Why Wind Energy is Important

Energy is a hot topic in the news today: increased consumption, increased cost, depleted natural resources, our dependence on foreign sources, and the impact on the environment and the danger of global warming. Something has to change.

Wind energy has great potential to lessen our dependence on traditional resources like oil, gas and coal and to do it without as much damage to the environment.

3M and Discovery Education have collaborated to produce this interactive exercise to highlight how wind power can produce clean, inexhaustible energy locally.

Alternative energy sources, also called renewable resources, deliver power with minimal impact on the environment. These sources are typically more green/clean than traditional methods such as oil or coal. In addition, alternative resources are inexhaustible.

These benefits, as well as data that suggest the drop-off of conventional oil drilling will overtake the output of new drilling by 2014, make renewable energy a viable source to pursue.

Wind Energy

According to the U.S. Department of Energy, wind has been the fastest growing source of electricity generation in the world through the 1990s.

With largely untapped wind energy resources throughout the country and declining wind energy costs, the United States is now moving forward into the 21st century with an aggressive initiative to accelerate the progress of wind technology and further reduce its costs, to create new jobs, and to improve environmental quality.

Advantages of wind energy:

- Wind is free.
- No fossil fuels are used to generate electricity.
- Newer technologies make energy production much more efficient.
- Wind turbines take up less space than the average power station (a few square feet for the base). The turbines can be placed in remote locations, such as offshore, mountains and deserts.
- When combined with other alternative energy sources, wind can provide a reliable supply of electricity.

Virtual Lab: Wind Power

What is a Virtual Lab?

A Virtual Lab is intended to give your students real-life problems to solve in a virtual environment found on their classroom computer. For an engineering design problem, such as the Wind Energy Virtual Lab, students must define the problem, determine the design requirements and constraints (including cost per watt of power produced), brainstorm solutions and do a little research, build and test a prototype, and collect data in a systematic way. The lab will generate data they need in order to evaluate their designs and perhaps make design changes and retest until they are satisfied that they have filled the design requirements within the constraints.

An important skill for students to master is that of developing a plan before they begin testing. Virtual engineering labs are complex. A haphazard approach can produce a bewildering set of results.

One further goal of a Virtual Lab is for students to act as a community of research professionals (engineers, scientists, mathematicians, designers) working together toward the solution of a problem. For this reason, students are asked to communicate their process and results to you and to their classmates. The best results come when students or groups of students try different designs and then compare their results as a class. For those designs that meet the project specifications, then the question is “Which one was the best design in terms of cost and efficiency?”

The URL to access the virtual lab is the 3M and Discovery Education Science of Everyday Life site, http://scienceofeverydaylife.com/innovation/.

Purpose of the Wind Energy Lab

- Provide students with a two-stage engineering design experience: first designing and testing a new structure, and then testing how well the structure functions in a real-world application. The goal is to build a wind turbine to power at least 400 homes for a year at the least cost.
- Have students consider how the location of wind turbines affects cost and efficiency.
- Involve students in the design of the wind turbine and choice of 3M materials that will enhance efficiency.
- Introduce students to the idea of the interdependence of different areas of engineering.
- Encourage students to use innovation in design as they transfer their knowledge from the virtual engineering lab to a hands-on design investigation.

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Science of Everyday Life
Virtual Lab: Wind Power

The Wind Energy Virtual Lab

Wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft which is connected to a generator that produces electricity.

Overview

In this Virtual Lab, students are able to design and test wind turbines that are suitable for different geographic locations. Based on an initial challenge to create a turbine that will capture enough energy to supply 400 homes per year, students design turbines using different configurations and materials.

Good engineering practice requires an understanding of each of the many variables involved and their complex interactions. You may choose to organize students into groups based on a design goal, or allow the groups to determine their own goals.

There are three parts to the virtual lab:

1. The first part begins with choosing the location for the wind turbine.
2. Students design the blade (structure) then test the newly developed turbine.
3. Students then select 3M materials to increase the efficiency of the blades.

Students first decide which location they would like to place the wind turbine. They may choose an off-shore, plains or hill locale. You may wish to have students research the positive and negative aspects of each choice in order inform their decision, or allow them to choose and compare the output data from their designs based on the selected location. Research can be done on-line.
Virtual Lab: Wind Power

US Department of Energy resources:

- For more information about selecting different locales, see [http://www.windpoweringamerica.gov/wind_installed_capacity.asp](http://www.windpoweringamerica.gov/wind_installed_capacity.asp). This annotated map details current installed wind projects and the capacity produced by state.

When students enter the virtual lab, they first choose a location for the wind turbine. Once selected, they enter the Design area where they choose the blade design elements for the most efficient wind capture: e.g., length, shape and angle variables. (For detailed lists of the blade design options available within the Design Lab, see the Appendix at the end of this document.) When the blade design is complete, students are presented with 3M efficiency materials that can be added to improve aerodynamics and/or lifespan. They can then test that blade design for the turbine, revise their design, or go back and try designing a different configuration.

Once these choices are made, the students can test and observe the results of their design: watts produced, efficiency, cost per watt, and number of homes powered.

The Review page shows a record of their design with the input choices for each design.

Students may then decide whether to test the same blade design under different conditions or return to the Design Lab to make revisions. Each time students make a design change in the wind turbines, that design is given a new number, so that the data from the earlier test can be compared.

**Learning Outcomes**

Upon completion of this activity, the student will be able to:

- Identify the need or purpose for the design
- Explain the design-redesign process
- Develop a design (using parameters provided in the virtual lab)
- Develop a design where innovative performance products are used
- Collect and organize data from the tests
- Analyze data and draw conclusions about whether the design met the outcome targets
- Explain the interrelationship between materials and structural engineering
- Describe the advantages and disadvantages of virtual design/testing and real-world design/testing

**Learning Process**

The Virtual Lab is designed to be open-ended in order to foster inquiry-based STEM learning. Students follow a scaffolded version of the engineering design process:

- Determine their own design plans based their interpretation of the design challenge.
- Identify the design needs and the criteria and constraints that affect their design.
- Develop a design plan and create a prototype using the tools provided in the Virtual Lab.
- Test their blade design, evaluate the data, and revise their designs.

Students are responsible for coming up with an efficient method for recording their process, decisions, and data.

There is no one right design, procedure, or answer. Given the number of variables available within the Design and Test Labs, students or groups of students should be encouraged to investigate different blade design needs with the idea that all students will come together as a class at the end to compare designs and discuss which designs offer the most advantages for a particular location use and energy output.
Virtual Lab: Wind Power

In the Classroom

As a Teacher Demonstration
You may choose to use the Virtual Lab as a tool to demonstrate basic principles of wind energy. For example, it is relatively simple to design three turbines with similar blade lengths, but which have different efficiency materials. Comparing these three designs will reveal that the materials affect the blade, which in turn affects how efficiently the turbine turns to generate power. This opens up class discussion about why the turbines aren’t built with longer or wider blades. What trade-offs do engineers face in selecting materials?

Getting Students Started using the Virtual Lab
Before allowing students to work on the virtual lab, you may wish to demonstrate the lab functionality to students. Taking them once through the design process will help to reduce the amount of “messing around” time they will need in order to figure out how the lab variables work.

Collaboration
The Virtual Lab can be used successfully by students working alone. However, collaboration in pairs or in small groups increases the likelihood of success and fosters 21st Century skills. When they collaborate, students can divide the work according to their skills and interests. One student may feel more comfortable interacting with the screen while another may want to record data. One student may want to lead the small-group discussion while another may want to present the group’s results to the class.

The social interaction involved in teamwork has its own value. If your students collaborate in the Virtual Lab, it is up to you to decide whether they should write their experiment plans and summaries separately or together.

Sharing Results
One goal of the Virtual Lab is for students and student groups to act as a community of researchers working toward the solution of a problem. For this reason, students are asked to share their design plans and summaries with their classmates. You may wish to direct this class discussion in one of these ways:

Discuss any differences in the students’ procedures. Ask them what kinds of thinking led to their different approaches.

All students started with the same challenge, but students will have identified different needs as they interpret that challenge and which advantages to address with their turbine design. Discuss differences in the product need and target users identified by students.

- List all of the criteria and constraints identified by student groups. Are there constraints common to everyone’s design?
- Ask your students to analyze the trade-offs involved in bringing the turbine to market. What are the trade-offs in producing the most efficient wind capturing design?
Virtual Lab: Wind Power

Allocating Class Time

This Virtual Lab can be completed by students in three or four class periods. Here is a suggested use of the time:

**Period 1:** Introduce the challenge problem. This is when you may choose to demonstrate the functionality of the Design and Test Labs or allow students very limited time in the Design and Materials Labs to just become familiar with the variable settings. Students may do research in class or as homework on some of the factors involved in the design.

**Period 2:** Students brainstorm. They identify the design criteria and constraints. Students then write a design plan. This plan will include which data students will need to compare from multiple tests.

**Period 3:** Students design wind turbine blades in the Design Lab and test them in the Materials Lab. The virtual lab does not save data from session to session, so it is important that students design and test all of their blade designs, and gather all data during the same class session. Remind them to print their work.

**Period 4:** Students share results and participate in class discussion.

Two class periods are allocated for the optional hands-on engineering activity.

<table>
<thead>
<tr>
<th>Time</th>
<th>Element</th>
<th>Set-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 minutes</td>
<td><strong>Introduction: Introduce the learning activity</strong></td>
<td>Computer lab – will need access to the virtual lab and external sites</td>
</tr>
<tr>
<td></td>
<td>• Introduce the lab, explaining the relevance of wind energy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Demonstrate how to navigate the lab tabs and save data</td>
<td></td>
</tr>
<tr>
<td>50 minutes</td>
<td><strong>Brainstorm: Identify design constraints</strong></td>
<td>(May want to combine with first session)</td>
</tr>
<tr>
<td></td>
<td>• Class discussion to explore cause-effect of design decisions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Students develop design plan</td>
<td></td>
</tr>
<tr>
<td>50 minutes</td>
<td><strong>Virtual lab: Students design the blades</strong></td>
<td>Computer lab – will need access to the virtual lab site at</td>
</tr>
<tr>
<td></td>
<td>• Assign locales or allow students to choose; the activity can be conducted independently or in groups (based on computer availability)</td>
<td>Student Activity Sheet (1-page PDF)</td>
</tr>
<tr>
<td></td>
<td>• Recommend conducting at least three tests</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Direct students to save/print/export the data</td>
<td></td>
</tr>
<tr>
<td>50 minutes</td>
<td><strong>Debrief Activity</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Students share their results</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Analyze whether results map to identified constraints</td>
<td></td>
</tr>
</tbody>
</table>
Virtual Lab: Wind Power

Virtual Labs Procedure

The virtual lab consists of six major sections:

Menu tabs

1. Introduction
2. Location
3. Design
4. 3M Materials
5. Review
6. Wind Energy

Introduction – a brief problem to setup the challenge for the students so the activity is both relevant and realistic

Introduction

You will be able to design, build and test a wind turbine, a device that converts kinetic energy from the wind into mechanical energy, suitable for different geographic locations. A generator connected to the turbine shaft immediately converts the mechanical energy into electrical energy. Your challenge is to create a turbine that will capture enough energy to supply 400 homes in a village to achieve the highest efficiency.

Lab Goals

The target is to generate enough energy to supply at least 400 homes with renewable wind energy per year with the highest efficiency and lowest cost. The turbine will be based on a lifespan of 20 years production. Click here to review elements of a wind turbine unit, blade, nacelle and tower.

Location

Three options are available: Hills, Plains, Off-shore. There is no one “right” answer for the lab. The idea is that the design of the blades will vary, based on the environment where it is deployed.

Students can reference information about building in each locale by resting the cursor over the red marker.
Virtual Lab: Wind Power

Design – students set variables for the design of the rotor blades attached to the drive train.

The goal of blade design: reduce the blade weight (so it moves faster), but with the most width and length to capture the wind and still be able to flex without breaking.

- Blades that are too short won’t move fast enough to generate power. Blades that are too long may capture more wind, but add weight to the rotor. The key is to balance the variables.
- Generally, the rotor blades are wider at the base and narrower at the tips, since the area swept by the inner portion of blades is relatively small. The taper adds strength to the blade base where stress is highest.
- The angle of the blade will impact efficiency – e.g., less of an angle improves high speed performance in locales with high wind patterns.

Students select variables for the rotor blades. At the end of the selections, students are given an option to revise or test the design against standard variables.

An animation shows how air moves around the student’s design. Students can alter their design, and then test again before saving.

The test is saved on a separate page (students can tab/page through the data to make comparisons and adjustments).

A “save point” allows the students to print the data, and then record their impressions. At this point, students can only change the design options.
Virtual Lab: Wind Power

Task: Design the blades for the maximum wind capture.

Note: A list of the definitions for the variables is included in the Appendix.

<table>
<thead>
<tr>
<th>Design Input variables</th>
<th>Design Output variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade length</td>
<td>• Watts produced</td>
</tr>
<tr>
<td>• Blade length</td>
<td>• Efficiency factor</td>
</tr>
<tr>
<td>• Blade pitch</td>
<td>• Cost</td>
</tr>
<tr>
<td>• Blade twist</td>
<td>• Homes powered</td>
</tr>
<tr>
<td>• Tip shape</td>
<td></td>
</tr>
<tr>
<td>• Airfoil shape</td>
<td></td>
</tr>
<tr>
<td>• Turbine height</td>
<td></td>
</tr>
</tbody>
</table>
Virtual Lab: Wind Power

Materials Performance Products – students select efficiency material combination for the blades.

The task is to select performance materials to add to the blade design. Three blades will be attached to a standard drive train (horizontal axis).

Surface treatments will reduce friction and prevent erosion on the blade edge. These choices may add lifespan (and reduce maintenance), but add to the cost.

To learn more about commercial material options, see the 3M website at http://solutions.3m.com/wps/portal/3M/en_US/Wind/Energy/

- At the end of the selections, students given an option to revise their design.
- The student can perform tests; data for each test is saved on a separate page (students can tab/page through the data to make comparisons and adjustments). An animation shows the result.
- A “save point” allows the students to print the data, and then record their impressions. At this point, students can change the design options.
Virtual Lab: Wind Power

Task: Select 3M Materials to increase efficiency.

<table>
<thead>
<tr>
<th>3M Option</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M Matrix Resin</td>
<td>3M Matrix Resins are designed to increase the strength, toughness, and durability of composites while reducing weight.</td>
</tr>
<tr>
<td>3M Riblets Film</td>
<td>Provides improvement in drag reduction in a passive manner for any high speed vessels, without adding significant weight or complexity.</td>
</tr>
<tr>
<td>3M Filler</td>
<td>Polyurethane filler used to finish, smooth and repair wind blade surfaces.</td>
</tr>
<tr>
<td>3M Wind Protection Tape</td>
<td>These tapes significantly reduce and even eliminate leading edge erosion in wind turbine blades.</td>
</tr>
<tr>
<td>3M WindBlade Bonding Adhesive</td>
<td>An epoxy paste adhesive for bonding composite wind turbine blades. This high performance, toughened adhesive combines outstanding shear and peel strength along with excellent durability.</td>
</tr>
</tbody>
</table>
Virtual Lab: Wind Power

Review—summarizes the test data, and allows the student to save and export it for further analysis.

Students can review the number of homes supplied energy based on the output of each test.

Students have the option to start a new design or print this page. The data can be exported as a text file (for manipulation in a spreadsheet or other program).

<table>
<thead>
<tr>
<th>Location</th>
<th>Blade Length</th>
<th>Blade Pitch</th>
<th>Blade Twist</th>
<th>Tip Shape</th>
<th>Airfoil Shape</th>
<th>Turbine Weight</th>
<th>3M Materials</th>
<th>Watts Produced</th>
<th>Swept Area</th>
<th>Air Density</th>
<th>Air Velocity</th>
<th>Eff. Factor</th>
<th>Unit Cost</th>
<th>Homes Powered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>37 m</td>
<td>5”</td>
<td>Yes</td>
<td>Wide</td>
<td>Thin</td>
<td>80 m</td>
<td>Resin: No</td>
<td>238276</td>
<td>4301</td>
<td>1.2</td>
<td>8.5</td>
<td>0.33</td>
<td>0.21</td>
<td>156</td>
</tr>
</tbody>
</table>

![Virtual Lab: Wind Power Image](image-url)
Virtual Lab: Wind Power

Wind Energy - this section provides additional information related to wind power

Why pursue alternative sources of energy?

Alternative energy sources, also called renewable resources, deliver power with minimal impact on the environment. These sources are typically more green/clean than traditional methods such as oil or coal. In addition, alternative resources are inexhaustible. These benefits, as well as data that suggest the drop-off of conventional oil drilling will overtake the output of new drilling by 2014, make renewable energy a viable source to pursue.

The United States is second in the world to China in total renewable energy consumption for electricity production. By 2035, renewable-generated electricity will account for 17% of electricity generated in the U.S. (Source: U.S. Energy Information Administration)

Sustainability at 3M grew from a commitment to both innovation and ethical conduct. By continually increasing sustainability at the economic, social, and environmental levels, 3M believes we are building a strong, vital company today, and leaving a rich legacy on which future generations can build.

Solar energy

Solar power generation offers the advantage of synchronized peak output with peak demand. Another advantage is in geography: locations for solar plants are flexible, even remote (like the Mojave Desert). Solar panels can be scaled in a modular layout, so building the power plants is cost-effective.
Virtual Lab: Wind Power

Wind Energy Resources

How wind energy works
US Department of Energy resources:
- General information about wind energy is available at http://www.eere.energy.gov/topics/wind.html.
- A YouTube video on wind energy basics (2:16) is available at http://youtu.be/tsZITSeQFR0.

US Energy Information Administration: Energy Kids
- Teacher Guide, with resources and lesson plans at http://www.eia.gov/kids/energy.cfm?page=6

Discussion Questions
- In two sentences, can you explain how wind energy works?
- What are the advantages of wind power as an energy source?

Locations for wind turbines
Considerations for placement include: amount of consistent wind, distance of the transmission line to the grid, proximity to nearest city, environmental considerations, and so on.
- For more information about selecting different locales, see the US Department of Entergy site at http://www.windpoweringamerica.gov/wind_installed_capacity.asp. This annotated map details current installed wind projects and the capacity produced by state.

Discussion Questions
- How do wind turbines affect the community (aesthetics, noise and environmental considerations)?
- How have other communities addressed these issues?

Elements of a wind turbine
Review 3M products at www.3m.com/wind.

Discussion Questions
- What would you do to improve wind plant power production?
- How does blade design affect other variables, e.g., height of the tower and proximity to the next unit?
- How does ongoing research into blade materials and protectants fit into the iterative design process?

Factors affecting investment
There are federal, state and local incentives available for companies/municipalities to invest in alternative energy sources, making the entry into the market attractive. However, a company’s return on investment is a consideration – and one of the major obstacles to this energy source. Break-even is typically 6 to 8 years.
Other factors affecting the cost of wind farming include maintenance of the turbines (materials and labor). Typically the blades need to last 20 years. To repair or replace a blade is a huge cost in terms of the material and time needed to take the unit out of service.

Discussion Questions
- What capital costs can be managed in the design and manufacturing process?
- How can engineering design contribute to the reliability of wind plants? Lower operation and management costs?
- What research needs to be done for wind energy to be a viable, large-scale source of energy?
Virtual Lab: Wind Power

Engineering Design Process

Nearly all products that come to market have gone through an engineering design process. Some products, such as cars or washing machines or even ballpoint pens, have gone through this process.

In the Wind Energy Virtual Lab, students are asked to follow a variation on the engineering design process. The following are some general thoughts on the critical parts of the engineering design process:

Identify the need

The first thing students need to do is reword the challenge given in the Virtual Lab so that it expresses what it is specifically that the target user of the product needs. They should express the challenge as a statement that follows the general format: “I am designing a (product) for (target user) so that they may (a useful function that satisfies the target user’s need).”

For the Wind Energy Virtual Lab, one design need might be: “I am designing a wind turbine that will supply energy to 400 homes efficiently and cost-effectively.”

There are many good design need statements that students might pose in this lab. The best results are achieved when individuals or groups each investigates a different need or evaluates the same need using different design plans. This strategy makes good use of scarce resources and promotes collaboration. Toward the end of the lab time, as part of the sharing process, the students can put together the evidence from their separate designs and tests and arrive at a common solution to the larger question.

Do research and brainstorm ideas

Encourage students to do research before they begin writing their design plan. Students should focus their research and brainstorming on what makes a “best” blade design to produce the required energy. Students may choose to brainstorm before they do their research, after they do research, or even do some research before and after brainstorming. Available time is a limiting factor and you should remind them of the schedule for the activity.

There are three other resources that are important in doing this lab:

Identify design criteria and constraints

In order to write a design plan, students must next take their identified design need and identify the design criteria and constraints for that need. This is a bridge between the virtual simulation and the real-world. The intent of the virtual lab is to address key elements in building a wind turbine; it cannot address all of the variables in design and structural analysis.

Criteria are those things against which the student can measure the success or failure of meeting the challenge.

- For example, if a turbine is designed to efficiently capture the most wind, is it expensive to manufacture (i.e., material cost)?

Students must also determine what constraints exist on their design.

- The most obvious constraint on the design is the limited number of design choices available within the virtual lab. The student cannot select an option for a variable if it is not available within the lab. In the real world, available technology, resource availability, time, and cost are design constraints.

The design inputs for the virtual lab are captured on the Student Activity Sheet (see the Appendix at the end of this document).

Develop a design plan

It is suggested that you have students write down their design plan either using a text processor or pencil and paper. The design plan should also include a statement of the design need, a list of identified design criteria and constraints, a description of their preliminary design including choices for variables within the Design Lab, and a description of their testing plan including choices for variables within the Test Lab.
Virtual Lab: Wind Power

You may want to read and approve students’ design plans before letting them enter the Design Lab. Challenge students to tell you why their proposed blade design “best” meets the need of the target user. Ask how they will know if their blade design does not “best” meet the needs of the selected location.

Students may also not understand how different variables are linked and affect each other. One of the strengths of the Virtual Lab is that it makes these misunderstandings explicit and forces students to struggle with them. For instance, choosing a larger length for the turbine may increase the wind capture, but it also increases the weight and production cost. The goal is to design a light blade design that will last.

Implement the design plan and test the design

Students next enter the Design Lab and, following their design plan, construct their first wind turbine blades. Students may revise their initial design before taking it to the Materials Lab; however, students should know that there will not be any data saved for any design that does not get tested in the Materials Lab.

Once students are satisfied with their design, they should move to the Materials Lab and carry out their testing plan.

Evaluate test results, revise design and retest

Unlike the commonly accepted scientific method, the engineering design process is iterative. Within the constraints of time and budget, design prototypes can be built, tested, and then modified to create better designs. Students may modify a design before taking it to the Materials Lab. They can test the same design or return to the Design Lab to modify their original design and then test the revisions.

At each stage, it is important for the students to understand and document their decisions and explain what data (e.g., data outputs, test results) led them to make changes. Students should be able to answer the question, “In what way did this change better meet the design criteria?”

As with science investigations, students will be tempted to change more than one variable at a time. You may wish to caution against this, or let them discover on their own how that confounds their results. It is possible for students to print the results or to save them as a spreadsheet file and manipulate or graph the data.

Communicate process, results, and recommendations

Finally, students should be prepared to share their work with you and with their classmates. Students should be prepared to present their written summary, which includes the design need, their design criteria and constraints, a description of their design process, a summary of data including how it may have caused them to revise their designs, and their conclusions/recommendations.
Virtual Lab: Wind Power

About Lab Results
The Wind Energy Virtual Lab is a simulation. The calculations performed behind the scenes are based on real numbers from wind turbines currently in commercial production, but are not meant to suggest that they are real numbers. That is, the Virtual Lab may say that the wind turbine designed by the student weighs 2250 pounds. In reality, that only approximates the weight that general description or with the characteristics matching what the student has selected. What’s more important is that the relative numbers are accurate.

Here are a few examples of results your students should find:

- The same blade design will perform differently based on the selected performance materials.
- Longer/wider blades will capture more wind, but will weigh more. Heavier blades will produce less energy output.
- Lighter materials will cost more to manufacture, but typically last longer.
- Surface protectants will extend the life of the blades, reducing maintenance costs, but have an upfront cost.

Inquiry in the Virtual Lab
Most of students’ work in the Virtual Lab is done on a computer. Students are given a problem situation (e.g., design an efficient wind turbine to supply 400 homes with power), some information, and a virtual laboratory with some resources with which they can test their ideas.

What happens next is up to them.

They must identify the design need, evaluate design criteria and constraints, develop a design plan, build and test their design, analyze how their initial design meets their stated goals, and then revise and retest their design if necessary. The amount of guidance you provide will depend on how much experience your students have in designing good investigations.

Remember that this Virtual Lab is an inquiry-based activity. It is as much concerned with curiosity and investigation as it is with specific engineering, mathematics, or science content.

How will you know inquiry when you see it? Look for the following:

- Students plan and carry out their own investigations.
- Students behave as engineers, scientists, and mathematicians.
- Students work cooperatively with their peers and collaborate with other student researchers to find solutions to problems.
- Students take opportunities to try out their own ideas, to question or verify findings, and to revise and retest less-than-successful designs.
- Students are interested in unexpected results and regard “failure” in the lab as an invitation to rethink assumptions and try again.
- Students exhibit curiosity, skepticism, open-mindedness, and “what-if” thinking.
- Students listen actively and communicate their ideas using a variety of methods.
Virtual Lab: Wind Power

Hands-on Engineering Activity (Optional)

A hands-on engineering activity challenges students to use what they learned from the virtual engineering lab to design, construct and test a model turbine using a fan as the wind source. Students use readily available materials, such as Popsicle sticks, or may choose to shape wood pieces or other materials themselves to test the blade design (lengths, widths, angles). The hands-on test can include using a small model motor fixed to the turbine assembly and a multimeter (or some other method of measuring the energy output).

Objective: Design and build a wind turbine that uses wind power to generate an output of at least

- Simulate the wind with a box fan, and position the “wind” near your turbine
- The wind should produce enough power to run the small engine
- Measure the current and voltage produced

<table>
<thead>
<tr>
<th>Time</th>
<th>Element</th>
<th>Set-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 minutes</td>
<td><strong>Hands-on engineering activity: Students design a turbine</strong></td>
<td>Need a box fan, stopwatch or clock with second hand</td>
</tr>
<tr>
<td></td>
<td>- Give instructions, explain materials, and guide students in their design (create turbines outside class)</td>
<td></td>
</tr>
<tr>
<td>50 minutes</td>
<td><strong>Hands-on engineering activity: Students build a turbine</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Perform tests in classroom</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

Your role as the teacher in an inquiry classroom is not to impart factual information or even to tell students what to do. Your role is to promote inquiry and manage the learning environment. When your students are doing a Virtual Lab, you serve as a facilitator. You offer support and head off the occasional wild notion, but you mostly observe. When your students collaborate and share their results, you encourage engagement and point out that they are building their own knowledge. Again, your role is facilitation. Your students’ goal is discovery. This is a very empowering kind of teaching. It may be as much a challenge for you as for your students. But, like all discovery, it is also very exciting, and it will lead you and your students in many new and productive directions.

A special thanks to Santhosh Krishna Chandrabalan and Glenn Carter from 3M for their guidance and support on this project.
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Meeting the Standards

Grades 9-12 National Standards and Benchmarks for Technology Education

Benchmark 2.X Systems, which are building blocks of technology, are embedded within larger technological, social, and environmental systems.

Benchmark 2.Z Selection of resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

Benchmark 3.H Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields.

Benchmark 8.H The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications refining the design, creating or making it, and communicating processes and results.

Benchmark 8.J The design needs to be continually checked and critiqued, and the ideas of the design must be redefined and improved.

Benchmark 9.J Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

Benchmark 9.K A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

Benchmark 11.R Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

National Science Education Standards

(1996 – used as model for current state standards)

Physical Science: Transfer of Energy

Grades 5-8: Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei and the nature of a chemical. Energy is transferred in many ways.

Grades 9-12: All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
## Appendix

### Virtual Lab Inputs

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Why it matters:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blade length</strong></td>
<td>The measure of the blade from end-to-end. Choices are in meters: 37, 40, and 45.</td>
<td>Blades that are too short won’t move fast enough to generate power. Blades that are too long may capture more wind, but add weight to the rotor. Longer blades also cost more to produce.</td>
</tr>
<tr>
<td><strong>Blade pitch</strong></td>
<td>The angle of the blades on the rotor. Wind turbines use blade pitch to adjust the rotation speed. Choices are 5, 10, and variable.</td>
<td>The angle of the blade will impact efficiency – e.g., less of an angle improves high speed performance in locations with high wind patterns. A variable pitch increases efficiency (and cost).</td>
</tr>
<tr>
<td><strong>Blade twist</strong></td>
<td>A blade twist built into the blade to equalize the lift. The pitch angle is greater at the hub than at the tip. Choices are yes or no.</td>
<td>During rotation of the turbine, the blade tips move at a faster pace than those near the hub. Blade twist provides symmetrical rotation speed and lift. Adding a blade twist increases cost and efficiency.</td>
</tr>
<tr>
<td><strong>Tip shape</strong></td>
<td>The taper of the blade tip. Choices are wide and thin.</td>
<td>Generally, the rotor blades are wider at the base and narrower at the tips, since the area swept by the inner portion of blades is relatively small. The taper adds strength to the blade base where stress is highest. A wider tip increases cost, while a thinner tip increases efficiency.</td>
</tr>
<tr>
<td><strong>Airfoil shape</strong></td>
<td>The curved shape of the blade. Choices are thin, thick, or super thick.</td>
<td>The airfoil affects aerodynamics. Thicker blades result in lower efficiency as well as higher production costs.</td>
</tr>
<tr>
<td><strong>Turbine height</strong></td>
<td>The height of the turbine when installed at the top of the tower. Choices are in meters: 80, 100, and 120.</td>
<td>Wind velocities increase at higher altitudes. The higher the turbine height, the lower the air density and higher velocity. However, the increased height also increases costs.</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Location of the wind plant. Choices are offshore, plains and hills.</td>
<td>An off-shore location will have a higher efficiency factor, as well as a higher production cost.</td>
</tr>
<tr>
<td><strong>3M Options</strong></td>
<td>Performance materials added to the blades in order to increase lifespan and efficiency.</td>
<td>3M performance materials can increase efficiency, but may add to the cost.</td>
</tr>
</tbody>
</table>
Virtual Lab: Wind Power

Best and Worst Configurations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade length</td>
<td>45</td>
<td>37</td>
</tr>
<tr>
<td>Blade pitch</td>
<td>Variable</td>
<td>10</td>
</tr>
<tr>
<td>Blade twist</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Tip shape</td>
<td>2 Thin</td>
<td>1 Wide</td>
</tr>
<tr>
<td>Airfoil shape</td>
<td>Thin</td>
<td>Super Thick</td>
</tr>
<tr>
<td>Turbine height</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Efficiency factor</td>
<td>44%</td>
<td>21%</td>
</tr>
</tbody>
</table>

The middle point is 32% or 33% to be called efficient.

Virtual Lab Outputs

<table>
<thead>
<tr>
<th>Watts produced</th>
<th>Calculation based on swipe area, air density, velocity of air, and efficiency factor.</th>
</tr>
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<tbody>
<tr>
<td>Swipe area</td>
<td>The area swept by the rotor. Calculation is based on the radius of the turbine and blade length.</td>
</tr>
<tr>
<td>Air density</td>
<td>Wind power density is the annual power available per square meter of swept area of a turbine, and is tabulated for different heights above ground. It is based on wind velocity and mass.</td>
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<tr>
<td>Air velocity</td>
<td>Speed of the wind. Calculation: V (m/s)</td>
</tr>
<tr>
<td>Efficiency factor</td>
<td>Efficiency is the ratio of the useful output to the effort input – in this case, the input and the output are energy.</td>
</tr>
<tr>
<td>Watt/unit cost</td>
<td>The cost to produce each watt (Power/unit cost)</td>
</tr>
<tr>
<td>Homes powered</td>
<td>Based on all calculations, the number of homes powered for a year. Challenge is to supply 400 homes with enough power for one year.</td>
</tr>
</tbody>
</table>
Student Activity Sheet

Wind Energy

According to the U.S. Department of Energy, wind has been the fastest growing source of electricity generation in the world through the 1990s.

With large untapped wind energy resources throughout the country and declining wind energy costs, the United States is now moving forward into the 21st century with an aggressive initiative to accelerate the progress of wind technology.

Alternative energy sources like wind energy deliver power with minimal impact on the environment. These sources are typically more green/clean than traditional methods such as oil or coal. In addition, alternative resources are inexhaustible.

Your Task

The engineering challenge is to design a wind turbine that can generate energy to supply 400 homes for a year. Besides the number of watts produced, consider the efficiency factor and production cost.

Design Choices

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<tr>
<th>Blade Design</th>
<th>Definition</th>
<th>Choices</th>
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3M Materials

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<tr>
<td>3M Matrix Resin</td>
<td>3M Matrix Resins are designed to increase the strength, toughness, and durability of composites while reducing weight.</td>
</tr>
<tr>
<td>3M Riblets Film</td>
<td>Provides improvement in drag reduction in a passive manner for any high speed vessels, without adding significant weight or complexity.</td>
</tr>
<tr>
<td>3M Filler</td>
<td>Polyurethane filler used to finish, smooth and repair wind blade surfaces.</td>
</tr>
<tr>
<td>3M Wind Protection Tape</td>
<td>These tapes significantly reduce and even eliminate leading edge erosion in wind turbine blades.</td>
</tr>
<tr>
<td>3M WindBlade Bonding Adhesive</td>
<td>An epoxy paste adhesive for bonding composite wind turbine blades. This high performance, toughened adhesive combines outstanding shear and peel strength along with excellent durability.</td>
</tr>
</tbody>
</table>