 – alligator clips
- 1 – simple multimeter
- 1 – demonstration motor w/ mini prop
- 20 – ¼" diameter poplar dowels (maybe more if large group)
- 10 – 18" x 3" sheets of balsa wood
- 1 – 3" black 3-blade propeller
- Wire cutters
- Wind speed meter (optional)
- Tachometer (optional)
- Rulers
- 1–protractor
- Duct tape
- Glue
- Paper plates
- Cardboard
- Cups

Safety Reminders

Monitor use of knives, tacks and fans

Activity Time

45 – 90 Minutes

Notes on this Turbine

This turbine will have a horizontal axis and looks like a windmill. Construction roughly takes 30 minutes. Observations and lesson can range from 30 minutes to 60 minutes. For youth ages 9 - 13.

Advanced Preparation

For younger groups or compressed workshop times, have the base built before the class begins the activity. See Figure 1.

Constructing the base

- Connect 4 – PVC elbows (90º) to 4 – 6" length PVC pipe pieces and two PVC tees facing each other to make the Turbine base sides. (Figure 2)
- Connect the two sides of the base using the remaining 2 – 6" lengths of PVC and the tee with hole drilled in the middle.
- The instructor should build the Nacelle (the upper housing unit for inner working parts of the turbine, Figure 3) and it will need to be fitted on the top of the base when the first group is ready to test their blades.

Constructing the Tower

- Thread generator wires from the Nacelle through the 24" length of PVC and down through the bottom of the PVC tee with hole drilled in it.
- Make sure the Nacelle is securely placed on top of the tower. The tower should look like Figure 1.

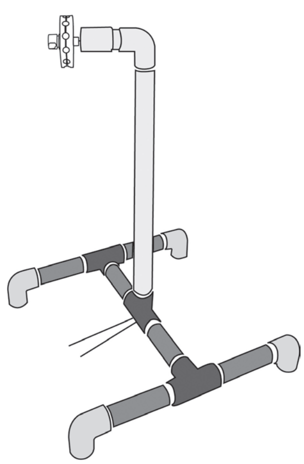


Figure 1: Completed turbine tower. NEED Exploring Wind Energy: Teacher guide (pg 23)

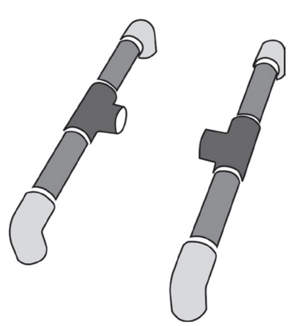


Figure 2: Turbine base sides. NEED Exploring Wind Energy: Teacher guide (pg 22)

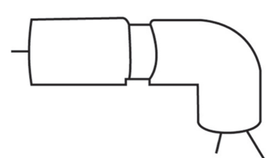


Figure 3: Nacelle. NEED Exploring Wind Energy: Teacher guide (pg 22)

Activity Instructions

- Make sure all the materials for students to create their blades are in one location.
- Divide the class into groups.
- Explain to the class that they are going to design turbine blades that will effectively convert the kinetic energy in wind into electricity.
- Have the groups write a hypothesis for their experiment. The manipulated variable can be the number of blades, the blade pitch, etc. and the responding variable is the electrical output.
- Let the groups decide on what material they are going to use and how many blades they want to make. They can make between three and five blade designs.
- Once the groups have their first set of blades, bring them to the testing area and use the multimeter to see what, if any, is the voltage and amperage to find out the amount of power their blades produce. Record results.
- The groups will need to attach their blades to the hub that has already been assembled by putting the dowels into the holes of the hub. They then need to attach the hub to the Nacelle by pressing it onto the generator's drive shaft.
- Whether or not the groups produce successful blades the first time, they can go back and make changes to their design to try and produce more power the next time.
- Let the groups have three chances to see which group produces the most power with their blade design.

Discussion

1. Which blade angle did you choose for your turbine design?
2. What changes did you make and why?
3. What might your next design look like?
4. Which design most resembles a large-scale turbine?

Tips on Improving Blades

Shorten the blades

Wind turbines with longer blades usually generate more power. However, on our small turbine, it is hard for students to make large, long blades that don't add a lot of drag and create inefficiency. Try to shorten the blades by a few centimeters.

Change the pitch

Students usually want to set the angle of the blades to about 45º the first time they use the turbine. Have them try to make the blades flatter toward the fan (0º–5º). Pitch affects power output so the students can experiment with this aspect to see what happens. They can use a protractor to measure the pitch. Finding a way to twist the blades (0º near the tip and around 10º - 20º near the base) could really improve performance.

Use fewer blades

To reduce drag, try to only use 2 - 4 blades.

Use light material

To reduce the weight of the blades, use less material or lighter material.

Smooth surface

Smooth blade surfaces create less drag. Try removing any tape you don't really need or smooth any rough edges.

Blades vs. fan

If your blades are bigger than the fan or if the blade tips are wider than the fan, they are not catching any wind, they just add drag. Find more wind.

Blade shape

The tips travel much faster than the base and can travel faster if they are light and small, meaning, that if you have wide or heavy tips, you may be adding more drag.

This activity was adapted from www.kidwind.org.

Siting Wind Turbines

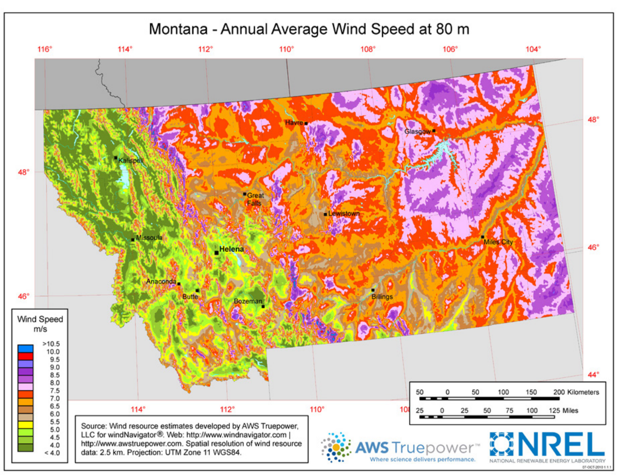
The location of a wind turbine is very important. In commercial (utility) scale wind, each turbine location is studied and evaluated by engineers to determine the best location for the turbine. Engineers and other scientists consider the wind resource, the topography of the site, wildlife (especially birds and bats), and things like the distance to power transmission lines.

Even though all wind turbines (commercial and small scale) need to be properly sited, it can be easier for us to understand wind turbine siting if we consider small (1-10 kilowatt) systems, like those that might install to power a home.

Understanding Your Wind Resource

Several of the wind activities in this series have helped you to better understand the wind at your location. There are wind maps available online as well:
Free wind-mapping data is available from:

- Department of Energy: Wind Powering America State Wind Maps: www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp
- Renewable Energy Atlas of the West: www.energyatlas.org/
- National Renewable Energy Lab In My Back yard: www.nrel.gov/eis/imby/about.html



You can also get information from weather stations in your community. Check the local airport or you can find local weather stations online at www.noaa.gov. Enter your zip code. On the right hand side under "Current Conditions," you will find a link for "More Local Wx"—this will provide you with a list of weather towers in your area.

Remember, the free maps and data will give an indication of the wind at your location, but will not be perfect—the wind will behave differently at your location, especially if you are far away from the point where the data is collected. The mapping tools often use wind "modeling" software, so depending on the quality of the data used and the proximity to your location, free maps can have a high degree of error. These sources will give you an estimate of your wind speed, however.

Looking Around

When siting a wind turbine, you want to find the spot on your property that has the best access to the best wind, but there are other things to consider as well. Let's look at a few of those other issues:

Height of the Tower

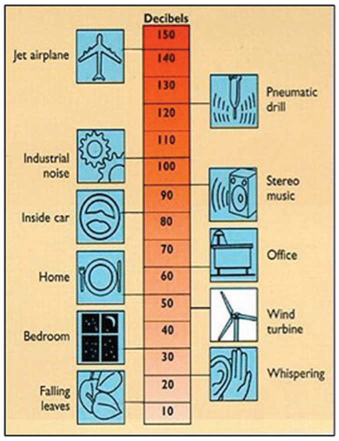
The best wind is free of turbulence and obstruction, so the turbine blades need to be above the disturbance area caused by structures, trees, topography, and other ground clutter. The basic rule of thumb is to site the turbine with the bottom edge of the rotor blades at least 30 feet above the tallest obstacle within 500 feet. Some experts recommend that the bottom edge of the blade should pass three times above the tallest upwind barrier. Keep in mind that some barriers change—especially trees, which grow over time. The most common error in small turbine siting is placing the wind turbine on a tower that is too short.

Finding the Spot

To find the best access to the wind, start by looking at a possible site on the highest point on the property. This spot may not have the best wind or be the best location, but is often the point with the best access to the wind. Here are some additional considerations:

- Soil: Look at the soil. Soils vary in their capacity to support weight. Weak soils may not be suited for supporting a wind turbine, or may require additional engineering to ensure safe operation of the turbine. Got rocks? Big rocks may increase the total cost of preparing the site.

- Are turbines allowed in your area? Some communities and subdivisions limit the height of structures or prohibit wind turbines altogether.
- Noise: Sound may carry differently according to topography and structures. Some small wind turbine owners report almost no sound from their turbines, but also report that their neighbors experience sound from the turbine.



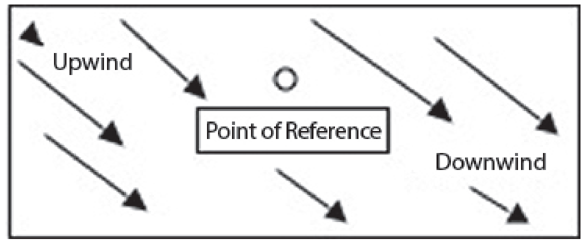
Source: NREL

  For this reason, some communities limit the noise levels (in decibels) as measured from the closest neighboring inhabited dwelling. The amount and type of noise may vary by wind turbine and by site.
- Air traffic: Are you near an airport or military post? Are you in an area where crop dusting is common? If so you should check to see if there are rules about where you can place a small wind turbine.
- Do you have enough room? You should have a half-acre or more around the turbine site. Many experts recommend one acre and some communities require five acres of vacant space around a turbine. Could you fit a turbine in your location?
- Setback: Setbacks refer to the distance you must site your turbine away from public areas or property lines. Setbacks usually refer to all parts of the system, which include guy-wires for guyed towers. Check with your community—do setbacks apply to you?

You may need to check with your community to find out more about the regulations in your area. You can check with the city or county zoning office.

Upwind? Downwind?

When looking at your site, you should locate the turbine so that the bottom edge of the blade should pass three times above the tallest upwind barrier. But what is "upwind?" Perhaps it is easiest to explain using a graphic:



Upwind is the "upper" side of a point of reference. So if the point of reference is a barn, you want to site a turbine on the upper side of the barn to avoid wind turbulence.

You also want to consider the most prevalent wind direction—use the wind measurement and observation activities or local weather data to help determine where "upwind" is at a location most of the time. In Montana, the best wind energy occurs in the winter, so if you have to choose between prevailing wind directions (summer vs. winter) most locations will have higher energy output by maximizing the winter wind resource.

Siting a Small Wind Turbine

This lesson provides learners an opportunity to evaluate a location for siting a small wind turbine. You can expand this lesson to include a field trip to the city or zoning office in your community where learners can find out if ordinances allow wind turbines and if there are restrictions on locations and tower height. In each community, the office you visit may be different. In cities, the city clerk should be able to help you find ordinances that would pertain to small wind. In unincorporated towns or counties, the county Clerk and Recorder's office may have the records. In addition, check subdivision covenants to see if they have language regarding wind turbines or height of structures. Many communities do not have specific language regarding wind turbines, but may have other restrictions (like height of structures) or setbacks for construction that will limit wind turbine siting. Exploring the rules in your area can be a great exercise in understanding local government!

Note: This lesson is best used after the wind measuring and observation activities have been completed. If using this lesson without having completed those activities, review pages 3-6 of the wind series and make copies of wind maps prior to the lesson.

Life Skills

Critical thinking, problem solving, observation

Lesson Overview/Objective

This unit is designed for ages 9 to 13. The lesson provides an introduction to the basic concept of siting a small wind turbine.

Montana Science Standards

Learners will evaluate a location for wind speed, obstruction, and height of obstacles. This addresses Science Content Standard 1.2 (select and use appropriate tools to make measurements, gather, process and analyze data from scientific investigations), 2.3 (describe energy and compare and contrast energy transformations and characteristics …of motion), 5.2 (apply scientific knowledge and process skills to understand issues and everyday events).

Essential Learning Expectations

Understand factors influencing wind turbine energy output and apply information to selecting a site.

Success Indicators

Learner's ability to make critical observations about a location, ask questions, and communicate understanding in a science notebook will be assessed. An informal assessment will be utilized to ascertain content knowledge.

Learner Goals

Learners will draw a rough map of a location. Observations regarding wind behavior and obstacles will indicate the optimum siting for a wind turbine.

Vocabulary

Wind velocity, wind direction, turbulence, obstacle, wind rose, upwind, downwind

Learners can provide examples of:

- Obstacles on a property location
- Using the shadow method to measure the height of obstacles
- Using critical thinking to find the best location on their property

Learners can:

- Complete all activities in the lesson
- Explain the phrase: The highest point on the property may not have the best wind resource.

Things to love about this lesson:

- Can be adapted for several ages
- Few materials required
- Investigations into local restrictions that apply to small wind can be added

Considerations for Success:

- Learners need to be outside
- There will be better observation on sites that are larger and have a variety of obstacles and spaces—trees, buildings, open spaces, etc. You may want to define the boundaries of the area
- Easiest to do early in the day
- The lesson is best used after wind measurement and observation activities

5E SITING A TURBINE LESSON PLAN

Engage
- Pretend the group has been hired to find the best possible location for a small wind turbine on a property.
- How does the wind behave around buildings or trees? Up high (in treetops or at tops of buildings)?
- What might we hypothesize about the best location for a wind turbine based on our observations?
- Explore
- Have learners create a map of the location, drawing obstacles (buildings, trees, topography, etc.) on their maps.
- Is there a high point at the location? If so, what can be observed about that point? Is it free from obstruction?

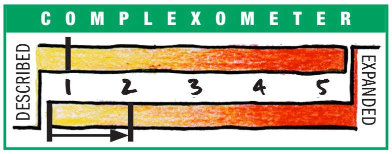
Explain
Begin the explanation phase by having learners share their observations, questions and reflections of the EXPLORE activities.
- Explain that turbines should be located upwind of obstacles and at least 30 feet above the tallest obstacle within 500 feet. Demonstrate the use of the shadow technique to measure the height of obstacles.
- Send learners back to their locations to measure obstacles. Measure 500 feet from obstacles. Note heights and observations on maps.

Extend
Use the following:
- What is the tallest obstacle at the location? How tall is it?
- Where is “upwind” of the tallest obstacle?
- If the tower needs to be at least 30 feet higher than the tallest obstacle within 500 feet, how tall would the tower have to be?
- What other factors would influence the decision on where to locate a turbine? Are there other obstructions on the property?
- Are there obstructions on the neighbor’s property that would influence our decision?
- What else do we know about wind that would help us to make a recommendation on where to site the turbine?
- Use your own home or an area nearby to determine the possibility of a wind turbine and the best location.
- What is the average wind speed in your community?
- What limitations should be considered before installing a wind turbine?
- What are some environmental benefits of wind power?
- What are some environmental concerns of wind power?
- How can you make sure that all opinions are respected as wind energy options are explored?
- How can you share information about wind energy with others in your community and state? Why would it be important to share this information?
- Research the amount of power generated by wind turbines and wind farms in your area, state and country.
- Research where power is sent from wind farms in your area.
- Why might people in your community be for or against the development of a wind farm? What might be the social issues, environmental issues, economic issues or cultural issues?
- Explore careers in wind energy. What are possible careers and what training/degrees are available in this field of study? Both professional and skilled workers are needed in a variety of fields: construction, environmental engineering, computer programming, meteorology, turbine manufacturing, energy analysis, management, law, etc. In a news or journal article, describe what the person you learned about might do in a typical day. Make a brochure of different careers that are required to build a wind farm.
- Debate the pros and cons of alternative energy and wind turbines. Work with an adult to organize a debate or town hall meeting to explore the issues associated with building and operating wind turbines in your community.
- Compose a newspaper article for your local paper that would help community members learn about

wind power.

- Make a presentation to a group about what you have learned about wind energy.
- Contact your local power company and find out if they offer electricity generated from renewable energy sources. Report what you find.
- Find out what geographical locations in the world are best for wind generation and what countries are actually using the most wind energy. Be sure to give website addresses of where the information is found and why you think they are reliable.
- Write one page about the current energy policy of the United States. What types of energy technology are we trying to develop? In what way is the government encouraging people to use energy wisely? What would you do differently if you were in the government?
- Write song lyrics or compose music about wind energy.
- Write a poem about wind. Think of all of the words that describe or name the wind.
- Write and illustrate a myth about wind.
- Draw or paint a picture showing the impact of wind energy.

1.9 Mapping Exercise



Materials

- Measuring tape (100 foot preferred)*
- Blank paper or graph paper
- Notebooks
- Pencil

Safety Reminders

Monitor youth while making outdoor observations

Activity Time

30 - 60 Minutes

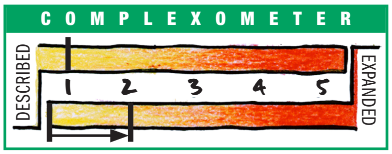
Notes on this Activity

You may wish to have several measuring tapes available and divide learners into groups to complete the activity. This activity can also be assigned for youth to do at home. They can observe their own yards or neighborhoods and bring their maps to the next meeting.

Instructions/Discussion

- Define an area for learners to map (a city lot, a several acre plot, etc.)
- Have learners map the area on their blank sheet of paper.
    - How large is the area? Measure it and record distances on the paper.
    - What obstacles exist on the property? Trees? Houses? Natural barriers like cliffs or creeks?
    - Is there a high point on the property?
    - Is there at least one-half acre of space that is free of obstruction? (An acre is roughly the size of a football field.)
    - Where is upwind on the map? (Go to www.wrcc.dri.edu/wraws/nidwmtF.html to find wind roses for your area and find the prevailing wind direction)
    - Is there space available upwind of obstacles where you might place a wind turbine?
    - What local ordinances do you need to pay attention to when thinking about your map?
        - Do you have to be “set back” from the property line? If so, by how many feet?
        - Are there a minimum number of acres for a wind turbine?
- (Option) Add wind observations to the map using either the Beaufort scale or the wind gauge activities. Are there places on the property where the wind is stronger? Sheltered? Turbulent?

2.0 Using the Shadow Method to Measure Obstacles



Materials

- Measuring tape (100 foot preferred)*
- Shovel or a stake (at least 2 feet long)
- Pencil
- Calculator
- Notebooks

Safety Reminders

Monitor youth while making outdoor observations

Activity Time

30-60 Minutes

Notes on this Activity

You may wish to have several measuring tapes available and divide learners into groups to complete the activity.

Instructions

- Drive a shovel or stake vertically into the ground.
- Measure the height of the shovel or stake. Record the height. (If shovels are not available, learners can measure each other or another static object.)
- Find the shadow cast by the shovel or stake. Measure the shadow and record the length.
- Find the shadow of the obstacle you wish to measure. Measure the shadow and record the length.
- Math:
  - Divide: Height of Shovel/Length of Shovel Shadow = Result
  - Divide: Length of Obstacle Shadow/Result = Height of Obstacle
- Measure the tallest structure on the property. How high would your wind turbine need to be if it is 30 feet above the tallest obstacle?

Discussion Questions

1. Why do we need to measure the obstacles around the site we want to use to place a wind turbine?
2. Can the shadow method be used to determine the height of all obstacles?
3. How else could you use this shadow method for other projects?

Math

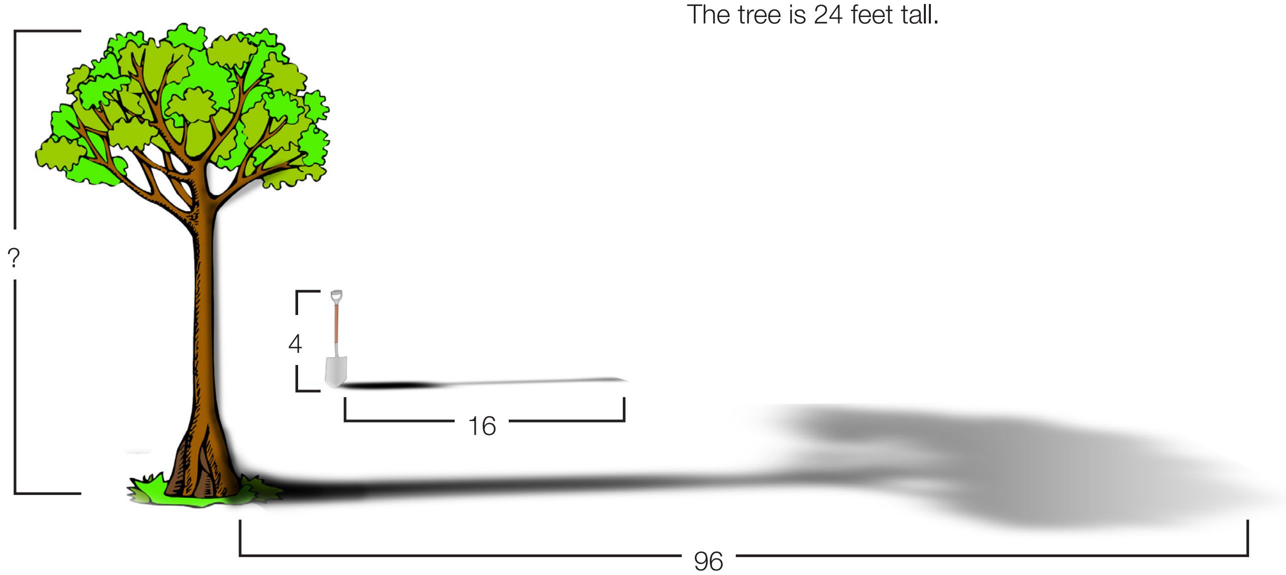
- Height of Shovel = 4 ft
- Shovel Shadow = 16 ft

4/16 = 4
(for every 1 foot of shovel,
there are 4 feet of shadow)

- Height of Tree = ???
- Tree Shadow = 96 ft

96/4 = 24

The tree is 24 feet tall.



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