



# Science and Innovation

A Boeing/Teaching Channel Partnership

## ALTERNATIVE ENERGY Teacher Handbook

## Alternative Energy

### Days 1 through 4: How a Wind Turbine Harnesses the Wind

Grade Level	Grade 4
Lesson Length	Four 50-minute sessions (if possible, consider adding another day)



#### Lesson Overview

This introductory lesson begins with an exploration of wind energy and the ways in which wind turbines can harness the wind. Students are introduced to the components of a prototype desk unit wind turbine. Students use this prototype for early design testing, during which students create a blade design to maximize the rotational speed of the prototype.

On Day 1, students work with the idea that wind can make a pinwheel or wind turbine spin. Students generate an initial model explaining how they think the wind makes a pinwheel spin.

On Day 2, students consider the idea that wind energy can be converted into electrical energy. Students generate an initial model explaining how they think the wind energy is converted into electrical energy.

On Days 3 and 4, students test their initial models by designing and testing wind turbine blades. Based on their test results, students refine their models and redesign their wind turbine blades.



#### Connecting to the Next Generation Science Standards

On Days 1 through 4, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices:** Developing and Using Models, Planning and Carrying Out Investigations, Constructing Explanations and Designing Solutions
- **Disciplinary Core Ideas:** ETS1.B Developing Possible Solutions, ETS1.C Optimizing the Design Solutions, PS3.A Definitions of Energy, PS3.B Conservation of Energy and Energy Transfer
- **Crosscutting Concepts:** Energy and Matter

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

#### Performance Expectations

This lesson contributes toward building understanding of the following *engineering* performance expectations:

3-5-ETS1-2. *Generate and compare multiple possible solutions to a problem* based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3. *Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.*

This lesson contributes toward building understanding of the following *physical science* performance expectations:

**4-PS3-1.** Use evidence to *construct an explanation relating the speed of an object to the energy of that object.*

**4-PS3-4.** *Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.*

### Specific Connections to Classroom Activity

On Days 1 through 4, students investigate the science ideas behind what makes a pinwheel spin, why a pinwheel or wind turbine spins faster or slower, how the wind can be converted into electrical energy through a wind turbine, and how to optimize wind turbine blades to generate the most electrical output. Students engage in the design challenge of designing, testing, and refining a wind turbine to convert wind energy into electrical energy. Through the design process, students test and compare multiple solutions, build on science ideas to inform design characteristics, and relate the speed of an object to the energy of that object.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	<p><b>Developing and Using Models</b></p> <ul style="list-style-type: none"> <li>• <i>Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events.</i></li> <li>• <i>Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution.</i></li> </ul> <p><b>Planning and Carrying Out Investigations</b></p> <ul style="list-style-type: none"> <li>• <i>Make observations to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.</i></li> <li>• <i>Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials are considered.</i></li> </ul> <p><b>Constructing Explanations and Designing Solutions</b></p> <ul style="list-style-type: none"> <li>• <i>Use evidence (e.g., measurements, observations, patterns) to construct an explanation.</i></li> <li>• <i>Apply scientific ideas to solve design problems.</i></li> <li>• <i>Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem.</i></li> </ul>	<p>On Day 1, students make observations of a pinwheel to develop an initial model, and draw a diagram on chart paper to describe their understanding of the phenomenon (how the pinwheel turns, what makes the pinwheel turn faster).</p> <p>On Day 2, students add to their models to show how wind energy is converted into electrical energy in a wind turbine.</p> <p>On Days 3 and 4, students revise their models as they test wind turbine blade designs.</p> <p>On Days 3 and 4, students test wind turbine blade designs. Students produce data to use as evidence for their ideas about what causes the wind turbine to spin faster. Student observations about voltage are used as evidence to support (or refute) the first draft of their design solution. At the end of the day, students use their experience to predict the outcomes for a revision to their design.</p> <p>Students use their data to think about their solution to the design challenge and to propose revisions to their design solution. Students should be applying ideas elicited on Days 1 and 2 to their design solutions. The class, as a whole, generates multiple solutions to the design challenge based on the criteria/constraints provided.</p>
Disciplinary Core Ideas	<p><b>ETS1.B: Developing Possible Solutions</b></p> <ul style="list-style-type: none"> <li>• <i>At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.</i></li> </ul>	Students test their wind turbine blades to determine how well they work. Students compare their test results to the test results from other design teams. Based on their test results, students redesign their wind turbine blades.

	<ul style="list-style-type: none"> <li><i>Tests are often designed to identify failure points or difficulties, which suggest the elements of a design that need to be improved.</i></li> </ul> <p><b>ETS1.C: Optimizing the Design Solution</b></p> <ul style="list-style-type: none"> <li><i>Different solutions need to be tested</i> in order to determine which of them best solves the problem, given the criteria and the constraints.</li> </ul> <p><b>PS3.A: Definitions of Energy</b></p> <ul style="list-style-type: none"> <li><i>The faster a given object is moving; the more energy it possesses.</i></li> </ul> <p><b>PS3.B: Conservation of Energy and Energy Transfer</b></p> <ul style="list-style-type: none"> <li>Energy can also be transferred from place to place by electrical currents, which can then be used locally to produce motion, sound, heat, or light. <i>The currents may have been produced to begin with by transforming the energy of motion into electrical energy.</i></li> </ul>	<p>The class, as a whole, tests multiple design solutions (wind turbine blades). Students compare the results of their tests.</p> <p>On Day 1, students experiment with ways to change the speed of a spinning pinwheel.</p> <p>On Days 2, 3, and 4, students observe a prototype wind turbine. They notice that as a wind turbine spins faster, it generates greater energy output. Through this investigation, students begin to relate the speed of an object to the energy it possesses.*</p> <p>On Day 2, students engage in a discussion about transforming the energy of motion into electrical energy to make the LED light on the prototype wind turbine turn on.*</p> <p>*<i>On Days 3 and 4, students use ideas from both PS3.A and PS3.B to design their wind turbine blades.</i></p>
<b>Grosscutting Concepts</b>	<p><b>Energy and Matter</b></p> <ul style="list-style-type: none"> <li><i>Energy can be transferred in various ways and between objects.</i></li> </ul>	<p>Students work with the idea that wind energy can be converted into electrical energy as they consider the design of the wind turbine prototype model.</p>

### Possible Extensions

This lesson can be adapted to focus on three additional Disciplinary Core Ideas. The connection between this module and the three Disciplinary Core Ideas listed below does not necessarily fall within the Grade 4 year; however, this module can be adapted to be used to prepare students for modules in later grade levels that address the following Disciplinary Core Ideas:

**PS1.A Structure and Properties of Matter:** Matter of any type can be subdivided into particles that are too small to see, but even then, the matter still exists and can be detected by other means (e.g., by weighing or by its effects on other objects).

**PS2.A Forces and Motion:** Each force acts on one particular object and has both a strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion.

**ESS3.A Natural Resources:** All materials, energy, and fuels that humans use are derived from natural sources, and their use affects the environment in multiple ways. Some resources are renewable over time, and others are not.



### Basic Teacher Preparation

Day 1 sets the stage for much of the exploration and learning that will occur later in the module. Sufficient preparation is required and should include the following:

- Establish student teams of 3 or 4 before beginning Day 1. Students work with their teams throughout the module.
- Explore the **Suggested Teacher Resources** to foster a basic understanding of wind turbines.

- Build a prototype wind turbine model for use in upcoming demonstrations, testing, and instruction.
- Watch several short videos to build background knowledge.

To prepare for the whole group discussions, review the [Talk Science Primer](#) (refer to the [Suggested Teacher Resources](#) at the end of this lesson).

The following table lists the preparation needed for Days 1 through 4. Additional content-related information is available in the [Suggested Teacher Resources](#) at the end of Day 4.

Required Preparation	Links/Additional Information
<input type="checkbox"/> Gather or purchase the required materials for the lesson	Refer to the <a href="#">Materials List</a> below
<input type="checkbox"/> Review all videos and resources in the <a href="#">Suggested Teacher Resources</a>	Refer to the <a href="#">Suggested Teacher Resources</a> at the end of this lesson
<input type="checkbox"/> Background Information about Wind	Refer to the <a href="#">Suggested Teacher Resources</a> at the end of this lesson
<input type="checkbox"/> Background Information about Modern Wind Turbines	Refer to the <a href="#">Suggested Teacher Resources</a> at the end of this lesson
<input type="checkbox"/> Build a Prototype Model	Refer to the <a href="#">Suggested Teacher Resources</a> at the end of this lesson
<input type="checkbox"/> View the Design Challenge video	Refer to the video in the <a href="#">Set Up for First Design Challenge</a> activity on Day 2
<input type="checkbox"/> View lift and drag videos	Refer to the <a href="#">Suggested Teacher Resources</a> at the end of this lesson



## Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Design Challenge Handout	Overall design challenge for the module	1 per student	Alternative Energy Teacher Handbook, Appendix C
Simple toy pinwheels on a stick	Students may take apart or modify pinwheels, so be sure to purchase enough for every class	2 for every design team	Most toy or hobby stores and online <a href="#">Web Link</a>
Prototype wind turbine	Instructions for building the wind turbine model are included in this booklet <i>Building the Basic PVC Wind Turbine</i> published by the Department of Energy for the Kidwind Project. (Specific materials are listed in this table.)	1 model for class	<i>Building the Basic PVC Wind Turbine</i> [PDF] <a href="#">[Web Link]</a>

Science notebooks or loose leaf paper		1 per student	Available in most schools
Marshmallow sticks or bamboo skewers		4 or 5 per team	Bamboo skewers <a href="#">[Web Link 1]</a> <a href="#">[Web Link 2]</a>
Cork for propeller hubs	12 x 12-inch tiles	1 package for build	4 pack of 12 x12-inch sheets, yields 16+ hubs <a href="#">[Web Link]</a>
Push pins		Several for each team	Push pins <a href="#">[Web Link]</a>
.5-inch wood screws		2 bags of 3 screws for each team	Local home improvement store <a href="#">[Web Link]</a>
PVC fittings and pipes	5 x 1-inch PVC 90 fittings 3 x 1-inch PVC T-fittings 1 x 2-foot section of PVC pipe 7 x 6-inch sections of PVC pipe 1 x 1-inch PVC coupler	1 set for turbine build	Most hardware or home improvement stores
Various sturdy/stiff paper products	Poster paper, foam core, cereal boxes, cardboard, and so forth	Several options per team	Craft stores, home, or most schools
Glue, duct tape	May be useful when building rotor blades	As needed	Local stores, home, and most schools

## Day 1: Why a Pinwheel Spins



### Introduction (10 minutes)

Begin the module by explaining that this module focuses on wind energy and wind turbines. Present the students with the driving question, *How can we design a wind turbine blade that generates the most electricity?* Tell students they will be working through the engineering design process to build a wind turbine blade that generates the most electricity. Review the Engineering Design Process graphic (Appendix A) with students.



#### NGSS Key Moment

Engineers often refer to the *engineering design process* when they discuss their work. In NGSS, the Science and Engineering Practices are used in place of the engineering design process. Students should understand that the engineering design process is not linear in practice. Rather, engineers engage in all of the steps, often jumping between steps. Students may want to think of the engineering design process as a web of practices.

Some students may not be familiar with wind turbines. To familiarize students with wind turbines, show one of the following two videos: [Energy 101: Wind Power](#) or [How Wind Turbines Work](#). At this point in the module, students do not need to understand the details included in the video (they will figure it out throughout the module!). The point of showing one of the videos is to familiarize students with wind turbines in general.

Emphasize the idea that wind power is one of the many solutions to the global energy crisis. For wind energy to work efficiently, the turbines must be designed to produce the most electrical energy possible. Relate this idea to the driving question, *How can we design a wind turbine blade that generates the most electricity?*

To begin the exploration of wind energy and wind turbines, ask students to think about what they already know about wind, energy, and wind turbines and what they need to know.

Have students work independently to generate their own lists for **What We Know** and **What We Need to Know**. After students create their lists, have them share their ideas to create a class list (see the following example).



#### Video Links

- ▶ [Energy 101: Wind Power \[YouTube Link\]](#)
- ▶ [How Wind Turbines Work \[YouTube Link\]](#)



#### NGSS Key Moment

To better frame the design problem, consider using this module immediately following a module that helps students build an understanding of renewable energy (ESS3.A). Alternatively, consider expanding this lesson to more explicitly address the idea of renewable energy.

## Example Class Question List

### What We Know

- When the wind blows, it moves things.
- Wind turbines can create energy that people use in their homes.
- Energy transfer occurs between two objects when they collide (see the **NGSS Key Moment**).

### What We Need to Know

- What does a wind turbine blade look like?
- What causes a wind turbine blade to turn?
- How can the wind change into energy that can be used to turn on lights?



### NGSS Key Moment

This unit fits well after students have built an initial understanding of energy transfer. Students should know that when objects collide, energy transfers occur (4-PS3-3). They may not yet understand that energy can also be transferred by sound, light, heat, and electric currents (4-PS3-2).

Tell students their goal throughout the module is to answer the **Need to Know** questions. Post the **Need to Know** questions so they can be easily referenced throughout the module.



## Investigation: What causes a pinwheel to turn? (15 minutes)

To begin the exploration of wind, energy, and wind turbines, students start by thinking about how wind turbine blades turn. While students might not be familiar with wind turbines, some of the basic features of a wind turbine, or a windmill, can be explored with a pinwheel toy.

Divide the class into their design teams. Give each team two handheld pinwheels. Encourage the teams to play with or manipulate their pinwheels. Students may choose to take the pinwheels apart or modify pinwheel designs—encourage this kind of tinkering. As students explore, encourage them to think about the following questions:

- *What causes the pinwheel blades to turn?*
- *What makes the pinwheel blades move faster or slower?*
- *What do you notice about the design of the pinwheel's blades?*
- *Why are the pinwheel blades shaped the way they are?*
- *What parts and features are absolutely necessary to make the pinwheel spin?*
- *How do you think the pinwheel's performance (spinning speed) might be improved?*



### Important Note

Students work with the same teams for the entire module. Carefully consider team composition beforehand.

After students have had an opportunity to experiment with the pinwheel and think about the questions listed above, distribute one piece of large chart paper to each group. Instruct student teams to create an initial model to show what causes the pinwheel to turn and what makes the blades move faster or slower. Students should use words, pictures, and symbols in their initial model. Students should focus specifically on modeling their understanding of their responses to

the following questions:

- *What causes the pinwheel blades to turn?*
- *What makes the pinwheel blades move faster or slower?*

Students should record evidence from their investigation to support their claims.

Throughout the module, students develop drafts of models explaining how a wind turbine works. All drafts should be created on chart paper. The models will be referred to as **Wind Turbine Models—Chart Paper**. These models are different from the **Wind Turbine Prototype Model**, which is the wind turbine testing structure.



### NGSS Key Moment

As students model their initial explanations of what causes the pinwheel to turn and what makes the blades move faster or slower, they engage in the core practices of modeling. At this point in the unit, the goal is for students to develop initial ideas relating the speed of an object to the energy of the object (4-PS 3-1) and to generate questions about what makes a pinwheel or wind turbine spin.



## Whole Group Discussion: What Causes a Pinwheel to Turn? (10 minutes)

Gather the class in a **Scientists Meeting**. Have students sit in a circle and place their **Wind Turbine Models—Chart Paper** in the middle of the circle. Start by allowing students time to look at the chart paper created by other teams.

Engage students in a discussion to share their initial ideas about, *What causes the pinwheel to turn?* and, *What makes the blades move faster or slower?* The goal of the discussion is to allow students to share their initial conjectures. At this point in the module, students should share their ideas and ground their ideas in evidence. Encourage all students to share their ideas, even if their ideas are not “right.” Remind students to continually use evidence. Scribe notes during the discussion. Suggested prompts include:

- *What do you think made the pinwheel spin? Why do you think that?*
- *Why do you think the pinwheel would sometimes spin faster or slower? Why do you think that?*
- *What did you do to change the way your pinwheel spun? Why do you think your change caused a change in the way the pinwheel spun?*



### NGSS Key Moment

Whole group discussions, particularly consensus discussions, can be an effective way to engage students in the science practices of argumentation and explanation. Leading whole group discussions requires proper preparation. Refer to the [Talk Science Primer](#) for useful strategies.



### NGSS Key Moment

Although not addressed until Grade 5, this discussion can help students begin to build an understanding that air is made of particles that are too small to see (PS1.A).

Throughout the discussion, work to draw out the following initial ideas:

- *When you blow harder on the pinwheel, it spins faster.*
- *Different blade angles cause the pinwheel to spin faster or slower.*

Students do not need to be able to explain *why* certain angles cause the pinwheel to spin

faster. They will continue to explore this phenomenon and the concepts of lift and drag throughout the module. The resources listed in the following Extension and in the Suggested Teacher Resources at the end of Day 4 can help you prepare for this discussion.



### Extension

Consider selecting clips from the following resources to show students as additional extension or support:

- ▶ How Wind Turbines Work—3D animation [[YouTube Link](#)]
- ▶ Energy 101: Wind Power [[YouTube Link](#)]
- ▶ Wind Energy Basics [[Web Link](#)]
- ▶ U.S. Energy Information Agency, Wind Energy for Kids [[Web Link](#)]
- ▶ KidWind Teacher Resources [[Web Link](#)]
- ▶ Bill Nye the Science Guy On Wind [[Web Link](#)]
- ▶ On Dancing Air (video) [[YouTube Link](#)]



### Whole Group Discussion: Models and Modeling (10 minutes)

Remind students that their goal for the module is to **design a wind turbine blade that generates the most electricity**. In the first investigation, students started to think about what makes blades spin and why they sometimes spin faster or slower.

Tell students that in addition to creating and using models to explain phenomena (as they just did on chart paper), engineers often use prototypes or models of existing or new technologies. Using scale models or prototypes allows engineers to test phenomena and revise design features.

Tell students they will be working with a prototype wind turbine model. Display the model. This model is the **Wind Turbine Prototype Model**, which should not to be confused with the **Wind Turbine Models—Chart Paper**.



### NGSS Key Moment

Relate the wind and pinwheel to two objects colliding (4-PS3-3) to help students think about energy transfer.



### Important Note

Build the prototype model in advance. The required materials are included in the **Materials and Resource** section.

Initiate a class discussion about the features, components, and operation of the Wind Turbine Prototype Model. Ask students to compare the model to an actual wind turbine. Ask students, *What are the components of the model that compare to an actual turbine?*

Ask the following questions and discuss the topics with the class:

- *What are the limitations of a model like this?*
- *Why do you think engineers use prototypes and models in their work?*
- *How can models assist with the design process?*
- *How might the cost of building materials impact the model building and engineering design process?*

Next, have students consider the similarities and differences between the Wind Turbine Prototype Model and the Wind Turbine Models—Chart Paper.

After discussing models and modeling, demonstrate the model wind turbine by using a desk fan to simulate wind moving toward the blades. This will rotate the blades and produce electricity that spins the connected motor and lights the LED. Point out the motor and light. Ask students to think about why the LED light turns on when the blades spin.

Students continue to consider this question in their homework.



▲ Desk Unit Wind Turbine



#### Important Note

For this early demo, be sure the fan is not directly in front of the blades (not a direct right angle), but in front of and slightly to the side.



### Lesson Close (5 minutes)

Ask each team to discuss why they think the LED light turns on when the blades of the turbine spin. For homework, have students expand on their initial ideas.



#### Homework

Have each student draw their own diagram of a wind turbine and its components based on the demonstration of the model wind turbine. Below their diagrams, have students explain (in their own words) why they think the LED light turns on when the blades spin.

## Day 2: How a Wind Turbine Harnesses the Wind



### Introduction (5 minutes)

Begin class by prompting students to reconsider their homework reflection. In the homework, students thought about why the LED light on the wind turbine model turns on when the turbine blades spin. Have students share their ideas with the other members of their design team.

After students share their ideas, show students that the voltage output can be measured using a **voltmeter**. Show students that the reading on the voltmeter changes as the speed of the turbine changes. Encourage students to think about why the voltmeter reading might change as the speed of the turbine changes.



### Investigation: How the LED Light Turns On (20 minutes)

Provide students with their chart paper from the pinwheel activity on Day 1 (**Wind Turbine Models—Chart Paper**). Also provide students with fresh chart paper. The fresh chart paper is for students to expand upon or revise their models. All pieces of chart paper should be stored together. Whenever **Wind Turbine Models—Chart Paper** are referenced, students should have access to all drafts of their chart paper models.

Instruct students to create a new model to explain **what makes the LED light turn on**. Students should incorporate ideas from their pinwheel model. As students work, circulate among the teams to encourage students to think carefully about the phenomena: When the wind blows, the wind turbine blades spin and the LED light turns on.

You can promote student thinking using the following prompts:

- *How were the turbine blades similar or different from the pinwheel blades?*
- *What are the turbine blades connected to?*
- *Other than the blades, what parts of the turbine are involved?*
- *How do you think the spinning blades relate to the light?*
- *What questions do you still have?*



#### NGSS Key Moment

At this point, students work with the idea that wind energy can be converted into electric energy (4-PS3-2). Students should be able to demonstrate that the spinning blades spin the motor, which turns the wind energy into electricity to light up the LED light. In Grade 4, students should focus on the idea that energy is converted, but they do not need to be able to explain how it is converted.



## Whole Group Discussion: How the LED Light Turns On (20 minutes)

Gather the class in a **Scientists Meeting**. Have students sit in a circle and place their chart paper in the middle of the circle. Be sure students place their revised chart paper models in the center of the circle. Start by allowing students time to look at the chart paper models created by other teams. Next, engage students in a discussion to share their initial ideas. The goal of the discussion is for students to share their initial conjectures as to **what causes the LED light to turn on**. Remind students to continually use evidence. Scribe notes during the discussion.

During the discussion, draw out the idea that the energy from the wind causes the turbine blades to turn. As the blades turn, a magnetic rotor turns inside the generator. Through the generator, the wind energy is converted into electrical energy. The electrical energy can be measured using the voltmeter or by watching the LED light turn on. The key idea is that energy is converted (4-PS3-2). Students should begin to wonder how the generator converts wind energy to electrical energy. Encourage students to puzzle about this question—later, students look more closely at the motor.



### NGSS Key Moment

During the whole group discussion, students should engage in the practices of modeling, argumentation, and explanation. To develop a class model explaining how the LED light turns on, students must present and defend their models, consider the models developed by classmates, and revise their models to fit the evidence.



## Lesson Close (5 minutes)

Ask each team to discuss how they think they could modify the turbine blades to spin at the maximum speed and generate the greatest amount of electricity.



### Homework

Have students share their initial ideas about how the wind turbine blades might be optimized to spin at the maximum speed and generate the greatest amount of electricity. Instruct students to draw at least two sketches of proposed turbine blades for homework. Below their sketches, students should explain why they think their proposed blades will cause the turbine to spin faster.

## Day 3: Maximize the Energy Output of Our Turbine (Part I)



### Introduction (10 minutes)

At this point, students have developed an initial model for how the wind turbine blades spin as well as how the LED light turns on and how wind energy converts into electrical energy.

Over the next few days, students refine their models through a series of design challenges. The design challenges serve two purposes. First, the design challenges help students develop a deeper understanding of what causes wind turbine blades to spin and how wind energy is converted into electrical energy. Second, the design challenges help students work towards their overall design challenge of designing a wind turbine that generates the most electricity.

During this first design challenge, students are asked to modify some aspects of the wind turbine blades on the model wind turbine in an effort to **optimize** its performance—faster rotation, greater speed, and more electricity generation.

Before giving directions to the students, watch the [Design Challenge](#) overview video created by one of the engineer authors. Use the video to set up the design challenge. Provide students with the **Design Challenge Handout (Appendix C)**.

Inform students how the initial wings for the prototype were created—two rectangular pieces of cardboard were cut out of a cereal box and stapled together. Wood marshmallow sticks (or wood skewers) were inserted into blades, and the cardboard was stapled into place. Using pushpins, the sharp ends of the marshmallow sticks were inserted into the cork rotor holding the blades at the set angle-of-attack.

Provide students with the necessary materials to make their own rotor blades. Basic materials include:

- Cardboard
- Staples and stapler
- Marshmallow sticks or wooden skewers
- Scissors

Explain the elements of the design challenge. If desired, use the **Design Challenge Handout (Appendix C)** as a supplement during the explanation.

**Overall Goal:** Create turbine blades that optimize the rotor speed and produce more electricity.



#### Important Note

Be sure students understand the term **optimization**. It is an important part of the engineering design process.



#### Video Link

- Design Challenge [\[YouTube Link\]](#)



#### Helpful Tip

While the basic materials fulfill the needs for this module, other options include:

- Different types of stiff paper in varying weights
- Recycled materials like paper milk cartons, plastics, foam core, and so forth

Possible changes, or optimizations, to the rotor blades that might be considered by students include changes to the blade's:

- Size, length, width
- Attachment angle
- Shape
- Number (2 through 4 blades)



### Important Note

During this first round of testing, avoid prompting students with design modifications. Let them experiment with variables on their own.



## Design Work: Optimize Rotor Speed and Produce More Electricity (20 minutes)

Student teams determine the rotor blade modifications they want to make. The teams create their new rotor blades and prepare for testing. As students work, circulate around the room and prompt students to explain their reasoning for design decisions. Suggested prompts include:

- *Why did you decide to make your blade look like that?*
- *Why do you think your design will improve the speed of the turbine?*
- *What evidence do you have that your design will optimize the solution?*
- *What weaknesses do you see in your design?*



### NGSS Key Moment

During this first round of testing, students design a possible solution (3-5-ETS1-2). Later, students optimize their solutions.



## Investigation: Test Our Revised Rotor Blades (15 minutes)

Each team conducts three trials by placing their rotor blades on the prototype model. Teams should use a data sheet to record the voltmeter output for each trial (see the example data tables later in this section). After testing their rotor blades, each team member should create an entry in their individual science notebook that includes:

- Drawing of their overall design modification
- Rationale (claim) for their design modification
- Summary of the evidence (data) that supports their reasoning of why it was or was not successful
- Sketch of suggested revisions to further refine the turbine blade

As a group, the design team should modify their **Wind Turbine Models—Chart Paper** on fresh chart paper. Students should focus on revising their models to explain how the wind turbine blades spin and how wind energy converts into electrical energy. Encourage students to highlight revisions to their model in a different color.



### NGSS Key Moment

Emphasize the intersection of the ETS (3-5-ETS1-2 and 3-5-ETS1-3) and PS (4-PS3-1 and 4-PS3-4) performance expectations in this design challenge.

## Example Data Tables

Two examples of data tables are provided. Select the data table most appropriate for your students, create your own data tables, or have students create their own data tables.

### Example #1

Students use a new table for each trial (three trials required).

Blade Length = _____ inches	Blade Width = _____ inches	Number of Blades = _____
Blade Angle (deg)	Voltage Output (Volts)	
0		
20		
45		
65		
90		

Blade Length = _____ inches	Blade Width = _____ inches	Number of Blades = _____
Blade Angle (deg)	Voltage Output (Volts)	
0		
20		
45		
65		
90		

**Example #2**

**Variable = Length of Blades**

1. Blade Width = \_\_\_\_\_ inches
2. Blade Angle = \_\_\_\_\_ °
3. Number of Blades = \_\_\_\_\_ inches

**Data:**

Blade Length (inches)	Order to Test In	Voltage Output (volts)
blade length = _____	3 <sup>rd</sup>	
blade length x 1.25 = _____	2 <sup>nd</sup>	
blade length x 1.5 = _____	1 <sup>st</sup>	

**Variable = Width of Blades**

1. Blade Length = \_\_\_\_\_ inches
2. Blade Angle = \_\_\_\_\_ °
3. Number of Blades = \_\_\_\_\_ inches

**Data:**

Blade Width (inches)	Voltage Output (volts)
4	
3	
2	

**Variable = Angle of Blades**

1. Blade Length = \_\_\_\_\_ inches
2. Blade Width = \_\_\_\_\_ inches
3. Number of Blades = \_\_\_\_\_ inches

**Data:**

Blade Angle (degrees)	Voltage Output (volts)
0°	
20°	
45°	
65°	
90°	

**Variable = Number of Blades**

1. Blade Width = \_\_\_\_\_ inches
2. Blade Length = \_\_\_\_\_ inches
3. Blade Angle = \_\_\_\_\_ °

**Data:**

Number of Blades	Voltage Output (volts)
2	
3	
4	

**Lesson Close (5 minutes)**

Have students clean up their work areas and return all supplies to the appropriate locations.

**Homework**

Have each team member create a science notebook entry that includes:

- ▶ Drawing of their overall design modification
- ▶ Rationale (claim) for their design alteration
- ▶ Summary of the evidence (data) that supports their reasoning of why it was or was not successful and why the proposed change will be successful
- ▶ Sketch of suggested revisions to further refine the turbine blade

## Day 4: Maximize the Energy Output of Our Turbine (Part 2)



### Introduction (5 minutes)

Have students meet with a student from a different team. Instruct students to share their homework reflections. Prompt students to discuss the following points:

- *What were the differences in blade designs between the two teams?*
- *What were the differences in performance between the two teams?*
- *How can you use information from both teams to redesign a better blade?*



#### NGSS Key Moment

Meeting with other groups helps students develop the idea that communicating with peers about proposed solutions is an important part of the design process and that shared ideas can lead to improved designs (3-5-ETS1-2).



### Whole Group Discussion: Lift and Drag (15 minutes)

Gather the students in a Scientists Meeting circle. Lead a class discussion about the previous day's rotor blade testing. Prompt students to use evidence during the discussion. Ask students to consider:

- Various blade designs used
- Differences in the materials used by different teams
- Why (rationale) teams selected the designs they did
- Student hypotheses about why some designs were more successful than others
- Which variables seemed to make the most difference

During the discussion, keep track of common ideas on chart paper. Students should start to see that the size, length, width, angle, shape, material, and number of blades changes the speed and voltage output of the turbine.

During the discussion, students should begin to speculate that the angle between the wind and blade matters. When students bring up



#### NGSS Key Moment

In order to design, test, and refine a device (4-PS3-4) students must understand and work with the science ideas behind why a device worked or failed. In this whole class discussion, students should work to develop science ideas related to the size, shape, material, and number of blades used in a turbine. Specifically, students should start to work with the ideas of lift and drag.



#### NGSS Key Moment

This discussion can help students build on their understanding (ideally developed in Grade 3) that greater force leads to more motion of an object (PS2.A).

this idea, encourage them to elaborate on their ideas based on their testing. Students should listen carefully to each other to compare their ideas to the ideas presented by their classmates.

Students might not use the terms *lift* and *drag* to explain their reasoning, but they might touch on some characteristics related to the two concepts. Students need to know that lift and drag are forces acting on the wind turbine. After students develop an initial understanding of lift and drag, show them the videos. Point out that they already developed the ideas included in the videos; the videos simply give terminology to the ideas.



### Video Links

- ▶ Lift and Drag [\[YouTube Link\]](#)
- ▶ Lift and Drag Continued [\[YouTube Link\]](#)



### Extension

Determine how much time students need to devote to the *lift* and *drag* concepts before moving on to the first engineering design challenge. If necessary, show two more basic videos that provide student-friendly information about these topics:

- ▶ NASA—How drag, lift and thrust work [\[YouTube Link\]](#)
- ▶ The Forces on an Airplane [\[YouTube Link\]](#)



## Design Work: Prepare for a Second Trial (15 minutes)

Based on the information previously discussed and demonstrated, students redesign their rotor blades for optimized success. At this juncture, encourage teams to reconsider some of their original design variables, including:

- Size, length, and width of the blade
- Angle of the blade's attachment
- Shape of the blade
- Number of blades (2 through 4)



### NGSS Key Moment

Students need to have an opportunity to redesign their blades. Through the redesign, students can test out their revised science ideas and designs. This helps students develop a core understanding of the importance of using science ideas to optimize design solutions (ETS1-C).



## Investigation: Second Trial Testing (10 minutes)

Tell teams to use the knowledge gained from their explorations as they begin their second testing trials. Before each team's blades are tested on the prototype, a team spokesperson should provide an oral summary of their design changes and the rationale for these changes to the whole class. Team should use their revised chart paper (models of how the turbine spins and creates energy) as part of their presentation.

Each group should conduct three trials to test their blades and record the voltage readings.

Students should reflect on the homework prompts in their science notebooks.

If time allows, the class should discuss any overall findings and trends.

As a group, the design team should modify their **Wind Turbine Models—Chart Paper** on fresh chart paper. Students should focus on revising their model to incorporate new evidence, explaining how the wind turbine blades spin and how the wind energy is converted into electrical energy.



## Lesson Close (5 minutes)

Have students clean up their work areas and return all supplies to the appropriate locations.



### Homework

Each team member should create a second entry in their science notebook, showing:

- ▶ Drawing of their overall design modification
- ▶ Rationale (claim) for their design alteration
- ▶ Summary of the evidence (data) that supports their reasoning of why it was or was not successful and why the proposed change will be successful
- ▶ Sketch of suggested revisions to further refine the turbine blade



## Assessment

Several opportunities for formative assessment exist in this lesson:

- **What We Know** and **What We Need to Know** lists developed on Day 1.
- Drafts of student models developed on all four days (Initial Model, Initial Model Including LED Light, Revised Model After Test #1, and Revised Model After Test #2).
- Homework on all four days (diagram of a wind turbine, ideas about the turbine blade, plans for turbine model, and revised plans for turbine model).
- Small and whole group discussions, particularly the discussion with small groups on Day 3.
- Oral summary of the design changes on Day 4.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary. Reference **Appendix B** for suggestions for meeting the needs of all learners.



## Community Connections

Most jobs require employees to collect relevant types of data that can be used for decision making. Ask students to poll their parents or other adults in their homes about the types of data they collect at work and how they use the information.



## Suggested Teacher Resources

Engineering Design Process	Alternative Energy Teacher Handbook, Appendix A
Meeting the Needs of All Learners	Alternative Energy Teacher Handbook, Appendix B
Design Challenge Handout	Alternative Energy Teacher Handbook, Appendix C
Talk Science Primer	<a href="#">[Web Link]</a>
How Wind Turbines Work	<a href="#">[YouTube Link]</a>
Energy 101: Wind Power	<a href="#">[YouTube Link]</a>
Wind Energy Development, Wind Energy Basics	<a href="#">[Web Link]</a>
U.S. Energy Information Agency, Wind Energy for Kids	<a href="#">[Web Link]</a>
KidWind Project Guidebook (PDF)	<a href="#">[Web Link]</a>
Lift and Drag	<a href="#">[YouTube Link]</a>
Lift and Drag Continued	<a href="#">[YouTube Link]</a>
PBS: The Challenge of Flight	<a href="#">[Web Link]</a>

<a href="#">Bill Nye the Science Guy On Wind</a>	[Web Link]
<a href="#">On Dancing Air Video</a>	[YouTube Link]
<a href="#">NASA—How drag, Lift and Thrust Work</a>	[YouTube Link]
<a href="#">The Forces on an Airplane</a>	[YouTube Link]
<a href="#">How Wind Turbines Work—3D Animation</a>	[YouTube Link]
<a href="#">Potential and Kinetic Energy</a>	[Web Link]
<a href="#">Energy Transformations</a>	[Web Link]
<a href="#">Wind Turbine Diagram</a>	[Web Link]



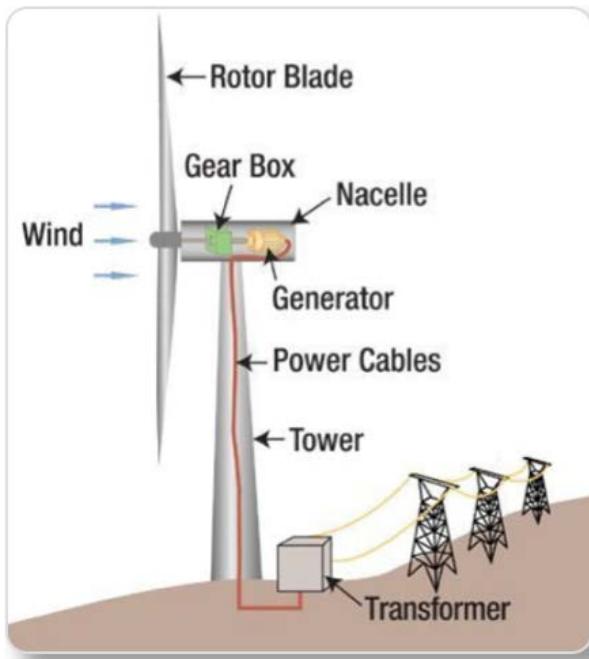
## Background Information about Wind

Wind is a form of solar energy and is a result of the uneven heating of the atmosphere by the sun, the irregularities of the Earth's surface, and the rotation of the Earth. Wind flow patterns and speeds vary greatly across the United States and are modified by bodies of water, vegetation, and differences in terrain. Humans use wind flow, or **motion energy**, for many purposes, including sailing, flying a kite, and generating electricity.

The terms **wind energy** and **wind power** describe the process in which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

Wind energy comes from the movement of air. If you have ever been outside on a windy day, you know how much energy the wind can have. It can push you around and flip your umbrella inside out. In towns struck by tornadoes or hurricanes, the extremely strong winds can blow roofs off buildings and uproot trees. To use wind as an alternative energy resource, its power must be captured and changed into electricity. Huge machines called wind turbines can do this.

The blowing wind turns a propeller on the turbine. That energy spins a device that creates electricity. Wind turbines are usually placed at least 30 meters (100 feet) in the air so that they can capture the fastest winds. Some of them even turn in different directions to face the wind most efficiently.



▲ Wind Turbine Diagram

Source: <https://www.n-somerset.gov.uk/wp-content/uploads/2015/11/wind-turbines-supplementary-planning-document.pdf>



## Background Information about Modern Turbines

Modern wind turbines fall into two basic groups based on their axis—horizontal and vertical. A **horizontal axis wind turbine (HAWT)** is shown in the top picture on the right. A **vertical axis wind turbine (VAWT)** is shown in the lower picture.

Vertical wind turbines are also known **Darrieus** turbines, named after its French inventor. Horizontal-axis wind turbines typically have two or three blades, and are operated "upwind," with the blades facing into the wind.

Wind turbines can be built on land or offshore in large bodies of water, like oceans and lakes. [In July 2015, the United States began construction on the first off-shore wind installation.](#) The Deepwater Wind project is located three miles southeast of Block Island, Rhode Island and is expected to begin operation in 2016.

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts. Larger wind turbines are more cost effective and are grouped together into wind farms, which provide bulk energy to electrical grids.

In recent years, there has been an increase in large offshore wind installations in order to harness the huge potential wind energy offers off the coasts of the United States; however, litigation and missed project deadlines have delayed several of the proposed build sites.

Single small turbines, below 100 kilowatts, are used for homes, communications dishes, or water pumping. Small turbines are sometimes used in connection with diesel generators, batteries, and photovoltaic systems. These systems are called **hybrid wind systems** and are typically used in remote, off-grid locations, where a connection to the utility grid is not available.





## Web Resources

- ▶ How Wind Turbines Work—3D Animation [[YouTube Link](#)]
- ▶ Potential and Kinetic Energy [[Web Link](#)]
- ▶ Energy Transformations [[Web Link](#)]
- ▶ Wind Turbine Diagram [[Web Link](#)]
- ▶ Energy 101: Wind Power [[YouTube Link](#)]
- ▶ Wind Energy Basics [[Web Link](#)]
- ▶ U.S. Energy Information Agency, Wind Energy for Kids [[Web Link](#)]
- ▶ PBS Learning Media: Putting Wind Energy to Work [[Web Link](#)]
- ▶ Holland Unesco Site: Kinderdijk [[Web Link](#)]
- ▶ Today in Energy [[Web Link](#)]
- ▶ Cape Cod Windmills [[Web Link](#)]
- ▶ Dutch Windmill [[Web Link](#)]



## Information for Building the Desktop Prototype Turbine

The Department of Energy's Kidwind Project developed a guidebook that details how to build a simple PVC wind turbine. Basic materials for the base, tower, and nacelle (white PVC pipe sections) are listed in the guidebook.

For purposes of this project, an overview of the model “build” materials and suggestions for building the rotor, rotor blades, and connecting the rotor and blades are provided. These videos address low-cost options for this part of the design build. View the videos in the suggested sequence.



## Video Links

- ▶ Overview of the Entire Turbine [[YouTube Link](#)]
- ▶ Rotor Build—Part 1 [[YouTube Link](#)]
- ▶ Rotor Build—Continued [[YouTube Link](#)]
- ▶ Rotor Blades [[YouTube Link](#)]
- ▶ Rotor Blades—Continued [[YouTube Link](#)]
- ▶ Rotor and Blades—Connecting the Rotor and Blades [[YouTube](#)]