WIND

Where is it Windy?

Key Concept

Students learn how topography and elevation affect wind speeds and will identify optimal locations for wind farms based on wind speed.

Time Required

45-90 minutes

Grades

6-8, 9-12

Next Generation Science Standards

Disciplinary Core Ideas

- MS-PS3.B | HS-PS3.B Conservation of Energy and Energy Transfer
- MS-ETS1.A | HS-ETS1.A Defining and Delimiting Engineering Problems
- MS-ETS1.B | HS-ETS1.B Developing Possible Solutions

Cross Cutting Concepts

- Patterns
- Cause and Effect
- Energy and Matter

Science and Engineering Practices

- Planning and Carrying out Investigations
- Developing and Using Models
- Engaging in Argument from Evidence

BACKGROUND

Wind turbines produce more power at higher wind speeds than at lower wind speeds. This lesson helps students understand how topography and elevation affect wind speed. Students analyze maps and make predictions on where wind farms may be located based on regional topography.

OBJECTIVES

At the end of the lesson, students will:

- understand how topography and elevation affect wind speed
- be able to identify optimal locations for wind farms based on wind speed
- know how to interpret topographic and wind speed maps

ADDITIONAL RESOURCES

Additional resources for this lesson can be found at kidwind.org/ww/wherewindy.

MATERIALS

- ○ Box fan (more than one is better)
- ○ Objects of different sizes that will not blow away
- ○ 20 wind flags for the model (Tape some string or tissue paper to a popsicle stick and place it in a piece of clay to hold it up.)
- ○ U.S. Wind Speed Resource Map at 80 Meters
- ○ Map of U.S. Wind Turbines
- ○ United States Utility-Scale Wind Turbine Map
- ○ Student reading passage
- ○ Student worksheets
- ○ Optional: Bubble gun

KidWind PROJECT

Click here to check out the NGSS Website, Full NGSS Standards, or Science and Engineering Practices in the NGSS.

GETTING READY

- Collect materials for creating the topography. For example, books, backpacks, blankets or weighted boxes can be stacked to create mountains and valleys.
- Make 20 “wind flags” (you could have students do this, as well).
- Make a copy of the U.S. Elevation and Shaded Relief Map and worksheet for each student.
- Present all maps on your screen from a computer to use for discussion of all maps or prepare to project them from a computer to use for class discussion.
- If you have access to a color copier, print wind maps.

ACTIVITY

Step 1: Suggested beginning questions for students (10 minutes)

- Where do you typically find wind?
- Where is it often calm?
- Where would you go to fly a kite?
- What geographical features influence the speed of the wind?
- Do we have wind farms in our state? If so, where are they located?
- Is it windier in a forest or a field? On a hill or in a valley?
- What parts of the U.S. have the “best” wind for energy production?

Guide students to consider how beaches or open areas such as fields may have more wind than an area with many buildings or trees. Help them extrapolate their local understanding of where it is windy to a regional or national level where larger topographical features come into play, such as mountains or coastlines.

You can also provide students with sticky notes and a large piece of paper or whiteboard area for each question. Students can move around the room, writing answers on their sticky notes and putting them under each question.

Step 2: Create a model landscape and wind farm (30 minutes)

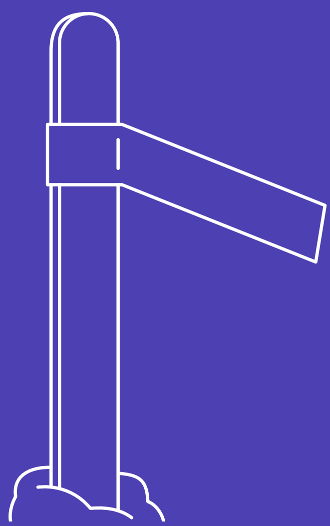
Using various objects around the classroom, tell students to create a model landscape. Students can use notebooks, textbooks, backpacks, weighted boxes, etc. Help students think about creating a variety of landscape features, such as a mountain range, rolling hills, valleys, plateaus, and open areas.

Conduct a “Think, Pair, Share” with students. They should take about five minutes to individually think about where to place their farm. Then, pair students together together or have them form their own groups to discuss their ideas and come to a consensus. Finally, give students two minutes to present their ideas to the class. If the group is in agreement, try out the model. If not, guide students towards making a decision based on the shared ideas, finding a compromise, or testing several ideas to see what works.

Tell students to create a wind farm by placing the wind flags where they think they will get the most wind.

WIND FLAGS

Tie tissue or string to a popsicle stick and stick it in a piece of clay to make a simple wind flag. Make sure the tissue is long enough to freely move.



Another way to visualize wind flow in a miniature landscape is to use a bubble gun and blow the bubbles through the landscape. If you watch closely, you will see eddies where bubbles get caught and where the flow is the fastest. Give it a try! It can be lots of fun!

Number the flags so you can easily track them on your worksheet. Place the box fan next to the landscape and turn it on. Ask students to record which wind flags are blowing and at what height they are blowing.. Reposition the fan and again record which flags are blowing. Are there some flags that always move and others that never move? Discuss the role that landscape plays in wind patterns.

Step 3: Analyze a state elevation map (30 minutes)

Give each student a topographic map of the U.S. and discuss how to read it by showing high and low points on a projected version of the map. Ask students to predict where they feel there is the most wind by shading in these areas.

Step 4: Compare predictions to data (10 minutes)

Project the U.S. Wind Resource Map for students and ask them to compare their predictions with this map. Were students' predictions similar to the actual wind speeds?

Step 5: Where are the wind farms in the U.S.? (10 minutes)

Project the Utility Scale Wind Turbines in United States Map on the screen. Ask students to look for relationships among this map and the topographical and wind speed maps and answer the questions on the worksheet.

Step 6: Wrap up (20 minutes)

Use the following questions to discuss the relationships among wind speed, elevation, and wind energy.

- Where are the windiest areas?
- Are there any trends? If so, what trends do you notice?
- How do wind speeds change as elevation increases?
- Why do you think this is the case?
- Where do you think the most desirable areas for wind farms are?
- Why do you think utility scale wind farms are located where they are?
- What role do you think elevation plays in the height of turbines? Where are the wind farms in the U.S.?
- Are turbines always in the windiest spots? Why or why not?

EXTENSION

- Ask students to examine a topographic map of the U.S. and make predictions about wind speed and wind farm locations. Compare their predictions to real data. Use some of the web resources from the end of this lesson.
- Tell students to create a scale drawing of their topography.

VOCABULARY

anemometer – An instrument that measures wind speed.

convection – Air movement due to density differences as heated air rises and is replaced by cooler air.

Coriolis effect – The Earth's rotation causes the wind to flow in a curved path rather than a straight line.

pressure gradient force – The difference in air pressure that causes air molecules to move causing wind.

surface roughness – A measure of surface texture. Trees, houses and other obstacles increase roughness, causing the wind to become more turbulent.

topography – The study and mapping of the shape of surface features of the Earth such as mountains, valleys, rivers, and lakes.

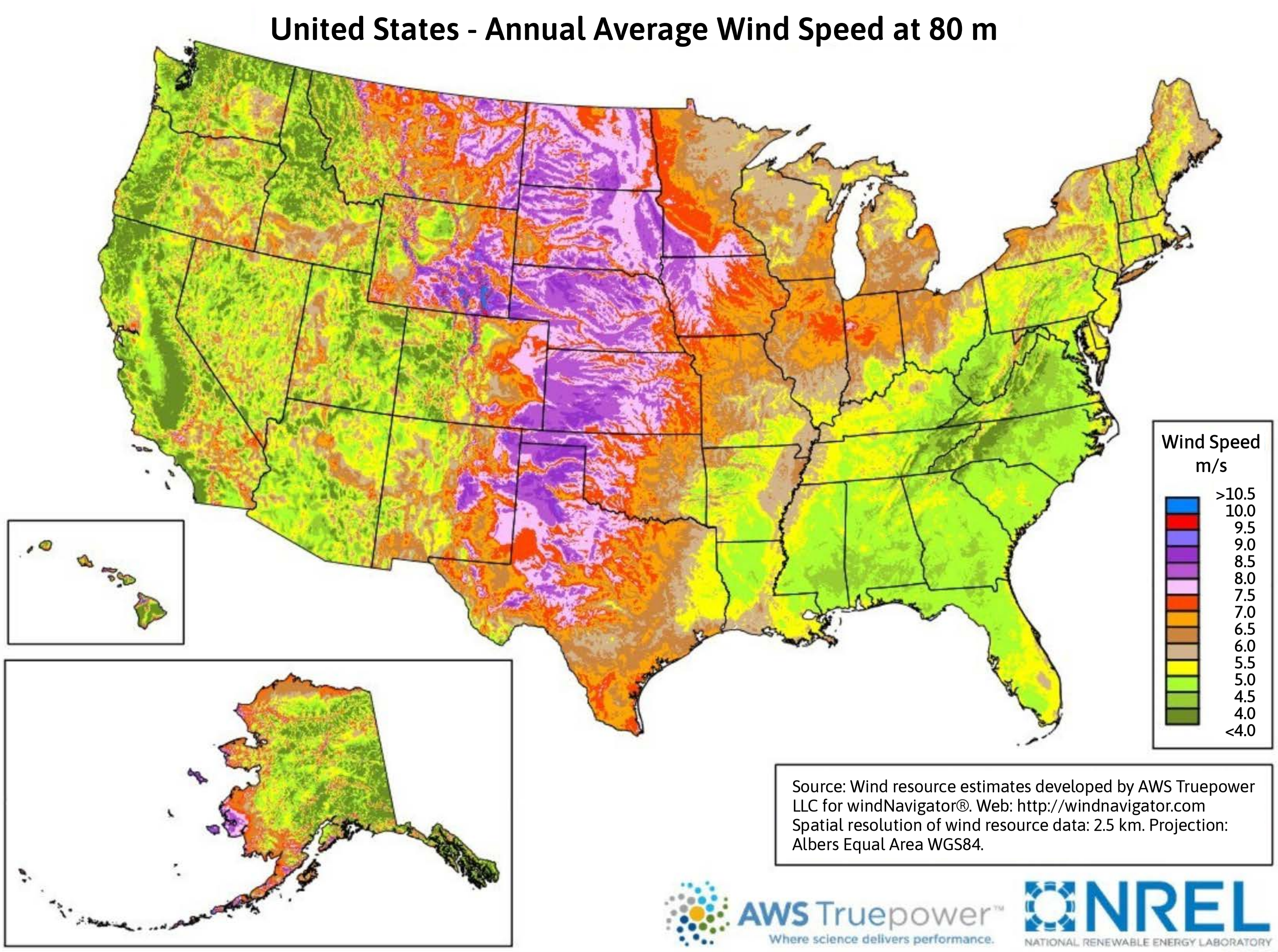
turbulence – An irregular or unstable movement of a gas or liquid.

wind speed – The rate at which air is moving horizontally past a given point.

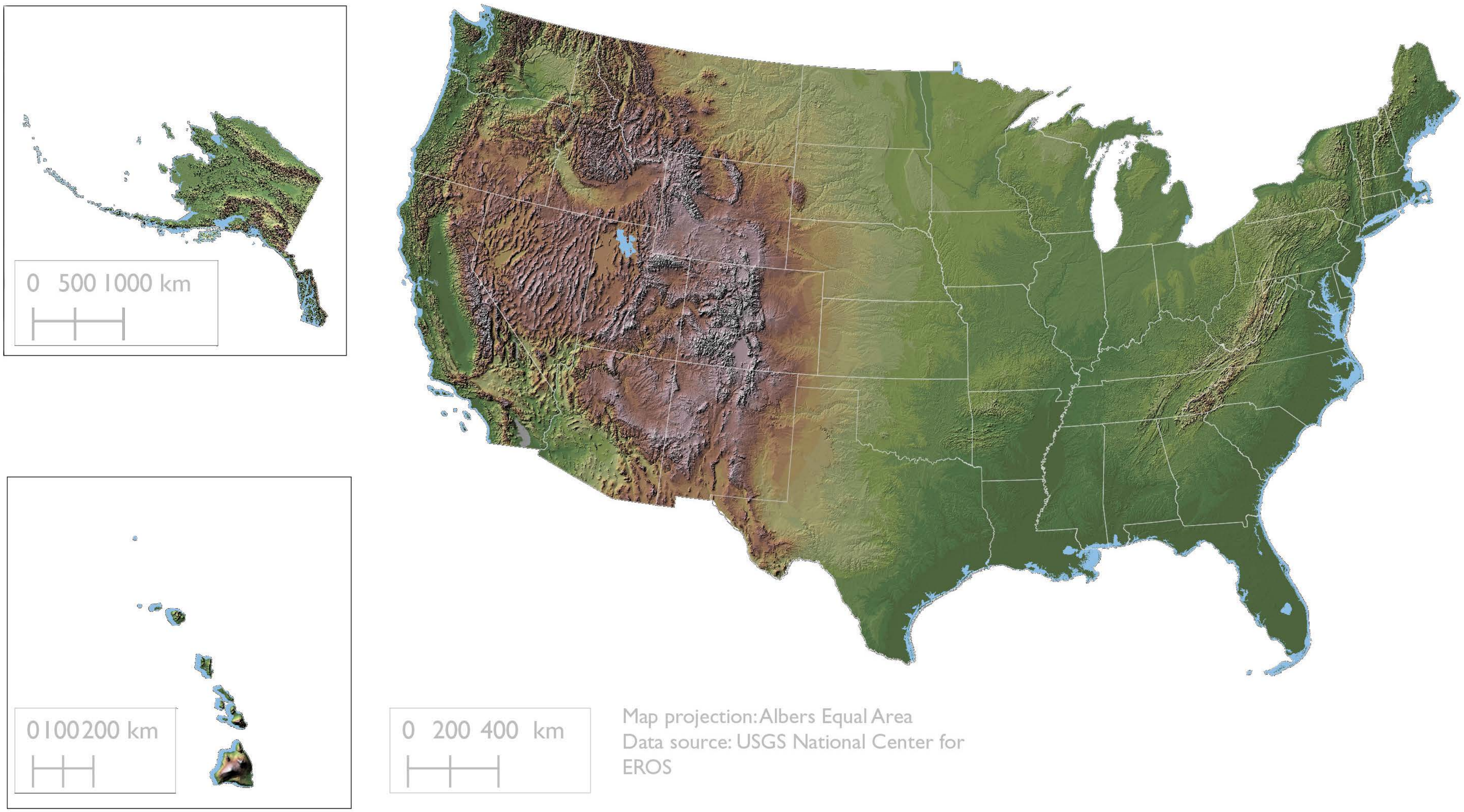
wind speed units – Wind speed is measured in meters/second (m/s) or miles per hour (mph). 1 m/s = 2.24 mph.

Where is it Windy?

U.S. WIND RESOURCE



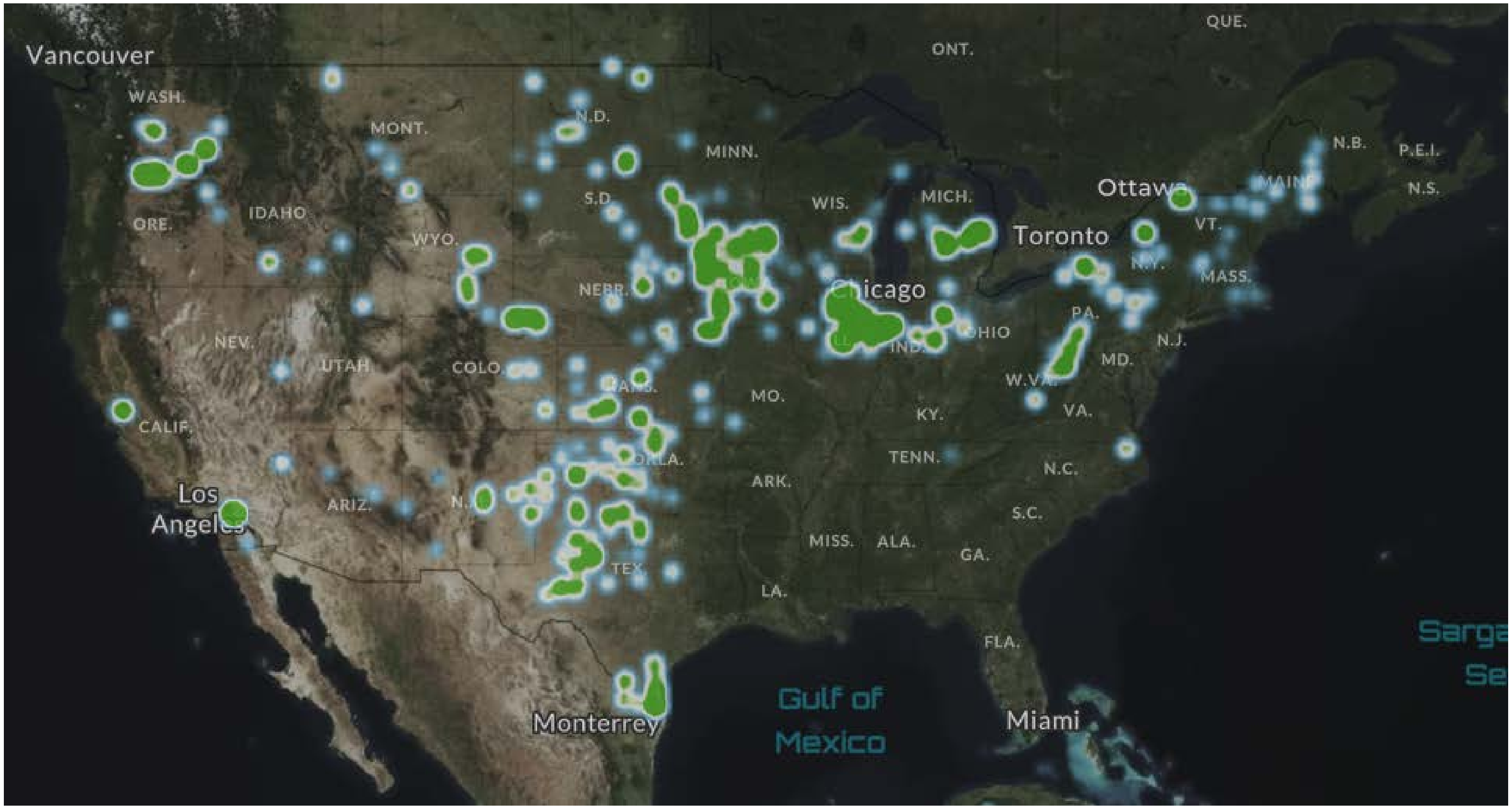
U.S. ELEVATION AND SHADED RELIEF MAP



Map projection: Albers Equal Area
Data source: USGS National Center for EROS

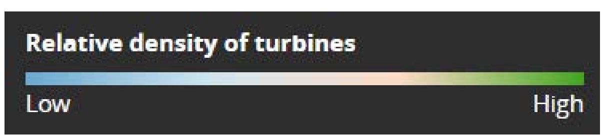
Where is it Windy?

MAP OF WIND TURBINES IN THE UNITED STATES[1]



United States Wind Turbine Database. (May 2023). U.S.GS, LBNL, and ACP.

Hoen, B.D., Diffendorfer, J.E., Rand, J.T., Kramer, L.A., Garrity, C.P., Hunt, H.E. (2023) United States Wind Turbine Database. U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release.



There are 72,731 turbines included in the database, representing a total rated capacity of 142,435 MW.

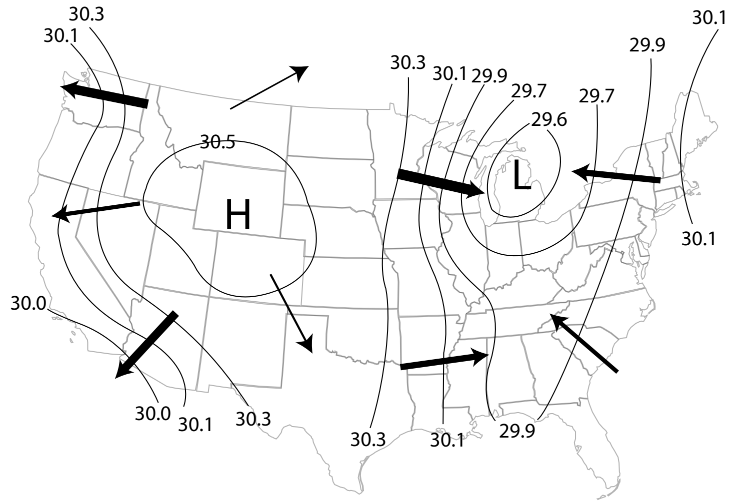
REFERENCES

[1] U.S. Department of Energy. (2011). U.S. average annual wind speed at 80 meters. WINDExchange. https://windexchange.energy.gov/maps-data/319

[2] Hoen, B.D., Diffendorfer, J.E., Rand, J.T., Kramer, L.A., Garrity, C.P., Hunt, H.E. (2023) United States Wind Turbine Database. U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release. https://eerscmap.usgs.gov/uswtdb.

[3] Hoen, B.D., Diffendorfer, J.E., Rand, J.T., Kramer, L.A., Garrity, C.P., and Hunt, H.E., 2018, United States Wind Turbine Database v6.0 (May 31, 2023): U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release, https://doi.org/10.5066/F7TX3DN0.

READING PASSAGE



Wind is the result of air moving from areas of high pressure to areas of low pressure. Air pressure changes are created by the uneven heating of the Earth. As parts of the Earth heat up, the air heats up, becomes less dense, and rises. As the hot air rises (convection), cooler air moves in, creating a breeze. This pressure difference, which causes wind, is called the pressure gradient force.

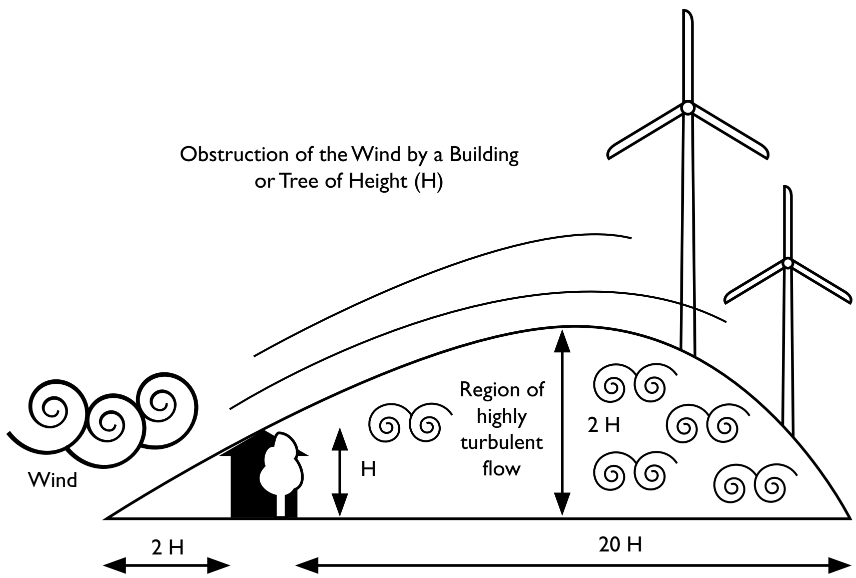
A number of factors determine the speed and direction of wind. Some factors, like the rotation of the Earth, create large-scale wind patterns, while other factors, such as the type of landscape, only affect local wind speeds. Wind developers may look at large-scale wind patterns to determine in what region to place a wind farm. When determining an exact location for the turbines, however, the wind developer collects years of wind data from proposed turbine locations.

Earth's Rotation

While wind is the movement of air from high to low pressure areas, the wind does not actually move in a straight line. Why not? The Earth's rotation actually causes the wind to flow in a curved path rather than a straight line. This is known as the Coriolis effect. The winds in the Northern Hemisphere turn to the right and the winds in the Southern Hemisphere turn to the left. The effect is zero at the equator.

Surface Roughness

Rough landscape surfaces tend to slow wind speeds, while smooth surfaces allow for higher wind speeds. For instance, a forested area creates more friction for moving air, resulting in slower wind speeds than a prairie. This is called surface roughness and can be defined according to different classes. An open sea provides very little friction for air and would be a class 0, whereas a large city with skyscrapers is a class 4. When siting a wind farm, it's important to look at the surrounding area to determine how the surface roughness will alter the local wind speeds.



Topography

Topography can impact wind speeds in two ways. First, land masses tend to heat up more quickly than oceans during the day. This results in warm air above the land rising and cooler air from the water blowing toward the land, creating "ocean breezes." A second impact of topography is natural or manmade obstacles that can block air movement. For example, a mountain range is an obstacle that winds have to move around. This can increase the wind speed in some areas while reducing it in others. Obstacles can also create turbulence in the air movement. Turbulence happens when the air moves irregularly, which creates the bumps you sometimes experience on an airplane flying over a thunderstorm or mountain.

Elevation

Wind speeds generally increase with elevation. As elevation increases, there are typically fewer obstacles, allowing wind to blow at faster speeds. Also, the friction with the Earth is reduced higher above the ground, so wind moves faster. Over time, engineers have designed turbines to be taller so that they can capture these faster winds.

CAREER PROFILE: ROLF MILLER, TECHNICAL CONSULTING SERVICES MANAGER

I am a Technical Consulting Services Manager for a wind resource assessment and wind energy forecasting company. We provide wind farm developers, financiers, and utilities with highly accurate estimates of how much clean, renewable energy a wind farm will produce. In this role, I work with a team of meteorologists and analysts to gather data from a variety of sources and help our customers understand how the weather will affect their wind farm.

As with many in the wind industry, I did not start out here. My undergraduate degree is in geology. At school, I wanted to meld the power of computers with studying natural systems. Geology had the irresistible appeal of working outdoors and a wide variety of things to study—fossils, plate tectonics, and mineral structures. For my senior thesis, I compiled a database of rock samples and mapped them with some of the earliest versions of geographic information system (GIS) software. I still use GIS software on a regular basis.

After school, I worked as a groundwater scientist for a consulting company, where I compiled one of the largest groundwater chemistry databases of its kind at the time. I also became interested in groundwater modeling, which uses computers to simulate the flow of water in the ground. It can predict where contaminants in the groundwater are likely to flow. I liked it so much that I enrolled in graduate school, where I studied groundwater flow.

Over time, I have held many jobs for the company, including research scientist, software designer, programmer, manager, and salesperson. My current job is exciting because I can help our customers solve challenging problems that also have significant financial impacts. My motivation is providing customers with valuable information that results in well-designed and efficient wind farms.

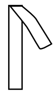
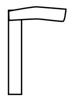
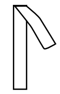
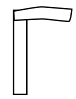
Name ______________________________ Date __________ Class ______________________________

WHERE IS IT WINDY?

Create a wind farm with popsicles and tissue. Make 25 flags in the 3 different styles listed in the chart below. Place them at various positions on your model.

Model Landscape and Wind Farm

1. Place a check under the appropriate angle for each flag in the model landscape.

	TRIAL 1			TRIAL 2		
FLAG						
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2. Were there some flags that never received any wind? If so, where were they located in the landscape?

3. Were there some flags that always received a lot of wind? If so, where were they located in the landscape?

4. Why do you think some flags received a lot of wind and others not as much?

WIND IN THE UNITED STATES

Where are the highest wind speeds in the United States?

Using the elevation map of the U.S., shade the areas that you believe might have the highest wind speeds. In one to two sentences, explain your predictions.

Were your predictions correct?

Compare your predictions to the U.S. Wind Resource Map.

1. Are your predictions similar to the actual wind speeds?

What happens to the wind speed as you go higher in the atmosphere?

2. How do wind speeds change as elevation increases?

3. Why do you think this happens?

4. What role do you think elevation plays in the engineering design of turbines?

Where are the wind farms in the United States?

Compare elevation and wind speed maps with the map of Utility Scale Wind Turbines in United States.

1. What is the wind speed and topography of the wind farm locations in the U.S.?

2. Why do you think these locations were selected as opposed to areas where wind speed is the highest?

1. Place a check under the appropriate angle for each flag in the model landscape.

    Student observation

2. Were there some flags that never received any wind? If so, where were they located in the landscape?

    Student observation

3. Were there some flags that always received a lot of wind? If so, where were they located in the landscape?

    Student observation

4. Why do you think some flags received a lot of wind and others not as much?

    Landscape features can get in the way of the path of wind. In nature, wind speeds increase as elevation increases.

WIND IN THE UNITED STATES

Where are the highest wind speeds in the United States?

Using the elevation map of the United States, shade the areas that you think might have the most wind.

Were your predictions correct?

Compare your predictions to the U.S. Wind Resource Map.

1. Are your predictions similar to the actual wind speeds?

    Answers will vary depending on student's predictions.

What happens to the wind speed as you go higher in the atmosphere?

2. How do wind speeds change as elevation increases?

    The wind speed increases with elevation.

3. Why do you think this happens?

    There are fewer obstructions as elevation increases.

5. What role do you think elevation plays in the engineering design of turbines?

    Over time, engineers have increased the height of turbines to access the higher wind speeds. With this increase in elevation, engineers have had to consider other issues, such as transportation of the wind turbine parts and the potential impacts on wildlife.

Where are the wind farms in the United States?

Compare topography and wind speed maps with the map of Utility Scale Wind Turbines in United States.

1. What is the wind speed and topography of the wind farm locations in the U.S.?

    See the map.

2. Why do you think these locations were selected as opposed to areas where wind speed is the highest.

    Sites are typically selected for a number of reasons: proximity to population centers (closer proximity means less energy loss due to transmission), land availability, and ability to get the project approved in a cost-effective way.

REFERENCES

1 Hoen, B.D., Diffendorfer, J.E., Rand, J.T., Kramer, L.A., Garrity, C.P., Hunt, H.E. (2023) United States Wind Turbine Database. U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release. https://eerscmap.usgs.gov/uswtdb.