Wind Power: History and Engineering

JOURNEYS IN FILM
educating for global understanding

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About *Journeys in Film*

Founded in 2003, ***Journeys in Film*** operates on the belief that teaching with film has the power to prepare students to live and work more successfully in the 21st century as informed and globally competent citizens. Its core mission is to advance global understanding among youth through the combination of age-appropriate films from around the world, interdisciplinary classroom materials coordinated with the films, and teachers' professional-development offerings. This comprehensive curriculum model promotes widespread use of film as a window to the world to help students to mitigate existing attitudes of cultural bias, cultivate empathy, develop a richer understanding of global issues, and prepare for effective participation in an increasingly interdependent world. Our standards-based lesson plans support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

Selected films act as springboards for lesson plans in subjects ranging from math, science, language arts, and social studies to other topics that have become critical for students, including environmental sustainability, poverty and hunger, global health, diversity, and immigration. Prominent educators on our team consult with filmmakers and cultural specialists in the development of curriculum guides, each one dedicated to an in-depth exploration of the culture and issues depicted in a specific film. The guides merge effectively into teachers' existing lesson plans and mandated curricular requirements, providing teachers with an innovative way to fulfill their school districts' standards-based goals.

Why use this program?

To be prepared to participate in tomorrow's global arena, students need to gain an understanding of the world beyond their own borders. ***Journeys in Film*** offers innovative and engaging tools to explore other cultures and social issues, beyond the often negative images seen in print, television, and film.

For today's media-centric youth, film is an appropriate and effective teaching tool. ***Journeys in Film*** has carefully selected quality films that tell the stories of young people living in locations that may otherwise never be experienced by your students. Students travel through these characters and their stories: They drink tea with an Iranian family in *Children of Heaven,* play soccer in a Tibetan monastery in *The Cup*, find themselves in the conflict between urban grandson and rural grandmother in South Korea in *The Way Home,* watch the ways modernity challenges Maori traditions in New Zealand in *Whale Rider,* tour an African school with a Nobel Prize–winning teenager in *He Named Me Malala,* or experience the transformative power of music in *The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble.*

In addition to our ongoing development of teaching guides for culturally sensitive foreign films, ***Journeys in Film*** brings outstanding documentary films to the classroom. We have identified exceptional narrative and documentary films that teach about a broad range of social issues in real-life settings such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. ***Journeys in Film*** guides help teachers integrate these films into their classrooms, examining complex issues, encouraging students to be active rather than passive viewers, and maximizing the power of film to enhance critical thinking skills and to meet the Common Core Standards.

Journeys in Film is a 501(c)(3) nonprofit organization.

A Letter from Chiwetel Ejiofor

I hope you enjoyed watching the film *The Boy Who Harnessed the Wind.*

William's story embodies the creativity of young people and acts as a powerful reminder of the achievements we can make when we are not afraid of failure. He encountered many obstacles, but his determination to get an education and unstoppable drive to do what he believed in will act, I hope, as an inspiration to you in this course.

This film tells the true story of a family in Malawi and the difficulties they faced; external factors like the weather, environment, politics, religion, and education have a profound effect on the daily life of many Malawians. I hope this film and the course spark a much wider discussion and action to engage with some of the issues that the film touches on.

William's story continues to inspire the next generation of innovators in Africa and around the world. I hope that watching *The Boy Who Harnessed the Wind* and the curriculum help to inspire you to never give up on your dreams.

Yours sincerely,

Lesson (ENGINEERING, WORLD HISTORY)

Wind Power: History and Engineering

Enduring Understandings

- Wind is formed by the uneven heating of the Earth's surface by solar radiation, differences in topography, and the rotation of the Earth.
- Gases move from areas of high pressure to low pressure.
- Local and atmospheric winds are produced due to pressure differences.
- As warm air rises, it leaves behind pockets of low pressure, causing air to rush in from high pressure areas in order to equalize the pressure.
- Warm air is displaced by denser cold air.
- Wind power, also known as wind energy, is a renewable energy source and can be converted into mechanical or electrical energy.
- Some examples of the use of wind throughout history have been to propel sailboats, mill flour, run sawmills, move water, and produce electricity.

Essential Questions

- How do pressure differences in the atmosphere cause the movement of air?
- What is the difference between a windmill and a wind turbine?
- What are the best locations for windmills and wind turbines?
- What are the essential components of a windmill?
- What is the history of the use of windmills?
- What are the ways in which windmills can irrigate fields to promote the production of crops?
- What are the essential components of a wind turbine?
- What is the history of the use of wind turbines?
- What is the projected use of wind turbines locally, nationally, and globally?
- What are the advantages and disadvantages of using wind turbines to produce electricity?

Notes to the Teacher

This lesson focuses on the science and technology behind William's accomplishment in *The Boy Who Harnessed the Wind.* It is important to stress at the beginning that wind is a renewable energy source with less environmental impact than many other energy sources. Windmills and wind turbines (with rare exceptions) do not release emissions that pollute the air or water and do not require water for cooling purposes. Wind energy can help reduce the amount of greenhouse gases and other pollutants released by nonrenewable energy sources used for the generation of electricity.

The suggested order of the activities provided can be altered depending upon each teacher's approach to this unit and the time needed to perform the activities. The lesson has four parts, each taking a minimum of two class periods of 45 minutes to one hour. Each part takes a hands-on approach to learning, followed by individual and/or group analysis and class discussion of key concepts.

Since you are using hot plates and generating steam, please make sure students are careful and aware of the dangers of being careless. For Part 2 of the lesson, check each station to be sure that hotplates are set below 451° Fahrenheit, or 233° Celsius, the ignition temperature of paper.

For additional information on wind energy, refer to:

Wind Explained History of Wind Power
https://www.eia.gov/energyexplained/index.php?page=wind_history

History of U.S. Wind Energy
https://www.energy.gov/eere/wind/history-us-wind-energy

Wind Energy Timeline—From Persian Windmills Crushing Grains to Vesta's Wind Turbines Churning out 8 MW of Output
https://www.altenergymag.com/article/2015/04/wind-energy-timeline-%E2%80%93-from-persian-windmills-crushing-grains-to-vesta%E2%80%99s-wind-turbines-churning-out-8-mw-of-output/19496

The Iconic Windmills That Made the American West
https://www.atlasobscura.com/articles/windmills-water-pumping-museum-indiana

Wind Energy
https://www.nationalgeographic.org/encyclopedia/wind-energy/

Wind Power Fundamentals
http://web.mit.edu/windenergy/windweek/Presentations/Wind%20Energy%20101.pdf

How a Wind Powered Sawmill Works- AMAZING
https://www.youtube.com/watch?v=Q6FxG3ll-lw

Wind Explained Wind Energy and the Environment
https://www.eia.gov/energyexplained/index.php?page=wind_environment

Wind Explained Where Wind Power Is Harnessed
https://www.eia.gov/energyexplained/index.php?page=wind_where

Wind Resource Map
http://windeis.anl.gov/guide/maps/map2.html

Wind Projects Map
https://www.windpowerengineering.com/wind-project-map/

How a Windmill Pumps Water
https://aermotorwindmill.com/pages/how-a-windmill-works

Wind Turbine Design
http://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-design.html

Wind Turbine Components
http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wtrb/comp/index.htm

Animation: How a Wind Turbine Works
https://www.energy.gov/eere/wind/animation-how-wind-turbine-works

Wind Project Development
https://windexchange.energy.gov/projects

Part 1 of this lesson focuses on the history of wind power use beginning with ancient Egyptian sail boats through the development of windmills to the current wind turbines used to generate electricity. Before the first class session, make a copy of **Handout 1: The History of Wind Power** for each student. Each pair of students will need to have access to the Internet connected to a color printer, one tri-fold corrugated poster board, scissors, markers, and glue sticks. Using **Teacher Resource 1**, each group will research the use(s) of wind power in a specific time period, create a poster, and present the poster to the class. A rubric for this activity is found on **Teacher Resource 2.** You may wish to use it just for scoring or you may share it with your students so that they can do a self-evaluation.

Part 2 explores pressure differences in atmospheric gases and convection as the sun heats the Earth's surface in order to give students a basic understanding of pressure differences leading to local and regional wind patterns and their effect on windmills and wind turbines. Before starting this part of the lesson, make a copy of **Handout 2: Understanding Pressure Differences, Convection, and the Wind** for each student. If the activity is done as a teacher demonstration, the teacher and students must wear safety glasses and aprons. If the activity is done in small groups, students must wear safety goggles and aprons. See **Teacher Resource 3** for sample answers. Check each station to be sure that hotplates are set **below** 451° Fahrenheit, or 233° Celsius, the ignition temperature of paper.

Part 3 focuses on researching and identifying the components of windmills and horizontal axis wind turbines and the basic difference between horizontal and vertical axis wind turbines. Before the first class session, make a copy of **Handout 3: The Components of Windmills and Horizontal Axis Wind Turbines** for each student. During the first session, students will watch a short animation on the difference between horizontal axis wind turbines and vertical axis wind turbines and then begin to research the components of windmills and wind turbines. During the second and third session, students will continue to research the windmill and wind turbine components and create posters. A rubric for this activity is found on **Teacher Resource 4**. You may wish to use it just for scoring or you may share it with your students for self-evaluation.

Part 4 is the summative assessment which requires students to design and construct a simple replica of a water-pumping windmill and to research information about a wind farm in

Common Core Science Standards Initiative

http://www.corestandards.org/ELA-Literacy/RST/introduction/
http://www.corestandards.org/ELA-Literacy/RST/9-10/
http://www.corestandards.org/ELA-Literacy/RST/11-12/

Key Ideas and Details:

CCSS.ELA-LITERACY.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-LITERACY.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.11-12.1
Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

CCSS.ELA-LITERACY.RST.11-12.2
Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

CCSS.ELA-LITERACY.RST.11-12.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

Craft and Structure:

CCSS.ELA-LITERACY.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-LITERACY.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).

CCSS.ELA-LITERACY.RST.11-12.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

CCSS.ELA-LITERACY.RST.11-12.6
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

Integration of Knowledge and Ideas:

CCSS.ELA-LITERACY.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

CCSS.ELA-LITERACY.RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

CCSS.ELA-LITERACY.RST.11-12.8
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CCSS.ELA-LITERACY.RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Duration of Lesson

Detailed completion of every part of the lesson will take several weeks. The procedures can easily be adapted to fit available time.

Assessments

Completion of posters

Completion of activity observation sheets

Completion of answers to questions

Group discussions

Windmill replica and wind farm poster (summative assessment)

Materials

For each part of the lesson a computer with a projector or an interactive board such as a smart board is needed.

For Part 1:

Computer, tablet or phone with Internet access

Color printer access

Tri-fold corrugated poster board or 22" x 28" (23" x 33") oak tag paper

Scissors

Glue

Markers

Handout 1: The History of Wind Power

Teacher Resource 1: The History of Wind Power (teacher notes)

Teacher Resource 2: Rubric for the History of Wind Power Poster

For Part 2:

Windmill spinner plant trellis or Mylar pinwheel (or similar)

Safety glasses and apron

Balloon

Saran Wrap™ or similar plastic wrap

Hot gloves or tongs

Erlenmeyer flask

Culture bowl (or similar)

Hot plate

Water and ice

Rubber band

2" wide masking tape

Cardboard tubes from toilet paper and paper towels

Small cardboard boxes; small tissue boxes work well.

Lightweight yarn or string

Index cards

Small object to use as a weight

Aluminum foil

Handout 2: Understanding Pressure Differences, Convection and the Wind

Teacher Resource 3: Answer Sheet for Handout 2

For Part 3:

Computer, tablet or phone with Internet access

Color printer access

22" by 28" or 23" x 33" oak tag paper

Scissors

Glue

Markers

Handout 3: The Components of Windmills and Horizontal Axis Wind Turbines

Teacher Resource 4: Rubric for The Components of Windmills and Horizontal Axis Wind Turbines Poster

Teacher Resource 5: Answer Sheet for Handout 3

For Part 4:

Safety glasses, aprons, and nitrile gloves

Windmill Spinner Plant Trellis or In The Breeze Classic Mylar Pinwheel (or similar)

Roofing nail

Hot glue gun

22–24 AWG bare copper wire

Wood skewers (or similar)

Scissors

Fan

Computer, tablet or phone with Internet access

Color printer access

22" by 28" or 23" x 33" oak tag paper

Markers

Glue

Handout 4: Windmill and Wind Turbine Summative Assessment

Teacher Resource 6: Guidance for Summative Assessment

Teacher Resource 7: Rubric for Windmill and Wind Turbine Summative Assessment

Procedure

Part 1: The History of Wind Power

1. Before class, calculate how many pairs of students you will have in your class and divide **Teacher Resource 1** into the same number of sections. Cut the handout into these sections.
2. When class begins, distribute copies of **Handout 1** and read through the background information, objective, and methods. Answer any student questions that may arise.
3. Arrange students into pairs and give each pair a section of the **Teacher Resource 1** timeline to research historical uses of wind power. (Note: Information on early wind power history varies due to a lack of recorded information for this time period and therefore is subject to interpretation of available evidence.)
4. Have each group use the Internet to research the topic(s) and prepare the poster while you circulate to supervise and answer questions.
5. After the students have completed their posters, have them present results to the class.
6. After each poster is presented, have students discuss as a whole class the information presented, using **Teacher Resource 2** as a guide for the discussion.

Part 2: Understanding Pressure Differences, Convection and the Wind

1. Before class, check to be sure that each station has the necessary supplies for the activity. (See Materials, above.)
2. Distribute copies of **Handout 2** and read through the background information, objectives, and methods. Answer any student questions that may arise.
3. Stress safety precautions when completing the activity in individual groups or as a teacher demonstration.
4. If students are working together, arrange them into pairs with each pair given the necessary prescribed materials. Suggest that they check to see that the lab set-up is complete and that they are familiar with all the materials. Allow students sufficient time to set up the activity and begin, while you circulate to supervise and answer any additional questions.
5. Monitor Part B to make sure student set-ups are not in an area in which the ventilation system or door and window drafts will interfere with the activity.
6. Monitor Part C to allow all students use of the fan(s). If fans are not available, students can perform this part by blowing on the pinwheel.
7. Make sure each group completes the observation tables for Parts A, B and C.

8. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers. The group work will probably extend into the next class period. Then have the students discuss as a whole class the answers to the questions. See **Teacher Resource 3** for suggested answers to the questions.

9. [Optional demonstration:] Hold a lit match a few inches from the mouth of the air intake tube; then move it closer so that students can see the flame being pulled toward the box. This should not be attempted by the students.

Part 3: The Components of Windmills and Horizontal Axis Wind Turbines

1. Distribute copies of **Handout 3** and read through the background information, objectives, and methods. Arrange students into pairs and answer any student questions that may arise.

2. Have each group use the Internet to view the animation on horizontal wind turbines and vertical wind turbines, research their topic, and prepare their poster while you circulate to supervise and answer any additional questions. Note that there are several empty spaces at the bottom of the table of windmill components if you or the students wish to add additional components.

3. After the students have completed making their posters, have them present results to the class.

4. After each poster is presented, have students discuss as a whole class the information presented using **Teacher Resource 5** as a guide for the discussion.

Part 4: Windmill and Wind Turbine (Summative Assessment)

1. Before class, check to be sure that each station has the necessary supplies for the activity.

2. Distribute copies of **Handout 4** and read through the background information, objectives, and methods. Answer any student questions that may arise.

3. Stress safety precautions when completing the activity.

4. Arrange students into small groups with each group given the necessary prescribed materials. Suggest that they check to see that the lab set-up is complete and that they are familiar with all the materials.

5. Allow students sufficient time to design and construct a replica of a simple water pumping windmill, while you circulate to supervise and answer any questions.

6. Display all of the windmill replicas around the room and have each group perform their water pumping simulation.

7. In the second part of the assessment, have each group use the Internet to run the wind turbine simulation, research a specific wind farm, and prepare their poster, while you circulate to supervise and answer any additional questions.

8. After the students have completed making their posters, have them present results to the class.

9. After each poster is presented, have students discuss as a whole class the information presented.

Lesson (ENGINEERING, WORLD HISTORY)

Handout 1

The History of Wind Power

Background Information

The power of the wind has been harnessed for thousands of years. Historians believe that beginning approximately in 5000 BCE, wind power was harnessed by ancient civilizations. Currently, wind power is being developed as a renewable source of energy to produce electricity.

Objective

To research the history of the use of wind power and develop a timeline of the use of wind power throughout the centuries.

Materials

Computer, tablet, or phone with Internet access
Color printer access
Tri-fold corrugated poster board or 22" x 28" (23" x 33") oak tag paper
Scissors
Glue
Markers

Methods

1. Using the Internet, research the use(s) of wind power during your assigned time in history.
2. Print pictures of any wind power machines researched. Be sure to clearly label pictures of wind power machines and their uses.
3. Create a poster that presents the use(s) of wind power during the time period you researched; it should include pictures, written explanation, and citations. Enlarge pictures if necessary so they will be visible to the class during your poster presentation. Make sure all sources of information and pictures are cited.
4. Present the poster to the class and discuss the use(s) of wind power machine(s) during the assigned time in history.

Lesson (ENGINEERING, WORLD HISTORY)

Teacher Resource 1 ▸ P.1

The History of Wind Power

Notes to the teacher:

- In recent years, some historians have opted to use religiously neutral abbreviations. BCE = Before Common Era replaces BC. CE = Common Era replaces AD.[1]
- There are some significant discrepancies in some of the early historical information on wind power which need to be taken into consideration when assessing student work.

BCE	
5000/3500	Wind energy used to propel boats along the Nile
3500	Wind-powered water pumps used in China
CE	
200/500–900	Windmills with woven-reed blades grinding grain in Persia and the Middle East
1100s	Wind pumps and windmills used extensively in Middle East and Europe for food production
1000/1300	Large wind pumps used by Dutch to drain lakes and marshes in the Rhine River Delta; first horizontal axis blade windmills
1600s	Dutch windmill designs introduced to New World
1600s/1800s	American colonists' windmills to grind grain, to pump water, and to cut wood at sawmills
1887	First windmill for generating electricity built in Scotland
1850s	US Wind Engine Company established
1890s	Wind power used for pumping water and electricity
1890s	Steel blades invented for windmills
1893	Wind power showcased at the Chicago World's Fair
1920s	Wind turbines producing electricity in rural regions of Great Plains; first vertical axis wind turbine invented
1930s	In Russia, first wind power turbine commercial power plant to produce electricity
1941	Largest wind turbine powered local utility in Vermont during WWII
1970	Interest renewed in wind power due to high gas prices; first offshore wind farm in world beginning operation off coast of Denmark
1977	The US Department of Energy (DOE) formed; National Renewable Energy Laboratory in operation
1978	President Jimmy Carter signs Public Utility Regulatory Policies Act of 1978 requiring companies to buy electricity from renewable energy sources

Teacher Resource 1 ▸ P.2 The History of Wind Power

1980s	First wind farm in the world built in New Hampshire, U.S., but considered a failed project
1981	National Aeronautics and Space Administration scientists (NASA) developing "The Viterna Method," used for predicting wind turbine performance
1990	The amount of electricity in the U.S. produced from wind power less than 1%
1991	U.K.'s first onshore wind farm with a capacity of 10 turbines supplying enough power for 2,700 homes
1992	Energy Policy Act in the U.S.; production tax credit to focus on renewable energy
1993	The National Wind Technology Center (NWTC) built to be the nation's premier wind energy technology research facility
2003	Legal compliance in Europe encouraging the use of wind energy; 70% of total global wind energy production found in Europe
2005	The updated Energy Policy Act in the U.S. with incentives for renewable energy sources
2008	The European Union's target for the U.K. government to increase contribution of renewables to 20% by 2020; the U.S. Department of Energy's goal of 20% Wind Energy by 2030 report; U.S. installed wind farms reaching 25.4 Gigawatts
2009	Wind energy providing 2% of the total global electricity usage
2011	The U.S. Department of Energy's National Offshore Wind Strategy, a plan to develop offshore wind energy in the U.S.
2012	U.S. installed wind farms reaching 60 gigawatts; wind energy power in 15 million homes in the U.S. as the primary renewable source of electricity
2013	With a $12 million investment from the U.S. Department of Energy, at the University of Maine, the world's first concrete-composite floating platform wind turbine
2014	Wind energy contributing 20-30% of the annual electricity demand in nations such as Denmark and Spain
2015	The U.S. Wind Vision Report showing that 35% wind energy usage possible by 2050
2016	The U.S. Bureau of Labor Statistics naming wind turbine service technician as the fastest growing job of the decade
2016	First commercial U.S. offshore wind farm, Block Island Wind Farm, operating off the coast of Rhode Island; start year for China's 13th Five-Year Plan for Energy Technology Innovation, including the study of wind power in order to establish large-scale wind farms
2018	China the world leader with approximately 187 gigawatts produced from wind power; U.S. installed wind farms surpassing 89 gigawatts, enough to power over 20 million homes; approximately 7% of U.S. electricity produced from wind power; Germany producing approximately 56 gigawatts of wind power
2020	China's goal to produce 210 gigawatts of grid connected wind energy

Teacher Resource 2

Rubric for the History of Wind Power Poster

Group Members:____

Title of Poster:____

Category	Excellent: 4	Good: 3	Satisfactory: 2	Needs Improvement: 1
Required Content	Poster incorporates all required content along with supplemental information.	Poster incorporates all required content.	Poster incorporates some of the required content elements.	Poster incorporates few or none of the required content elements.
Accuracy of Content	All content in the poster is accurate.	1 content component in the poster is inaccurate.	2 content components in the poster are inaccurate.	3 or more content components in the poster are inaccurate.
Effectiveness	Poster provides an excellent understanding of the topic.	Poster lacks 1 important element associated with the topic, but still provides a good understanding.	Poster lacks 2 important elements associated with the topic and provides only a basic understanding.	Poster lacks 3 or more important elements associated with the topic and does not provide a basic understanding.
Graphics	All graphics on the poster are labeled and attractive, and they support the topic of the poster.	1–2 graphics on the poster are not attractive, but all are labeled and support the topic.	All graphics on the poster are attractive and labeled, but a few do not support the topic.	Many graphics on the poster are unattractive and/or are not labeled and/or do not support the topic.
Formatting	All required content components are clearly labeled and easily visible on the poster. Information is sequenced correctly.	All required content components are labeled, but not clearly visible on the poster. Information is sequenced correctly.	1–2 required content components are not labeled on the poster. Information is sequenced correctly.	More than 2 content components are not labeled and/or information is not sequenced correctly on the poster.
Grammar	Poster has no misspellings and no grammatical errors.	Poster has 1–2 misspellings and/or grammatical errors.	Poster has 3–4 misspellings and/or grammatical errors.	Poster has more than 4 misspellings and/or grammatical errors.
Citations	All information and graphics in the poster are properly source cited.	1–2 pieces of information and/or graphics in the poster are not properly source cited.	3–-4 pieces of information and/or graphics in the poster are not properly source cited.	More than 4 pieces of information and/or graphics in the poster are not properly source cited.

Understanding Pressure Differences, Convection, and the Wind

Background Information

Pressure differences in atmospheric gases as the sun heats the Earth's surface and atmosphere drive convection and cause both local and atmospheric wind patterns. In this activity, you will be using steam generated by boiling water to examine pressure differences. This allows for greater pressure differences than just using air alone. You should be aware that, in spite of the lack of water, the physics of wind and pressure over a dry desert involves very similar mechanisms.

Objectives

To observe the movement of gases due to pressure increases and decreases
To simulate the effect of varying wind direction and speed on windmills

Materials

Windmill spinner plant trellis or Mylar pinwheel (or similar)
Safety glasses and apron
Balloon
Saran Wrap™ (or similar plastic wrap)
Plastic pinwheel or metal garden windmill
Hot gloves or tongs
Erlenmeyer flask
Culture bowl (or similar)
Hot plate
Rubber band
2" wide masking tape
1 toilet paper cardboard tube
1 paper towel cardboard tube
1 small cardboard box, slightly smaller than your hotplate surface. (A small tissue box works well.)
Lightweight yarn or string
Index card
Small weight
Aluminum foil

Understanding Pressure Differences, Convection, and the Wind

Methods

Part A

1. Fill an Erlenmeyer flask ½ full with tap water
2. Tightly seal the flask with a balloon.
3. Place the flask on a hot plate and turn on the hot plate to high.
4. After the water in the flask has boiled for 10–15 minutes, sketch and record observations in Table 1, Part A.
5. Turn off the hot plate.
6. Using hot gloves or tongs, remove the Erlenmeyer flask from the hot plate.
7. After the water in the Erlenmeyer flask cools, sketch and record observations in Table 1, Part A.
8. Repeat steps 1–7 using plastic wrap and a rubber band to tightly seal the flask.

Part B:

1. Cut a hole in the bottom of the box to allow heat to enter rapidly. If you are using a tissue box, the hole is the right size, but be sure to remove any plastic.
2. On the opposite side (the top), place the end of the toilet paper tube on the box, trace around it, and cut out a hole. Push the toilet paper tube a half inch into the hole; it should fit snugly in the hole. Any leaks can be covered with masking tape. (This is your chimney.)
3. On the side of the box, place the end of the paper towel tube on the box, trace around it, and cut out a hole. Push the paper towel tube a half inch into the hole; it should fit snugly in the hole. Any leaks can be covered with masking tape. (This is your air intake pipe.)
4. Cut about 18 inches of light string or yarn. Cut a square from the index card large enough that it will just cover the end of the paper towel tube. Affix the string to the card with a small piece of masking tape.
5. Place a square of aluminum foil on the hotplate to protect its surface.
6. Place the box with the chimney pointed up on the hotplate. Make sure the end of the paper towel tube is well off to the side of the hotplate. Add a small weight on top of the box to make sure the bottom is flush with the aluminum foil on the hotplate. Without turning the hotplate on, dangle the card a half inch away from the open end of the paper towel tube.
7. Turn the hotplate on and set it to 400° Fahrenheit (204° Celsius); do not exceed this temperature. Again dangle the card a half inch away from the open end of the paper towel tube. See if you can get it to “stick” and block the end of the tube.

Understanding Pressure Differences, Convection, and the Wind

Part C:

1. Place a plastic pinwheel in an Erlenmeyer flask so that it is supported with masking tape and stands upright. (A metal garden windmill may also be used.)
2. Place a fan 1 meter away from the pinwheel.
3. Turn the fan on low.
4. Move the fan so that it strikes the pinwheel at different angles at the same distance.
5. Orient the pinwheel so that it directly faces the fan at varying distances.
6. Record observations in Table 3, Part C.

Understanding Pressure Differences, Convection, and the Wind

Observations:

Sketch and describe what happened in Part A of the exploration

Table 1—Part A	
Balloon covered boiling water flask	**Plastic wrap covered boiling water flask**
Balloon covered flask after the water has cooled	**Plastic wrap covered flask after the water has cooled**

Understanding Pressure Differences, Convection, and the Wind

Table 2—Part B: Sketch and Observations of Index Card	
When hotplate was off	**When hotplate was on**

Understanding Pressure Differences, Convection, and the Wind

Table 3—Part C
Observations of Pinwheel Placed at Various Angles and Distances from a Fan

Understanding Pressure Differences, Convection, and the Wind

Conclusion:

Discuss the following questions with your group members and record your answers in the spaces provided.

1. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was heated? Explain your answer.

2. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was cooled? Explain your answer.

3. How is the movement of the air demonstrated by the behavior of the index card in Part B similar to air flow caused by the heating and cooling of the Earth's surface? Does the temperature difference of the air coming from the chimney and that entering the paper towel tube play any role?

4. In Part C, what caused the changes observed in the pinwheel when the fan was moved to strike the pinwheel at different angles and at different distances?

5. How do the observations in Part C relate to the positioning of windmills and wind turbines?

Teacher Resource 3 ▸ P.1 Answer Sheet for Handout 2

Note: Students have varying levels of understanding and answers should be discussed and clarified by the teacher.

1. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was heated? Explain your answer.

- The balloon and plastic wrap expanded above the rim of the flask as the water was heated.
- As water was heated, water molecules moved faster and farther apart and some went from a liquid to a gaseous state expanding outward into the balloon and plastic wrap causing them to expand.
- As the pressure in the flask increased, the expansion of gaseous water molecules to reach equilibrium pressed against the balloon and plastic wrap, causing them to expand and stretch outward from the rim of the flask.

2. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was cooled? Explain your answer.

- The balloon collapsed and the plastic wrap contracted below the rim of the flask as the water was cooled.
- As water was cooled, water molecules moved more slowly and the pressure in the flask decreased.
- As the pressure in the flask decreased when the water cooled, the plastic wrap was drawn into the flask as pressure was equalized.

3. How is the movement of the air demonstrated by the behavior of the index card in Part B similar to air flow caused by the heating and cooling of the Earth's surface? Does the temperature difference of the air coming from the chimney and that entering the paper towel tube play any role?

- Differences in the heating and cooling of the Earth cause differences in air pressure.
- As hot air rises, pressure is lowered and movement of molecules is seen when cooler air rushes in to equalize pressure.
- Denser cold air displaces warm air.
- Differences in pressure cause molecules to move from areas of high pressure to areas of low pressure.
- Air moves from areas of high pressure to areas of low pressure, causing the formation of wind.
- Rising air due to heating lowers surface pressure, creating a pressure gradient that causes air to move from higher pressure to the lower pressure area created by the rising air. The corrective force that equalizes the pressure differences is wind.
- The temperature difference between the chimney air and that entering the paper towel tube is important as the incoming air is cooler and denser, and hence rushes in to displace the hot air exiting the chimney.

Teacher Resource 3 ▸ P.2 Answer Sheet for Handout 2

4. In Part C, what caused the changes observed in the pinwheel when the fan was moved to strike the pinwheel at different angles and at different distances?

- As the pinwheel was moved away from the fan, the forces causing rotation of the pinwheel decreased in magnitude. Eventually, the forces were not adequate to move the pinwheel blades at all.
- As the pinwheel was moved at different angles to the fan, the differences in air movement between the fan and pinwheel caused the pinwheel movement to decrease, and at some angles the pinwheel did not move at all.
- When the artificial wind produced by the fan hit the pinwheel blades at different angles (called the angle of attack), the speed of the pinwheel blade varied.

5. How do the observations in Parts A, B and C relate to the positioning of windmills and wind turbines?

- Windmills and wind turbines need to be positioned in areas that produce sustained winds of sufficient speed during the year.
- If regional air pressure differences are insufficient, wind speeds will be less than needed to move the blades on windmills or wind turbines.
- Wind power is not converted to 100% efficiency; no turbine can capture more than 59.3% of the kinetic energy in wind. Therefore, windmills and wind turbines must be placed in areas in which the kinetic energy of the wind can be converted into the maximum amount of mechanical energy for irrigation, producing electricity, etc.

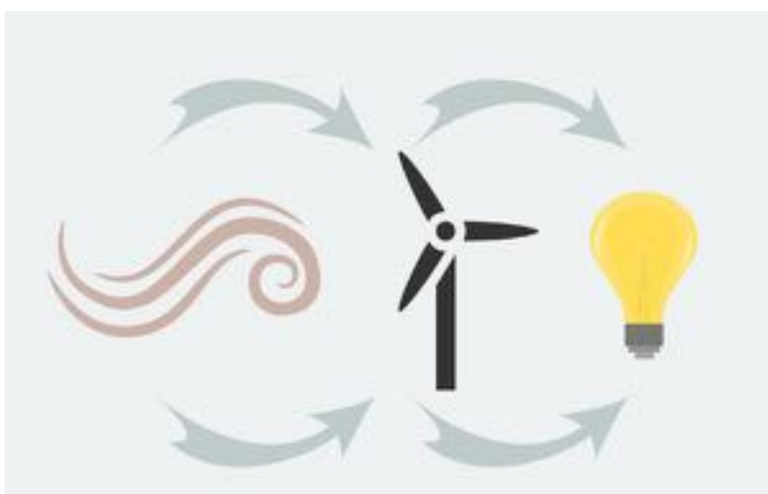


Image source: https://www.publicdomainpictures.net/en/view-image.php?image=290782&picture=wind-energy]

The Components of Windmills and Horizontal Axis Wind Turbines

Background Information

Traditional windmills provided mechanical energy to grind grain or pump water. Modern wind turbines are typically used to generate electricity.

Both traditional windmills and modern wind turbines use blades to harness the wind's kinetic energy. As the air flows over the blades on windmills and wind turbines, the blades begin to turn and the kinetic energy of wind is converted to mechanical energy.

Objectives

To gain a basic understanding of the difference in movement between horizontal axis wind turbines and vertical axis wind turbines.

To research the components of windmills and horizontal axis wind turbines.

Materials

Computer, tablet or phone with Internet access
Color printer access
22" by 28" or 23" x 33" oak tag paper
Scissors
Glue
Markers

Methods:

1. Using the Internet, view the following animation in order to understand a basic difference in the movement of horizontal axis wind turbines and vertical axis wind turbines:
https://fr.wikipedia.org/wiki/Fichier:HAWT_and_VAWTs_in_operation_large.gif
2. Using resources found on the Internet, define the terms listed in Table 1 on the next page.
3. Using the Internet, find pictures of windmills and wind turbines that could be used to label windmill and wind turbine components found in Table 1. (Your teacher may add additional terms.)
4. Create a poster that clearly identifies the components of the windmill and wind turbine pictures chosen in Step 3.

The Components of Windmills and Horizontal Axis Wind Turbines

Components of Windmills and Wind Turbines	
Component	**Definition**
Access Ladder	
Aeromotor Water Pump/Water Pump	
Anemometer	
Blade Pitch Control	
Brake	
Gear Box	
Generator	
Nacelle	
Rotor Blade/Fan	
Rotor Hub	
Shaft	
Sucker Rod	
Tower	
Wind Orientation Control/Yaw Control	

Teacher Resource 4

Rubric for The Components of Windmills and Horizontal Axis Wind Turbines Poster

Group Members:____

Title of Poster:____

Category	Excellent: 4	Good: 3	Satisfactory: 2	Needs Improvement: 1
Required Content	Poster incorporates all required content along with supplemental information.	Poster incorporates all required content.	Poster incorporates some of the required content elements.	Poster incorporates few or none of the required content elements.
Accuracy of Content	All content in the poster is accurate.	1 content component in the poster is inaccurate.	2 content components in the poster are inaccurate.	3 or more content components in the poster are inaccurate.
Effectiveness	Poster provides an excellent understanding of the topic.	Poster lacks 1 important element associated with the topic, but still provides a good understanding.	Poster lacks 2 important elements associated with the topic but provides a basic understanding.	Poster lacks 3 or more important elements associated with the topic and does not provide a basic understanding.
Graphics	All graphics on the poster are labeled, attractive, and support the topic of the poster.	1–2 graphics on the poster are not attractive, but all are labeled and support the topic.	All graphics on the poster are attractive and labeled, but a few do not support the topic.	Many graphics on the poster are unattractive and/or are not labeled and/or do not support the topic.
Formatting	All required content components are clearly labeled and easily visible on the poster. Information is sequenced correctly.	All required content components are labeled, but not clearly visible on the poster. Information is sequenced correctly.	1–2 required content components are not labeled on the poster. Information is sequenced correctly.	More than 2 content components are not labeled and/or information is not sequenced correctly on the poster.
Grammar	Poster has no misspellings and/or grammatical errors.	Poster has 1–2 misspellings and/or grammatical errors.	Poster has 3–4 misspellings and/or grammatical errors.	Poster has more than 4 misspellings and/or grammatical errors.
Citations	All information and graphics in the poster are properly source cited.	1–2 pieces of information and/or graphics in the poster are not properly source cited.	3–-4 pieces of information and/or graphics in the poster are not properly source cited.	More than 4 pieces of information and/or graphics in the poster are not properly source cited.

Lesson (ENGINEERING, WORLD HISTORY)

Teacher Resource 5

Answer Sheet for Handout 3

Components of Windmills and Wind Turbines	
Access Ladder	Can be up to 300 feet; provides access to service equipment in upper section of windmills and wind turbines.
Aeromotor Water Pump/ Water Pump	Wind water pumps in the past were mechanical mechanisms located on top of a wooden tower that pumped water for livestock and irrigation. The motor for a centrifugal electric water pump is driven by the electrical output from the wind turbine's alternator. Windmill generated electric pumping systems can provide a cost-effective alternative to small diesel pumps for both drinking water and small plot irrigation.
Anemometer	An anemometer measures wind speed and direction and is placed at the top of wind turbines to control the blades in order to ensure maximum efficiency.
Blade Pitch Control	Technology used to control the angle of the wind turbine blades, thereby the angle of attack relative to the angle of the wind.
Brake	Prevents over-speed and provides the ability to stop the blades.
Gear Box	Multiplies the wind turbine's speed and transmits it to the power of the generator.
Generator	Converts mechanical power to electrical power.
Nacelle	Contains key components of the wind turbine; such as the gearbox and electric generator.
Rotor Blade/Fan	Capture the wind and transfer its power to the rotor hub.
Rotor Hub	Connects blades to the main shaft to drive the gearbox and generator.
Shaft	When the rotor spins, the shaft also spins, transferring mechanical energy into rotational energy.
Sucker Rod	Gears convert rotary motion to an up-and-down motion which drives a long sucker rod/ pump rod up and down inside a cylinder. Water is alternately drawn into and expelled from the cylinder. Flow direction is controlled by check valves.
Tower	Carries the nacelle and rotor.
Wind Orientation Control/ Yaw Control	Uses electrical motors to turn the rotors against the wind.

Handout 4

Windmill and Wind Turbine Summative Assessment

Objectives

To build a simple replica of a water pumping windmill using the materials provided

To research a wind farm in your state or the closest wind farm in another state

Materials

Safety glasses, apron, and nitrile gloves

Windmill spinner plant trellis or Mylar pinwheel (or similar)

Roofing nail

Hot glue gun

22–24 AWG bare copper wire

Wood skewers (or similar).

Scissors

Fan

Computer, tablet or phone with Internet access

Color printer access

22" by 28" or 23" x 33" oak tag paper

Markers

Glue

Methods

1. Using information learned previously in this lesson, design and construct a replica of a simple water pumping windmill. The simple windmill must simulate the movement of the sucker rod, but will not show the movement of water.

2. Research a wind farm in the state or the closest windfarm in another state. Be sure to include:

   - the name and location of the wind farm
   - picture(s) of the wind farm
   - the number of wind turbines in the wind farm
   - the size of the wind turbines
   - the capacity of the wind turbines
   - the benefits of wind energy
   - the negative impacts of wind energy

3. Create a poster containing the information from Step 2.

Teacher Resource 6 ▸ P.1

Guidance for Summative Assessment

Student designs and simulated windmills will vary, but should show the sucker rod movement up and down within a pipe. Depending upon the level of the class, the design and simulated windmill can be more complex and show the generation of electricity. Websites such as: https://www.popularmechanics.com/science/environment/how-to/g118/make-your-own-miniature-wind-turbine/ can assist students.

Sample research answer:

Groton Wind Farm

https://www.epsilonassociates.com/groton-wind-farm

Groton Wind Power Project

https://en.wikipedia.org/wiki/Groton_Wind_Power_Project

Name of Wind Farm and Location:

Onshore

Site Area: 4,180 acres

Iberdrola Renewables' Groton Wind Farm

Grafton County

Groton, New Hampshire

Pictures:

https://www.epsilonassociates.com/groton-wind-farm?lightbox=imagectd

https://www.epsilonassociates.com/groton-wind-farm?lightbox=image15yu

Number of Wind Turbines:

24 Gamesa wind turbines

Size of Wind turbines:

Hub height: 78 meters (256 ft.)

Rotor diameter: 87 meters (285 ft.)

Guidance for Summative Assessment

Capacity of the Wind Turbines:

Each turbine has a nominal power rating (sometimes called nameplate) of 2 megawatts (MW) for a total of 48 MW.

Annual net energy output: 144–158 gigawatt hours (GWh)

Advantages of Wind Energy

Sustainable energy source

Economic benefits:

Direct and indirect employment opportunities

Land lease/purchase payments

Lower tax rates

Lower electricity rates

Challenges and Negative Impacts of Wind Energy

Good wind sites are often far from cities

Can have a negative impact on flying wildlife

Catastrophic wind turbine failure and public safety

Sound impacts

Negative property value impacts

Shadow flickering across the ground and nearby structures

Communication and radar interference

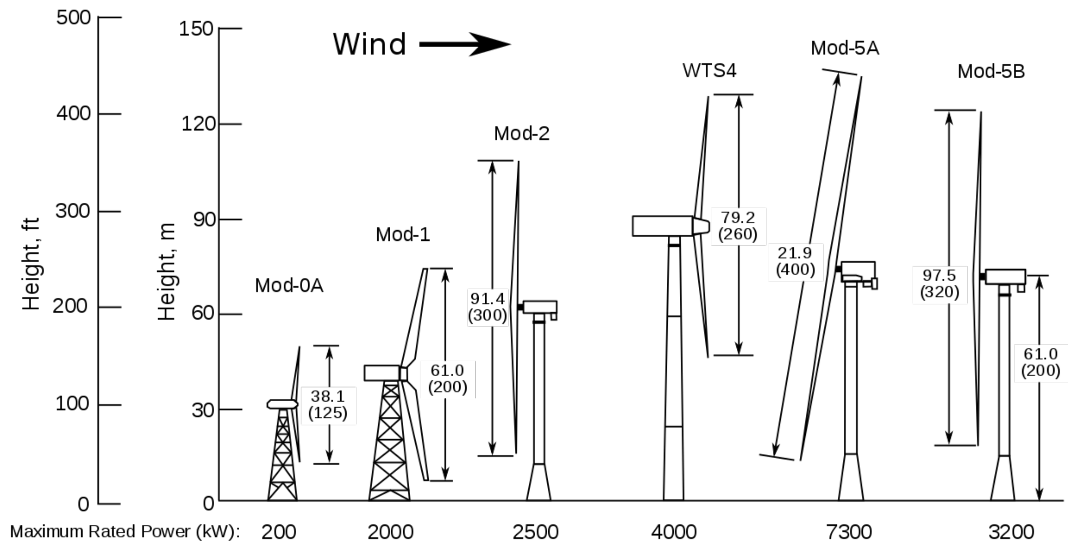
Alteration of neighboring community views

Sea wind farms may be a safety issue for boats at night

Community support (Example: New Hampshire residents have mixed feelings on wind farms:

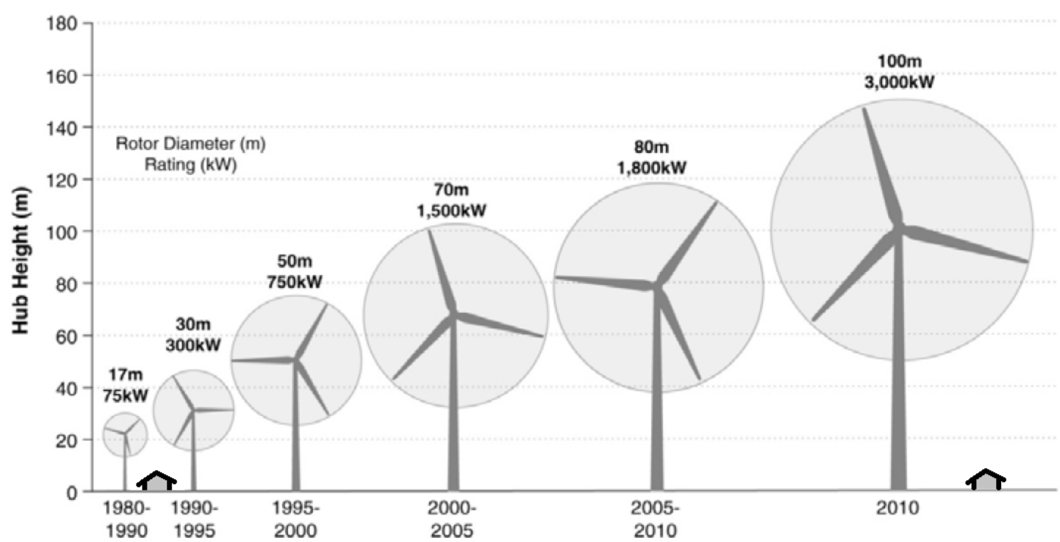
https://www.wmur.com/article/new-hampshire-residents-have-mixed-feelings-on-wind-farms-1/5182800)

Teacher Resource 6 ▸ P.3 Guidance for Summative Assessment



Department of Energy and NASA 1995 Comparison of Wind Generators

https://commons.wikimedia.org/wiki/File:Wind_generator_comparison.svg



Wind Turbine Size Increase 1980–2010

https://commons.wikimedia.org/wiki/File:Wind_turbine_size_increase_1980-2010.png

Lesson (ENGINEERING, WORLD HISTORY)

Teacher Resource 7

Rubric for Windmill and Wind Turbine Summative Assessment

Group Members:____

Category	Excellent: 4	Good: 3	Satisfactory: 2	Needs Improvement: 1
Windmill Replica **Originality and Creativity**	Innovative approach. Exceeds expectations for students' skill level.	Students adapt others' ideas and show some originality. Meets expectations for students' skill level.	Students adapt others' ideas but show very little originality. Does not meet students' skill level.	No originality shown. Minimum effort exhibited.
Windmill Replica **Quality**	Superior craftsmanship and attention to detail.	Some craftsmanship and attention to detail.	Project lacks quality and details were overlooked.	Project is sloppy and lacks detail.
Windmill Replica **Function**	Windmill replica functions extraordinarily well with increasing levels of stress.	Windmill replica functions well with increasing levels of stress.	Windmill replica functions well, but begins to deteriorate under increasing levels of stress.	Windmill replica completely fails under normal levels of stress.
Wind Farm Poster **Required Content**	Poster incorporates all required content along with supplemental information.	Poster incorporates all required content.	Poster incorporates many of the required content elements.	Poster incorporates few or none of the required content elements.
Wind Farm Poster **Accuracy of Content**	All content in the poster is accurate.	1 content component in the poster is inaccurate.	2 content components in the poster are inaccurate.	3 or more content components in the poster are inaccurate.
Wind Farm Poster **Formatting**	All required content components are clearly labeled and easily visible on the poster. Information is sequenced correctly.	All required content components are labeled, but not clearly visible on the poster. Information is sequenced correctly.	1-2 required content components are not labeled on the poster. Information is sequenced correctly.	More than 2 content components are not labeled and/or information is not sequenced correctly.
Wind Farm Poster **Grammar**	Poster has no misspellings and/or grammatical errors.	Poster has 1–2 misspellings and/or grammatical errors.	Poster has 3–4 misspellings and/or grammatical errors.	Poster has more than 4 misspellings and/or grammatical errors.
Wind Farm Poster **Citations**	All information and graphics in the poster are properly source cited.	1–2 pieces of information are not properly source cited.	3–4 pieces of information and/or graphics are not properly source cited.	More than 4 pieces of information and/or graphics in the poster are not properly source cited.

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