



TryEngineering

Working with Wind Energy



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Lesson Focus

Lesson focuses on how wind energy can be generated on both a large and small scale. Student teams design and build a working windmill out of everyday products and learn about anemometer and site testing. Student windmills must be able to sustain the wind generated by a fan or hairdryer at medium speed at 2 feet and rotate, lifting a small object upward. Students evaluate the effectiveness of their windmill and those of other teams, and present their findings to the class.

Lesson Synopsis

The "Working with Wind Energy" activity explores the growing use of wind energy to generate or augment energy in businesses and homes worldwide. Students work in teams of "engineers" to design and build their own windmill out of everyday items which they select and purchase with a budget. They test their windmill, evaluate their results, and present reflections to the class.

Age Levels

8-18.

Objectives

- ✦ Learn about wind energy and wind turbines.
- ✦ Learn about engineering design.
- ✦ Learn how engineering can help solve society's challenges.
- ✦ Learn about teamwork and problem solving.



Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- ✦ wind energy
- ✦ interaction of technology and societal issues
- ✦ engineering design
- ✦ teamwork

Lesson Activities

Students explore the impact of how technology can positively impact the world by learning about wind energy and equipment used for both site testing and the conversion of wind to energy. Students explore the technology behind wind energy, find out about site studies, and work in teams to develop a windmill out of everyday items. They test their windmill, evaluate their own designs and those of other students, and present their findings to the class.

Resources/Materials

- ✦ Teacher Resource Documents (attached)
- ✦ Student Resource Sheet (attached)
- ✦ Student Worksheet (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- ✦ TryEngineering (www.tryengineering.org)
- ✦ National Renewable Energy Laboratory - Wind Research (www.nrel.gov/wind)
- ✦ Wind Powering America (www.windpoweringamerica.gov)
- ✦ European Wind Energy Association (www.ewea.org)
- ✦ Danish Wind Industry Association (www.windpower.org)
- ✦ Global Wind Energy Council (www.gwec.net)
- ✦ Global Wind Day (www.globalwindday.org)
- ✦ National Science Education Standards (www.nsta.org/standards)
- ✦ ITEA Standards for Technological Literacy (www.iteaconnect.org/TAA)



Recommended Reading

- ✦ Wind Power: Renewable Energy for Home, Farm, and Business (ISBN: 1931498148)
- ✦ Wind Energy Basics: A Guide to Small and Micro Wind Systems (ISBN: 1890132071)
- ✦ The Homeowner's Guide to Renewable Energy (ISBN: 086571536X)

Optional Writing Activity

- ✦ Write an essay about whether a wind farm -- even if it would provide energy to the local area -- would be a good idea to put in the center of your hometown. What about on the Thames River in London or just off of a resort beach area?

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For Teachers: Teacher Resources

◆ Lesson Goal

Students explore the impact of how technology can positively impact the world by learning about wind energy and equipment used for both site testing and the conversion of wind to energy. Students explore the technology behind wind energy, find out about site studies, and work in teams to develop a windmill out of everyday items. They test their windmill, evaluate their own designs and those of other students, and present findings to the class.

◆ Lesson Objectives

- ✦ Learn about wind energy and wind turbines.
- ✦ Learn about engineering design.
- ✦ Learn how engineering can help solve society's challenges.
- ✦ Learn about teamwork and problem solving.

◆ Materials

- ✦ Student Resource Sheets
- ✦ Student Worksheets
- ✦ Hairdryer or Fan; small object for each team to lift (suggestions: toy car, yoghurt cup filled with a few coins, tea bag, battery, pencil)
- ✦ One set of materials for each group of students: wooden stick, wooden spoons, small wooden (balsa) pieces, bendable wire, string, paperclips, rubber bands, toothpicks, aluminum foil, tape, dowels, glue, paper, cardboard, plastic wrap, or other materials you have available.

◆ Procedure

1. Show students the various Student Reference Sheets. These may be read in class, or provided as reading material for the prior night's homework.
2. Divide students into groups of 2-3 students, providing a set of materials per group.
3. Explain that students must develop their own working windmill from everyday items, and that the windmill must be able to withstand a medium speed fan for one minute while winding a string to lift a small object such as a tea bag. (Note: as an extra challenge, test the windmill's ability to lift heavier objects such as coins or washers.)
4. Students will be given a "budget" from which they will need to purchase materials you provide. Assign a cost for each item that will result in the average team being able to purchase at least 30 material parts.
5. Students meet and develop a plan for their windmill. They agree on materials they will need, write or draw their plan, and then present their plan to the class.
6. Student groups next execute their plans. Student teams may request exchange materials or order more materials from the teacher, or may also trade unlimited materials with other teams to develop their ideal parts list. They will need to determine the "cost" of their design, however, which will be factored in to determine the most efficient classroom design.
7. Next....teams will test their windmills with the fan or hairdryer set up. (Note: you may wish to make the fan available during the building phase so they can test their windmill during the building phase prior to the classroom test.)
8. Teams then complete an evaluation worksheet, and present findings to the class.

◆ Time Needed

Two to three 45 minute sessions.

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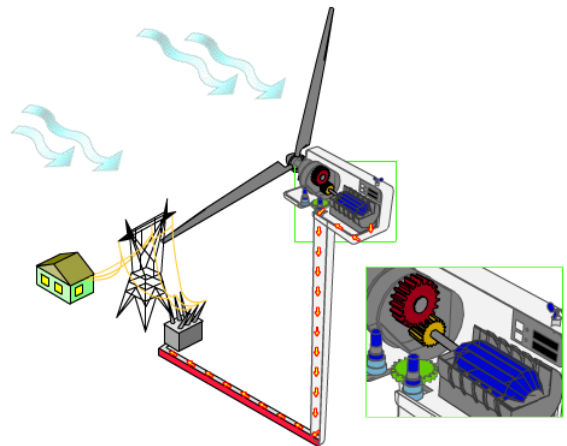
Student Resource: What is Wind Energy?

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity. The term "wind energy" describes the process by which the wind is used to generate mechanical energy or electricity. Wind turbines convert the kinetic energy in the wind into mechanical energy. Mechanical energy can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical energy into electricity.



◆ How Wind Turbines Work

A wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. Wind turbines, like windmills, are usually mounted on a tower to capture the most energy. Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Wind turbines are mounted on a tower to capture the most energy. At 100 feet (30 meters) or more above ground, they can take advantage of faster and less turbulent wind. A blade acts much like an airplane wing. When the wind blows, a pocket of low-pressure air forms on the downwind side of the blade. The low-pressure air pocket then pulls the blade toward it, causing the rotor to turn. This is called lift. The force of the lift is actually much stronger than the wind's force against the front side of the blade, which is called drag. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. Wind turbines can be used to produce electricity for a single home or building, or they can be connected to an electricity grid (see illustration to the right) for more widespread electricity distribution.



Wind speed and the height of the blades both contribute to the amount of energy generated. An interactive game from the Danish Wind Industry Association (www.windpower.org/composite-106.htm) lets you explore this concept in a game.

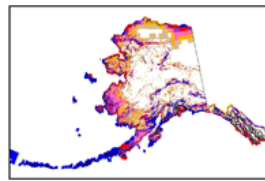
Source: Some of the information or images on this page are provided by the U.S. Department of Energy, the National Oceanic and Atmospheric Administration, or the National Renewable Energy Laboratory.

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Student Resource: Site Testing for Wind Energy

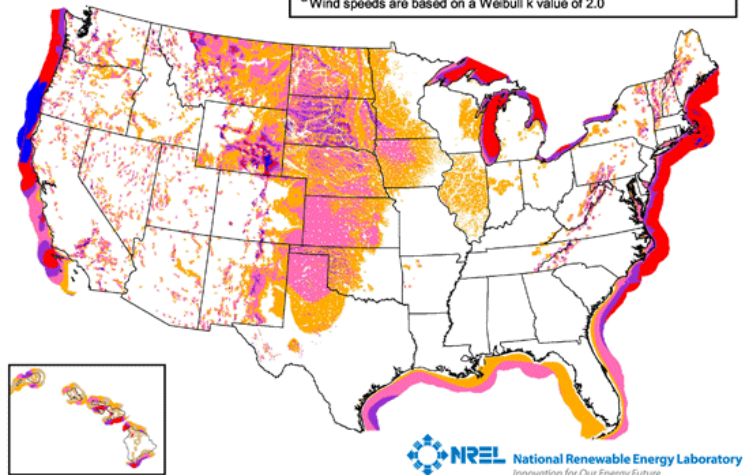
Not all locations are suitable for wind energy development. They need to be evaluated to determine if the cost associated with installing a wind turbine will likely be balanced by the value of energy generated over time.



Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed ^a at 50 m m/s	Wind Speed ^a at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

^aWind speeds are based on a Weibull k value of 2.0

One of the first steps to developing a wind energy project is to assess the area's wind resources and estimate the available energy. To help the wind industry identify the areas best suited for development, the U.S. Wind Energy Program works with the National Renewable Energy Laboratory (NREL) and other organizations to measure, characterize, and map wind resources 50 meters (m) to 100 m above ground. At the local level, towns and contractors will work with homeowners to determine the cost and likely financial benefits of wind turbine installation. Often the first step is to temporarily install an anemometer to test the wind at a farm or home over several months or even a year.



◆ Using Anemometers to Test Wind Potential

An anemometer is a device that is used for measuring wind speed. Many countries and organizations offer anemometer loan programs, so a company or individual can evaluate the wind at their site to determine if enough wind energy would be generated at their location. For these test sites, an anemometer might collect wind-speed data in 10-minute intervals over a long period of time.



◆ Global Wind Day!

There's even a "Global Wind Day" on June 15 of each year to raise awareness of wind energy worldwide. Thousands of public events are organized simultaneously around the world. More information is at www.globalwindday.org.

Source: Some of the information or images on this page are provided by the U.S. Department of Energy and the National Renewable Energy Laboratory.

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Student Resource: Blade Options

◆ Blade Design

Blades come in many shapes and sizes, and there is continuing research into which design is best. It turns out that the optimal design really depends on the application, or where and how the blade will be used. Designers look at the "tip speed ratio" that determines efficiency. This is the ratio between the speed of the wind and the speed the blade tip. High efficiency 3-blade-turbines have tip speed/wind speed ratios of between 6 and 7.

◆ How Many Blades?

Most wind turbines use either two or three blades. Research indicates that as more blades are added there is a increase in aerodynamic efficiency, but this efficiency decreases dramatically with each added blade. For example, increasing the number of blades from one to two can yield a six percent increase in aerodynamic efficiency, but increasing the blade count from two to three yields only an extra three percent in efficiency. And, of course, there are cost implications too. Each additional blade in a design will increase the cost of the end product, so engineers have to factor in both the increased efficiency and the increased cost of manufacturing to determine a design that will be the best for an application. Aesthetics is also a consideration. A small, two or three blade design might be best for a residential area, where a homeowner just wants to pull from the wind enough energy to power their own home, and would prefer a quieter option. A giant 12 blade design would not look very nice atop their home and would perhaps generate more energy than they need, and likely more noise too! To the right you can see how NASA tested a one-bladed rotor configuration. (Photo by NASA Glenn Research Center)



◆ Materials

Early windmills were made of wood with canvas sails. These deteriorated over time and required care – but they represented the materials readily available! More recently, older mechanical turbine blades were made out of heavy steel...but now many are made using fiberglass and other synthetic materials that offer strength at lower weights. And, lower weight building materials can result in larger blades to catch more wind in applications where size and space are less of an issue. Manufacturers also use epoxy-based composites which may offer manufacturing advantages over other materials because the process has less impact on the environment and can result in a smoother surface finish. Carbon fibers have also been identified as a cost-effective method to further reduce weight and increase stiffness. Smaller blades can be made from light metals such as aluminum.

Engineers will be working in this field for years to come to determine the optimal shape, weight, and materials to generate energy most efficiently!

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Student Resource: Blade Innovation and Testing

◆ Which Shape is Best?

Turbine blades are made in many different shapes – and sometimes it is the application that determines which shape is best. For example, a wind turbine blade design that researchers at Sandia National Laboratories developed in partnership with Knight & Carver of San Diego, CA promises to be more efficient than current designs. It should significantly reduce the cost-of-energy (COE) of wind turbines at low-wind-speed sites. Named “STAR” for Sweep Twist Adaptive Rotor, the blade (see prototype to the right) has a gently curved tip, termed “sweep,” which unlike the vast majority of blades in current use, is specially designed for low-wind-speed regions like the Midwest of the United States. The sites targeted by this effort have annual average wind speeds of 5.8 meters per second, measured at 10-meter height. Such sites are abundant in the U.S. and would increase by 20-fold the available land area that can be economically developed for wind energy. Sized at 27.1 meters long, it is almost three meters longer than the blades it will replace — and, instead of a traditional linear shape, the blade features a curvature toward the trailing edge, which allows the blade to respond to turbulent gusts in a manner that lowers fatigue loads on the blade. It is made of fiberglass and epoxy resin.



◆ Research and Testing

Before starting production of a new blade model, a prototype is tried out in a test bed (see image right courtesy of blade manufacturer LM Glasfiber. The blade is subjected to a strain corresponding to 20 years of operation during the testing process. LM Glasfiber is a good example of a "component" manufacturer – this is a business that does not manufacture an entire product, but focuses on a specific component – in this case turbine blades. LM Glasfiber has produced a total of more than 120,000 wind turbine blades since 1978. This amounts to more than one in three of all the blades in operation today, worldwide. One of the company's goals is to develop new technology that makes wind turbines more efficient and extends the service life of both the turbines and the blades. The company points out that "developing new types of blades is based on concrete decisions regarding design, materials and processes. Any adjustment to one parameter also impacts the others." This means that if they test a new shape, they may need to change a material as well.



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Student Worksheet: Design Your Own Windmill

You are working as a team of engineers who have been given the challenge to design a windmill out of everyday items. Your windmill will need to be able to withstand wind from a fan for at least one minute while winding a string or wire to lift a light object such as a teabag. You are working on a budget and will have to "purchase" materials from your teacher to create your design. You may return materials, exchange materials with other teams, but will need to determine the "cost" of your windmill – the least expensive design that meets the challenge will be considered the most efficient design! Your windmill may be vertical (pointing upward from a table) or horizontal (pointing off the edge of a table).

◆ Planning Stage

Meet as a team and discuss the problem you need to solve. Then develop and agree on a design for your windmill. You'll need to determine what materials you want to use -- keep in mind that your design must be strong enough to withstand wind from a fan or hairdryer and the base cannot move so it will have to be secured to a table or shelf. Draw your design in the box below, and be sure to indicate the description and number of parts you plan to use. Present your design to the class. You may choose to revise your teams' plan after you receive feedback from class.

Materials Needed and Budget:

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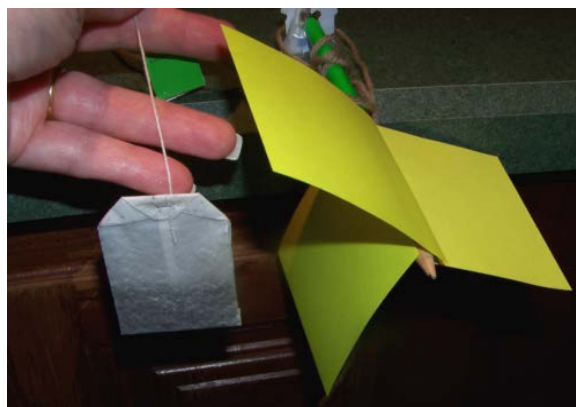
Student Worksheet (continued):

◆ Construction Phase

Build your windmill. During construction you may decide you need additional materials or that your design needs to change. This is ok -- just make a new sketch and revise your materials list and budget.

◆ Testing Phase

Each team will test their windmill using a classroom fan or hairdryer -- each windmill will be tested using the same wind speed -- medium -- at a distance of three feet. You'll need to make sure your windmill can operate for a minute at this speed while winding a light object up with a string. Be sure to watch the tests of the other teams and observe how their different designs worked.



◆ Evaluation Phase

Evaluate your teams' results, complete the evaluation worksheet, and present your findings to the class.

Use this worksheet to evaluate your team's results in the "Working with Wind Energy" lesson:

1. Did you succeed in creating a windmill that operated for a minute that could lift an object? If not, why did it fail?
2. Did you decide to revise your original design or request additional materials while in the construction phase? Why?
3. Did you negotiate any material trades with other teams? How did that process work for you?
4. If you could have had access to materials that were different than those provided, what would your team have requested? Why?

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Student Worksheet (continued):

5. Do you think that engineers have to adapt their original plans during the construction of systems or products? Why might they?

6. If you had to do it all over again, how would your planned design change? Why?

7. How did the most "efficient" design (the one with the lowest cost or budget) differ from your own?

8. Do you think you would have been able to complete this project easier if you were working alone? Explain...

9. What drawbacks does a wind turbine have as a reliable source of energy? What technologies exist that might compensate for these drawbacks?

10. What advantages does the windmill have as a renewable source of energy?

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For Teachers:

Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. [Science Education Standards](http://www.nap.edu/catalog.php?record_id=4962) (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (<http://www.nextgenscience.org/>)
- International Technology Education Association's Standards for Technological Literacy (<http://www.iteea.org/TAA/PDFs/xstnd.pdf>)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (<http://www.nctm.org/standards/content.aspx?id=16909>)
- U.S. Common Core State Standards for Mathematics (<http://www.corestandards.org/Math>)
- Computer Science Teachers Association K-12 Computer Science Standards (<http://csta.acm.org/Curriculum/sub/K12Standards.html>)

◆ National Science Education Standards Grades K-4 (ages 4 - 9)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of the activities, all students should develop an understanding of

- ✦ Position and motion of objects

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ✦ Abilities of technological design

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Science and technology in local challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ✦ Science as a human endeavor

◆ National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ✦ Motions and forces
- ✦ Transfer of energy

CONTENT STANDARD E: Science and Technology

As a result of activities in grades 5-8, all students should develop

- ✦ Abilities of technological design

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Science and technology in society

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For Teachers:

Alignment to Curriculum Frameworks (cont.)

◆ National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop understanding of

- ✦ Motions and forces
- ✦ Interactions of energy and matter

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ✦ Abilities of technological design

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ✦ Natural resources
- ✦ Science and technology in local, national, and global challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ✦ Historical perspectives

◆ Next Generation Science Standards Grades 3-5 (Ages 8-11)

Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

- ✦ 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

Energy

- ✦ 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.

Earth and Human Activity

Students who demonstrate understanding can:

- ✦ 4-ESS3-1. Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.

Engineering Design

Students who demonstrate understanding can:

- ✦ 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- ✦ 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.

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For Teachers:

Alignment to Curriculum Frameworks (cont.)

◆ Next Generation Science Standards Grades 6-8 (Ages 11-14)

Energy

Students who demonstrate understanding can:

- ✦ MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Engineering Design

Students who demonstrate understanding can:

- ✦ MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- ✦ MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

◆ Next Generation Science Standards Grades 9-12 (Ages 14-18)

Energy

Students who demonstrate understanding can:

- ✦ HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Engineering Design

Students who demonstrate understanding can:

- ✦ HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

◆ Standards for Technological Literacy - All Ages

The Nature of Technology

- ✦ Standard 2: Students will develop an understanding of the core concepts of technology.
- ✦ Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology and Society

- ✦ Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.
- ✦ Standard 5: Students will develop an understanding of the effects of technology on the environment.

Design

- ✦ Standard 9: Students will develop an understanding of engineering design.
- ✦ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities for a Technological World

- ✦ Standard 11: Students will develop abilities to apply the design process.
- ✦ Standard 13: Students will develop abilities to assess the impact of products and systems.

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**For Teachers:
Alignment to Curriculum Frameworks (cont.)**

◆Standards for Technological Literacy - All Ages

The Designed World

- ✦ Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.
- ✦ Standard 20: Students will develop an understanding of and be able to select and use construction technologies.