The Power of the Wind

Overview

After a general opening discussion, students work in small teams to create pinwheel windmills from a provided template. With "wind" from a blow dryer, they demonstrate that the kinetic energy of wind can be used to do work, raising pennies from floor to table height. Each student team uses a provided lab sheet, makes a prediction, and collects data on the number of pennies their windmill can lift. Then they average and graph their data to illustrate the relationship between the work performed (weight lifted) and time required. Throughout the lesson, windmills and wind turbines and the students' experiments are framed in terms of essential science concepts related to forms of energy, energy transformations, and work.

LESSON THREE 3

Core Concepts

Harvesting wind energy involves capturing the motion energy of the wind using wind turbines. Wind turbines may be used individually or placed in large arrays called wind farms. Wind energy can be used in mechanical applications, such as pumping water, or the mechanical energy may be used to rotate a turbine to activate a generator to produce electricity. Generating wind energy does not produce solid waste, hazardous waste, water pollution, air pollution, or greenhouse gases.

These concepts are from the Powering Our Future Energy Education Conceptual Framework (Appendix A).

3

LESSON THREE

Learning Objectives

ARIZONA DEPARTMENT OF EDUCATION ACADEMIC STANDARDS

See Appendix B for the full text of these ADE Standards.

Science	SC06-S1C1-01; SC06-S1C2-01; SC06-S1C2-03; SC06-S1C2-05; SC06-S1C3-01; SC06-S1C3-02; SC06-S1C4-02; SC06-S1C4-03; SC06-S1C4-05; SC06-S5C3-01; SC07-S1C1-03; SC07-S1C2-01; SC07-S1C2-03; SC07-S1C2-05; SC07-S1C3-01; SC07-S1C3-02; SC07-S1C3-03; SC07-S1C3-04; SC07-S1C3-05; SC07-S1C4-03; SC07-S1C4-05; SC08-S1C1-03; SC08-S1C2-01; SC08-S1C2-03; SC08-S1C2-05; SC08-S1C3-01; SC08-S1C3-02; SC08-S1C3-03; SC08-S1C3-05; SC08-S1C3-06; SC08-S1C4-01; SC08-S1C4-03; SC08-S1C4-05
Mathematics	M06-S2C1-02; M06-S2C1-03; M06-S2C1-04; M06-S2C1-06; M06-S2C1-07; M06-S4C4-03; M07-S1C2-01; M07-S1C2-02; M07-S2C1-07; M07-S2C1-08; M07-S4C4-02; M08-S2C1-08; M08-S2C1-10
Language Arts	R06-S3C2-01; R06-S3C2-03; R07-S3C2-01; R07-S3C2-03; R07-S3C2-01; R07-S3C2-03

TIME NEEDED

- Part One — 45 minutes
- Part Two — 45 minutes

After completing this lesson, students will be able to do the following:

- Explain why it is important in an experiment to keep all variables constant other than the variable being studied.
- Discuss the value of using averages and the value of presenting data graphically.
- Discuss examples of factors that may influence the results or validity of an experiment.
- Give the scientific definition of *work* and of *energy* and explain the relationship between energy and work.
- Explain the *forms of energy* and *energy transformations* involved in using wind to perform mechanical work and generate electricity.
- Describe a process of collecting, recording, graphing, and interpreting experimental data.
- Explain how their own experiments demonstrate use of the *scientific method*.

TEACHER BACKGROUND INFORMATION

Review these sections of the *Energy Primer*:

- Renewable Energy Sources
  - subsection on Wind Power

Advance Preparation

MATERIALS

- Template: *Making a Windmill* – photocopy one per three-person team, preferably on heavy paper or cover stock
- Student Lab Sheet: *Windmills and Work* – photocopy one per student
- stopwatches, watches, or wall clock displaying seconds – one per team
- 1” brass paper fasteners – one per team
- large-diameter straws – one per team
- standard-diameter straws – one per team
- 1 or 1.5 liter plastic bottles (empty) – one per team
- material to weight the plastic bottles (water, sand, or fine gravel) – enough to fill bottles 1/3 to 1/2
- lightweight string – approximately 1.5 meter per team
- large paper clips – one per team
- paper clips – 10 per team
- pennies – 10 per team
- meter sticks – one per team
- scissors – one per team
- tape – several inches per team
- “tool” with which to puncture paper (compass, fine-tip pen, etc.) – one per team
- blow dryers (hair dryers) – ideally one per team
- optional: ring stands – one per blow dryer, if available

GENERAL PREP

- Make a pinwheel windmill in advance. This will provide a model for students to examine as well as prepare you to answer their questions.
- When collecting materials, be aware that large-diameter straws are available at certain fast-food outlets (e.g., McDonald’s, Starbucks).
- Ask students to bring in plastic water bottles, pennies, and blow dryers well in advance.
- Review the one-page write-up about Wind Power within the student reading *Electricity for You and Me* (in the front section, *Module Overview Multi-Unit Materials* – of this module) and decide if you want to provide it to your class as background reading for this lesson.

Suggested Procedure

Part One:

Making Windmills

1 Open by inquiring what students know about **windmills** and the purposes for which windmills are used. (*to pump water for cattle and wildlife, to make electricity; also – historically – to grind grain*) Summarize these examples as all related to doing work. Define **energy** as the capacity to do work.

2 Ask if a volunteer can explain in scientific terms – that is, in terms of **energy transformations** – how a windmill functions: It captures the **motion energy** (kinetic energy) of wind to make it useful to humans. In the case of grinding or pumping, the kinetic energy of wind is converted to **mechanical energy** or kinetic energy in a machine. In the case of a modern **wind turbine**, or a windmill with a turbine generator, the kinetic energy is transformed to **electric energy** by the turbine.

3 Tell students that they will now build pinwheel windmills and test them to see if they can perform work. Define the scientific term **work**: Work is done when a force acts upon an object and the object moves from one place to another. State that when work is done on an object, the object gains energy – that is, it will have gained the capacity to do work. Demonstrate by raising an object up and noting that it has gained **gravitational** or **potential energy**.

4 Group students in three-person (or four-person) teams and give each team a copy of the template *Making a Windmill*. Show students the sample windmill you made in advance and point out the materials available. Explain as needed and then circulate among teams as they build windmills.

Part Two:

Testing Our Windmills

5 When the windmills are complete and students are ready to test them, set up a windmill and blow dryer as an example. Explain that teams will be testing how much work their windmills can do (how many pennies they can lift). Demonstrate how to time the lifting of a penny.

6 Discuss the distinction between a question, prediction, and testable **hypothesis**, emphasizing the role of the latter in scientific inquiry. Ask for suggestions for a hypothesis in the context of our windmills doing the work of lifting pennies. (*As we increase the number of pennies being lifted, the time required to lift them will also increase.*)

7 Ask what the **variables** are in this experiment. (*the weight being lifted and the time required to lift it*) Remind students that our hypothesis is a prediction about the relationship between these two variables; and if we want a good test of our hypothesis, we need to keep other variables constant. This is critical in any science experiment. Ask students to identify variables that should be kept constant. List ideas on the board where they will be visible throughout the lesson:

- *speed of blow-dryers – use the lowest speed*
- *distance of blow dryers from windmill – measure to 18 inches;*
- *angle of windmill – keep it facing blow-dryer straight on*
- *angle of blow-dryer – aim at center of windmill blades;*
- *friction on thread – keep it clear of the table edge;* plus other variables the class may identify.

PART TWO CONTINUED

Suggested Procedure Part Two: (continued)

Testing Our Windmills

8 Give each student a copy of the student lab sheet *Windmills and Work*. Show teams the blow dryers (and ring stands if available) and provide any guidelines about use or sharing of equipment as well as safety in terms of securing electric cords.

9 Circulate and provide assistance as teams proceed. Give special attention to monitoring whether students keep extraneous variables constant and offer reminders as needed.

10 When students are finished, focus as a class to review the scientific inquiry process and discuss the experiments and results, touching on such areas as:

- whether the results support their hypothesis;
- their conclusion and their confidence in its validity and reliability;
- their level of success at controlling extraneous variables;
- other potential sources of investigational error (inaccurate measurements, incorrect calculation of averages, etc.);
- the advantage of using multiple trials and averages; and
- the value of presenting their data graphically.

11 Also discuss:

- similarities and differences between our windmills and wind turbines; and
- the scientific definition of work and its relationship to energy.

12 If time allows and if you have a U.S. map available, inquire whether anyone knows the location of any **wind farms**. Locate any that students may have seen (for example, along Interstate 8 en route to San Diego). Discuss that people scattered around Arizona may use wind turbines to power their homes, but power companies only build wind farms in areas that are very windy all year. Only a few areas in Arizona may be windy enough to support wind generation on a commercial scale. Some power companies are experimenting here. Texas and the Dakotas are the states with the greatest potential for commercial wind generation. As with solar, hydro, biomass, and other renewable energy sources, the available resources and potential for power production varies from place to place.

ASSESSMENT IDEAS

Students' completion of the lab sheets and participation in the discussion might serve as an assessment. Before beginning the lesson, you could create a rubric in relation to their participation and successful completion of the lesson. Or for a formal written assessment, reframe the bulleted discussion items from step 9 above as questions and ask students to write a paragraph or two on each of these subjects.

EXTENSION IDEA

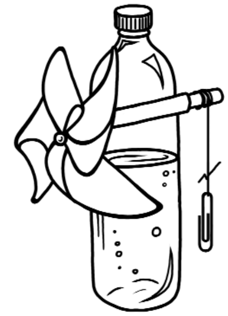
Using our windmills to make electricity: Present a demonstration or let students experiment to see if their windmills can create an electric current (enough current to make a compass needle deflect, or enough to register on a voltmeter sensitive to very low voltages). Use a fan for this, not a blow dryer. Props might include a small DC motor, approximately 1.5+ volt capacity; wire leads (connecting wires with clips or exposed wire on each end); a compass; miniature fan and/or buzzer and/or other device able to run on 1 to 5 volts DC; and a DC voltmeter or multi-meter able to display readings of 1 to 5 volts.

Teachers' Guide to Windmill Experiments

This information should help you guide students, deal with the range of materials that may be available, and ensure that experimental results are reasonably consistent:

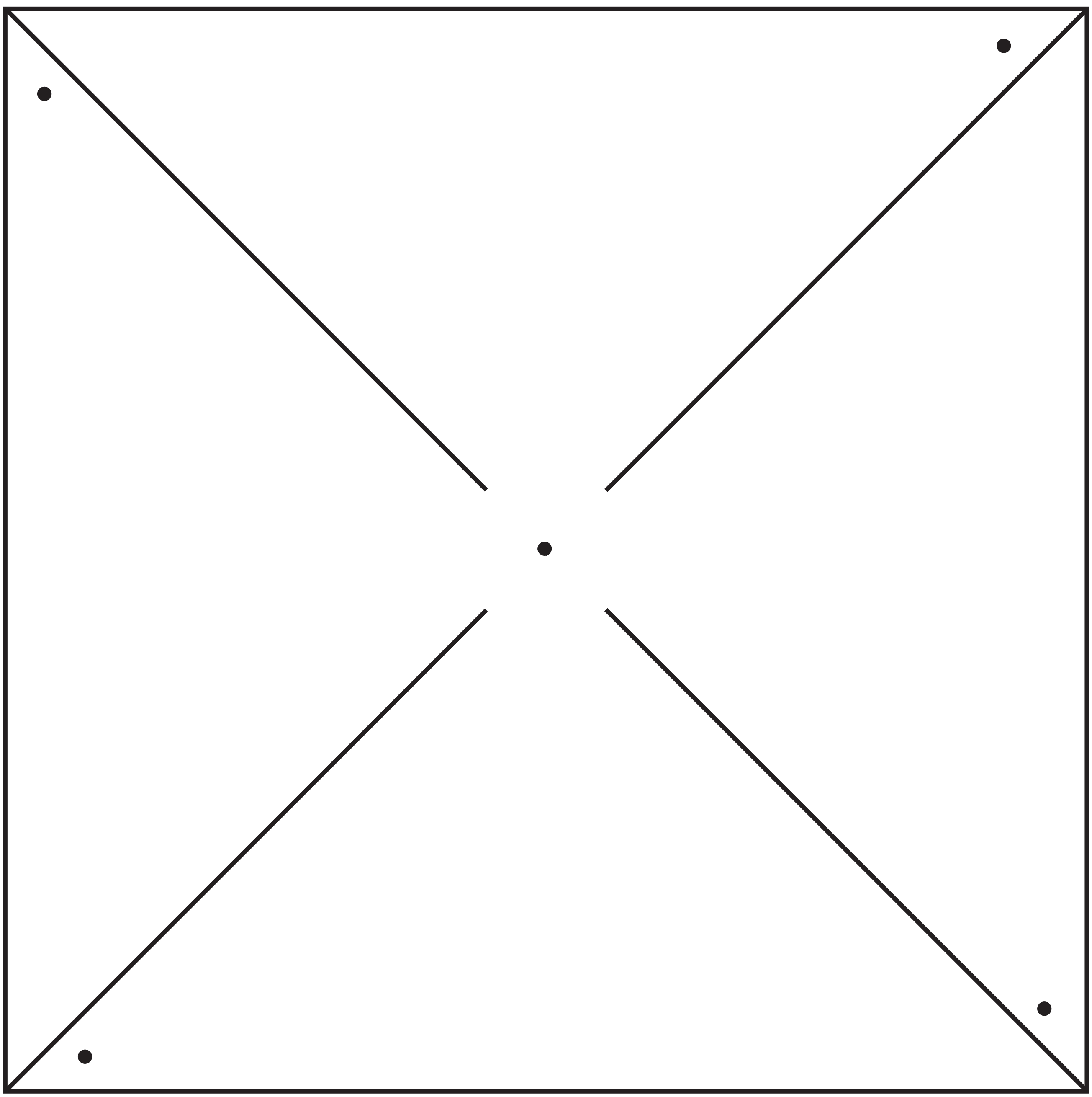
- **It is fine if the bottles collected for windmill towers vary in size and shape; but half-liter bottles may be too short (for the provided pinwheel template) and two-liter bottles may be too stout (for the length of the straw pinwheel shafts).**
- **The two-straw shaft design gets around the fact that holes students cut in the bottles are typically too rough for a straw-shaft to spin smoothly. Alternatives include the teacher using an electric drill to make all the holes in advance, and making slightly over-sized holes and using masking tape to create smooth edges.**
- **Heavy thread is best. String or yarn creates too much bulk as it winds around the shaft.**
- **Heavy paper (like Astrobright paper) or light cover stock is superior to lightweight bond.**
- **Fans can be used in lieu of blow-dryers, but you would need to experiment yourself with the specific fan(s) available and establish the distance at which students should place their windmills. (Too much "wind" will allow the windmill to lift 10 pennies as easily as one.) Actual wind outside will vary too much.**
- **If you have a blow dryer for each team of students, there is no need to weight the windmill towers / bottles with water or sand. Instead, masking tape can be used to secure them to the edge of the working surface.**
- **If students are taking turns at blow-dryers, be sure any given team always uses the same dryer. Differences between dryers would interfere with consistent results.**
- **If the thread tends to wind toward and slip off the end of the straw as pennies are lifted, students may not have made the slits through which the string is tied deep enough. Also students can gently and briefly tap the string with a finger to start it winding back toward the bottle. Or they can affix a brass paper fastener to the end of the straw, with each prong through a tiny slit and the prongs splayed out.**
- **If you wish, students can experiment with lifting other objects. A hand-held hole-punch can be used to make holes in a small polystyrene cup, which can then be tied to the string as a carrying basket. Note, for comparing the time required to lift a variety of objects, a bar graph would be more appropriate than a line graph.**

Template: *Making a Windmill*



Materials needed:

- ❑ one water bottle (1.0 or 1.5 liter)
- ❑ water, sand, or gravel (enough to fill bottle halfway)
- ❑ one large-diameter straw
- ❑ one small-diameter straw
- ❑ one brass paper fastener
- ❑ one sheet of card-stock (heavy) paper
- ❑ ruler
- ❑ pencil
- ❑ compass, pen, etc. with sturdy tip (to puncture the paper)
- ❑ scissors
- ❑ tape
- ❑ ~1.5 meters of heavy thread



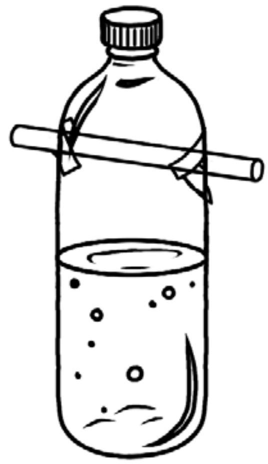
Template: *Making a Windmill*

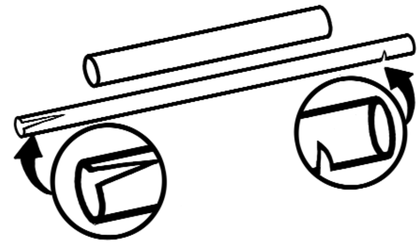
Instructions:

1. Cut two holes in your bottle for the large straw. Place them opposite each other and at least 16 cm from the bottom of the bottle.

2. Fill your bottle 1/3 to 1/2 full with water or sand.

3. Cut the tip off your large straw so that it is 5 cm shorter than your thin straw. Center the large straw in the holes and tape it in place.



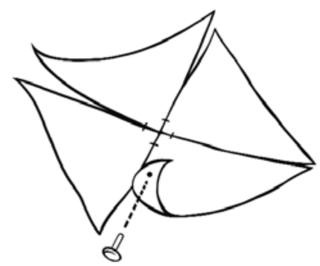


4. Cut slits at the ends of the thin straw.

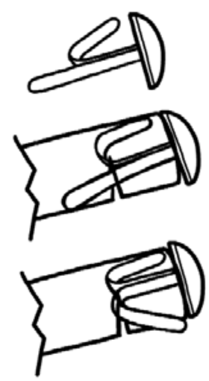
5. Cut out the square. Also cut along other solid lines.

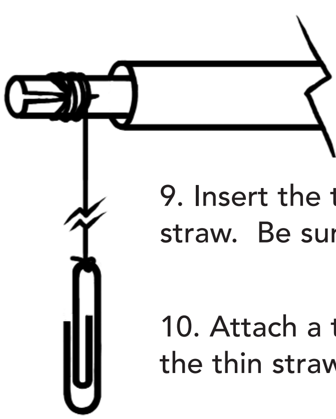
6. Punch a tiny starter hole at each "?" (with a compass, pen, or other tool).

7. Gently flex corners 1 to 4 toward the center. Put the brass paper fastener through each corner hole and then the center hole.



8. Attach the pinwheel on the end of the thin straw. (First bend one prong of the paper fastener into a "U". Wedge it into the thin straw, with the straight prong through the slit. Then bend back that prong too.)





9. Insert the thin straw into the large straw. Be sure it turns freely

10. Attach a thread to the other end of the thin straw.

11. Place your windmill near the edge of a table so the thread hangs free to the floor. Attach a large paperclip to the thread where it touches the floor.

12. Make weights with pennies and small paperclips.

Student Lab Sheet: *Windmills and Work*

Name: ________________________________ **Class / Period:** ______________________

Instructions:

1. *Read this entire lab sheet.*
2. *Form a hypothesis about your windmill's ability to do work. Write it down.*
3. *Assign responsibilities to team members, such as wind technician, windmill technician, and time keeper / recorder.*
4. *Conduct your experiment.*
5. *Record your data.*
6. *Make a line graph of your data.*
7. *Discuss your results.*
8. *Answer the rest of the questions below.*

Hypothesis: ____

____

____

Record and graph your data on the back of this page. Then continue below.

Do your data support your hypothesis? Explain your conclusion: ________________________

____

____

In science,_________________ is done when a force acts on an object as the object moves from one place to another.

Is our windmill capable of doing work? Why or why not? ____________________________

____

____

When______________ is done on an object, the object gains ____________________.

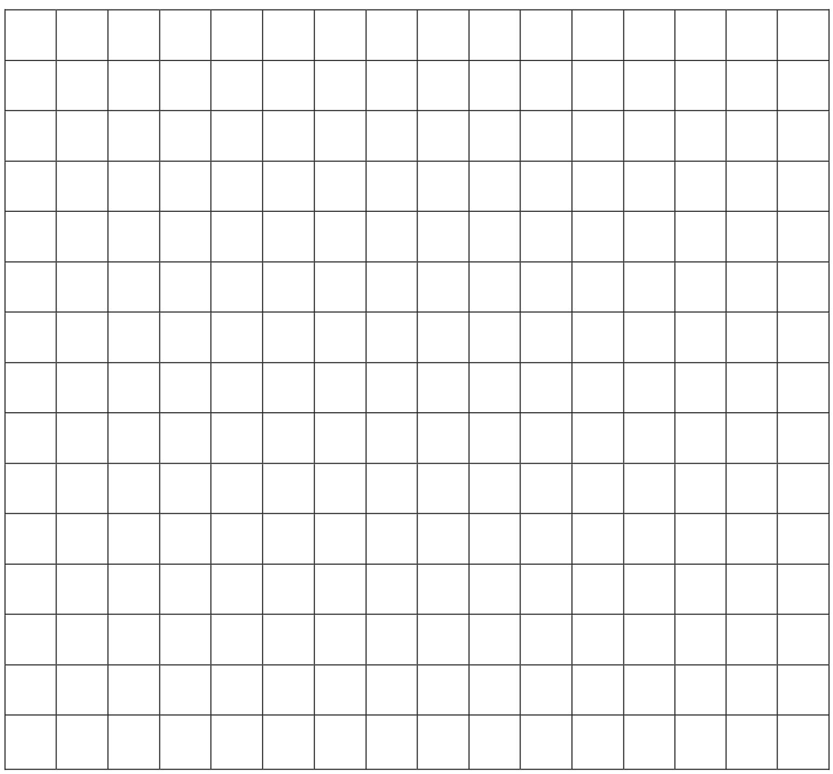
Match the work done on an object with the form of energy gained by the object:

If a machine lifts pennies from floor to table, the pennies gain	motion energy
If you swing a hammer, the hammer gains	thermal energy
If you rub your hands together briskly, your hands gain	gravitational energy

Number of Pennies	Trial #1 (seconds)	Trial #2 (seconds)	Trial #3 (seconds)	Average of Trials (seconds)	Change in Time * (seconds)
0					0
1					
2					
3					
4					
5					
6					
7					
8					

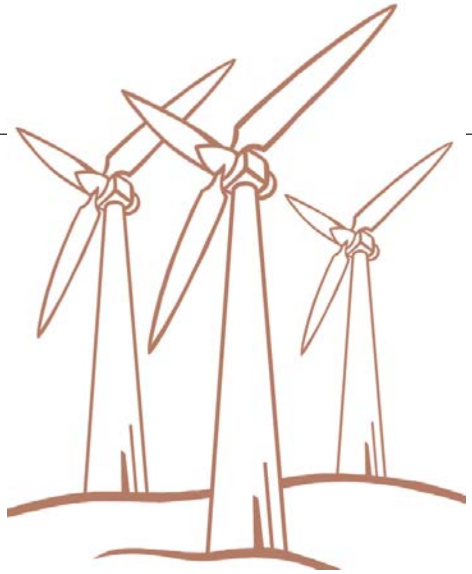
* In the last column, enter how much longer your windmill took to lift this weight than it took to lift no weight:
Change in Time = (average seconds with X pennies) – (average seconds with 0 pennies)

Time (in ______)



Work Performed (number of pennies lifted)

Student Reading: *Fact Sheet*
Wind Power in Arizona



What Is Wind?

Wind is caused partly by the uneven heating of Earth's surface by the sun. Warm air rises and cool air sinks. This causes air masses to move around, creating wind. The rotation of Earth on its axis also affects wind.

Wind is created through ongoing natural processes. Thus it is a **renewable** natural resource.

Wind farms are easy to build compared with new coal or hydropower plants. The cost of wind energy varies from three to ten cents per kilowatt-hour. Where the cost falls in this range depends on how windy an area is. Only in the windiest areas of the windiest states does the cost fall to the low end of this range. In Arizona the cost is likely to be about five cents per kilowatt-hour ($.05/kWh).

Use of Wind Power in Arizona

Windmills capture the <u>kinetic</u> (motion) energy of wind. The motion of air becomes motion in a machine – mechanical spinning energy. Modern **wind turbines** use this energy to make <u>electric</u> energy. The spinning windmill turns a turbine, which runs a generator that produces electricity.

Producing wind power for large numbers of homes and businesses requires many large wind turbines. The turbines used to produce power on a commercial scale are huge! The towers may be 40 to 80 meters tall. Each tower has a set of three blades, and each blade may be 15 to 35 meters long.

Tens or hundreds of wind turbines may be built in a group called a **wind farm**.

Wind power can be used on a small scale in many areas, with one small windmill making power for one house. Producing wind power on a large scale requires an area that is very windy all year. Most of Arizona has limited potential for commercial wind generation.

Arizona has a wind farm near St. Johns. It is home to ten 1.5 megawatt turbines with a total capacity of 15 megawatts. Studies are being done to find other sites for wind farms in the state. In addition, Arizona power companies purchase wind power from outside the state.

Wind Power and the Environment

Wind is a fairly low-impact energy source. Making power from the wind does not create solid waste, toxic waste, water pollution, air pollution, or greenhouse gases. However, large wind turbines can be quite noisy, so they must be located away from places that people live.

Roads must be built for installing and servicing the many turbines at a wind farm. These roads damage the natural habitat. Also, birds can die if they fly into the spinning blades of a wind turbine. Newer turbine styles greatly reduce this problem. Placing large wind farms away from major migration routes also helps keep bird deaths low.