PowerUp Lesson 3: Wind Turbine Design and Build Challenge

PowerUp Lesson Plan Overview

This lesson is one of six lessons developed as a classroom companion to PowerUp, a free, online, educational video game that allows students to experience the excitement and the diversity of modern engineering.

The lessons are designed to be flexible and scalable to meet your students' needs. Facilitation tips, extension activities and resources for learning more can be found in the Teachers' Guide, which is available for download along with each of the lessons. For these resources, as well as to download and play PowerUp for free, go to http://powerupthegame.org.

PowerUp was created by IBM and TryScience/The New York Hall of Science with scientific content and expertise provided by the Tech Museum of Innovation, the Bakken Museum, Idaho National Laboratory and the National Renewable Energy Laboratory.

Student Objectives

Using the Tech Museum of Innovation Design Challenge Learning pedagogy as a framework, students are introduced to the interconnected phases of the design cycle: Investigate, Create, Reflect.

Students read a newspaper article that recounts both sides of a debate over whether or not to build large-scale wind farms in Massachusetts. Students discuss the arguments for and against the projects and consider whether or not they would support building a large-scale wind farm in their own local community.

Students are given a design challenge: Work in groups to design and build a prototype wind turbine for a wind farm in Nantucket Bay. They will be designing and prototyping a simplified turbine (no gears, coils or magnets to turn kinetic energy into electricity). The prototype must be efficient – the apparatus must be able to lift a 5 gm weight a height of 1 meter in less than one minute – and the design must take into account one or more of the concerns of the opponents to the wind farm project (i.e. aesthetics, noise, bird migration, marine navigation, etc.)

Students are provided with printed background information including pictures of a number of wind turbines of various designs and scales, a few schematics illustrating how the parts of a wind turbine work together, and worksheets with hints to help the team work together throughout the design process

Students work with paper, pens and pencils and a collection of low-cost, recycled materials to conceptualize, construct and test their turbines. Student document their process by taking notes and drawing sketches and collecting them in a design portfolio.

Teams present their final designs (2D and 3D) to the other groups and reflect on their design process.

Optional Extension 1: Students use a stopwatch to measure the average time their turbine takes to move a 5 g mass one meter. Students calculate the velocity of the mass, and its kinetic energy in Joules. Students predict how they might change their prototype to increase KE, implement change and test new design, record new data.

Optional Extension 2: Team writes a letter to the editor of the local paper extolling the virtues of their superior design. Letter explains the benefits of wind energy, in general, and describes the elements of this new design that make the turbine efficient and responsive to the concerns of the community.

Team develops a logo for their Engineering Company and develops a strategy for communicating with and persuading voters to vote to either to support or block the building of a wind farm in Nantucket Bay (for example – storyboard a television ad, design a bumper sticker.

Class Time

Period 1

- Introduction to the Design Cycle (10 minutes)
- Case Study: Cape Wind Controversy (10 minutes)
- Begin Design & Build Challenge (20 minutes)
- Working in teams: Brainstorm, research, plan and sketch wind turbine designs

Period 2

- Working in teams, Continue Design & Build Challenge (40 minutes)
- Collect Materials
- Build, test, improve, retest, research, build something new, retest, etc
- Document process with notes and sketches
- Clean up

Period 3

- Finish Design & Build Challenge (15 minutes)
- Complete design portfolio and plan presentation (10 minutes)
- Clean up
- Present 2D and 3D designs. (15 minutes)

Materials

- Research materials for learning more about wind turbines and Nantucket Bay: (Some material for research is included in this teacher guide, you may want to supplement it with a collection of your own books, magazines, maps, computers with CD ROMS or internet connection.)
- Student brainstorming guides (included in this teacher guide)
- Binder clips or pocket folders to keep students and groups design portfolios together

Per group of students:

- 1 meter stick
- 2 meters sewing thread
- 8 paper clips (approx 5 gm)
- 1 pair of scissors
- 1 paper ½ gallon or quart carton
- 2 rubber bands
- 1 push pin
- masking tape
- 2 round drinking straws
- construction paper
- 1 aluminum pie plate
- 1 stopwatch (or timer)
- 1 cup of rocks, gravel, marbles, rice
- 2 smooth, round pencils, painted, w erasers
- 1 manila folder or paper cover stock (stiffer magazine covers will do, or greeting cards)
- scrap paper
- small (grape sized) ball of clay/putty
- (more decorative elements as desired

- Plus for all groups to share: 1 or 2 fans, preferably with variable wind speed.

Preparation

- Review Tips for Project Based Learning Section
- Decide how you will adapt lessons to fit your students' learning needs.
- Plan your assessment strategy – adapt rubric as needed
- (See Rubric in Tips for Project Based Learning Section)
- Gather research materials on wind turbines and Nantucket Bay.
- Gather materials for building prototypes.
- Make copies of Student Pages (including Newspaper Article about Cape Wind Controversy, Background Information about Wind Turbines, Pictures of Different Turbine Designs, and Brainstorming Guide)

National Science Standards 9-12

NS.9-12.1 Science as Inquiry
As a result of activities in grades 9-12, all students should develop understanding of:
- Abilities necessary to do scientific inquiry
- Understandings about scientific Inquiry

NS.9-12.2 Physical Science
As a result of activities in grades 9-12, all students should develop understanding of:
- Motions and Forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

NS.9-12.4 Earth and Space Science
As a result of activities in grades 9-12, all students should develop understanding of:
- Energy in the earth system

NS.9-12.5 Science and Technology
As a result of activities in grades 9-12, all students should develop understanding of:
- Abilities of technological design
- Understandings about Science and technology

NS.9-12.6 Personal and Social Perspectives
As a result of activities in grades 9-12, all students should develop understanding of:
- Natural Resources
- Environmental quality
- Natural and human-induces hazards
- Science and technology in local, national and global challenges

NS.9-12.7 History and Nature of Science
As a result of activities in grades 9-12, all students should develop understanding of:
- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

Classroom—Game Connections

When your students log in to PowerUp and enter the **Wind Mission** they will have many opportunities to apply and investigate concepts addressed in this lesson. You may chose to have your students play PowerUp before the lesson, as a primer on wind turbine components and a review of energy concepts or you may assign gameplay for homework after this lesson to reinforce lesson concepts in a highly motivating context.

Careful experimentation leads to optimal design
As students build virtual wind turbines in the game environment they will receive tailored feedback from a wind energy expert about the efficiency of their design and how much electricity each turbine is generating. If a turbine is not performing well the students must troubleshoot. They will learn through experience that success can be found when one variable at a time is isolated and tested.

Energy can not be created or destroyed, it can only be changed from one form to another
Students will learn that when all design factors are equal, a wind turbine's energy output is proportional to the average wind speed of its location. The turbine transforms the kinetic energy of the wind into electricity on a grid.

Lesson Facilitation

Period 1

Introduction to the Design Cycle (10 minutes)
Explain to your students that for the next few days they will be working in groups on a green energy design project. (You may wish to pre-assign groups or to let the students form their own groups, do what works best for your students.)

Explain that in order to maximize the creativity and the knowledge of every group member the groups will work through a cycles of investigate, create, and reflect. Engineers use these same cycles when solving problems and designing products. Explain that each cycle must be documented with sketches, diagrams, lists of ideas, and notes. These will be collected in a design portfolio. Each group will hand in a portfolio; each student is responsible for contributing to it.

Investigate:
The design process will begin with investigation, students will:
- identify the problem by reading a newspaper article
- brainstorm ideas and solutions (students will record ideas on handouts, provided)
- research the issues and possible solutions using materials provided and other book and online resources

The process starts with INVESTIGATE, and ends with REFLECT, but in the middle the process may go back and forth between the three cycles many times. Students may CREATE a prototype and ask for feedback from another student. As a group they may REFLECT and realize that they didn't take into account a certain constraint, and so the group may want to go back to INVESTIGATE and brainstorm some more ideas, and so on.

Create Re-create
- Select a solution from their brainstorming lists
- Design and construct a prototype
- Test
- Redesign or modify
- Retest

Reflect
- Share solutions
- Reflection and discussion

Case Study: Cape Wind Controversy (10 minutes)
Distribute articles on the Cape Wind controversy and have students read to themselves. When students are finished, discuss the main ideas as a class.

Begin Design & Build Challenge (20 minutes)
Distribute Brainstorming guides
(Optional - distribute a large binder clip for groups to clip all documentation together)

Working in teams, students:
- Brainstorm, research, plan and sketch wind turbine designs.
- Document design process with notes and sketches

Period 2

Discuss Design Journal (5 minutes)
- Remind the students that each group's design journal should include notes from brainstorming sessions, sketches including a final sketch of the solution to be prototyped – with scale indicated, notes on the building process, details of testing, analysis of the trial, problem solving ideas/steps, etc.

- Remind students that EACH student is responsible for contributing to the group's journal - there is no assigned "recorder." Discuss the value of recording all of your ideas – even the ones that don't pan out and the ones the group does not pursue.

Continue Design & Build Challenge (35 minutes)
Working in teams, students will:

- Collect materials
- Build, test, improve, retest, research, reflect, build something new, retest, etc
- Document design process with notes and sketches
- Clean up

Tips from the Tech Museum of Innovation for facilitating groups working on open-ended design projects are included in this Teacher's Guide.

Period 3

Finish Design & Build Challenge (10 minutes)

Complete design portfolio and plan presentation (10 minutes)

- Groups should be prepared to:
- Explain and demonstrate how the prototype works.
- Compare 3D prototype to 2D design for large-scale wind turbine in Nantucket Bay.
- Explain how the design will benefit the community and ecology of Nantucket Bay.
- Explain how the group used research to inform the design.
- Explain what they would do differently if they had more time to test and build.
- Describe the biggest challenge the group faced during their design process.

Groups present their 2D and 3D designs to class. (20 minutes)

- Groups demonstrate their invention and field questions.

Student Pages

Background Information

Wind Energy Basics

These wind turbines near Lamar, Colorado, are part of the 162-MW Colorado Green Wind Farm. Each turbine produces 1.5 megawatts of electricity.

We have been harnessing the wind's energy for hundreds of years. From old Holland to farms in the United States, windmills have been used for pumping water or grinding grain. Today, the windmill's modern equivalent—a wind turbine—can use the wind's energy to generate electricity.

Wind turbines, like windmills, are mounted on a tower to capture the most energy. At 100 feet (30 meters) or more aboveground, they can take advantage of the faster and less turbulent wind. Turbines catch the wind's energy with their propeller-like blades. Usually, two or three blades are mounted on a shaft to form a rotor.

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 as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are usually built close together to form a wind plant. Several electricity providers today use wind plants to supply power to their customers.

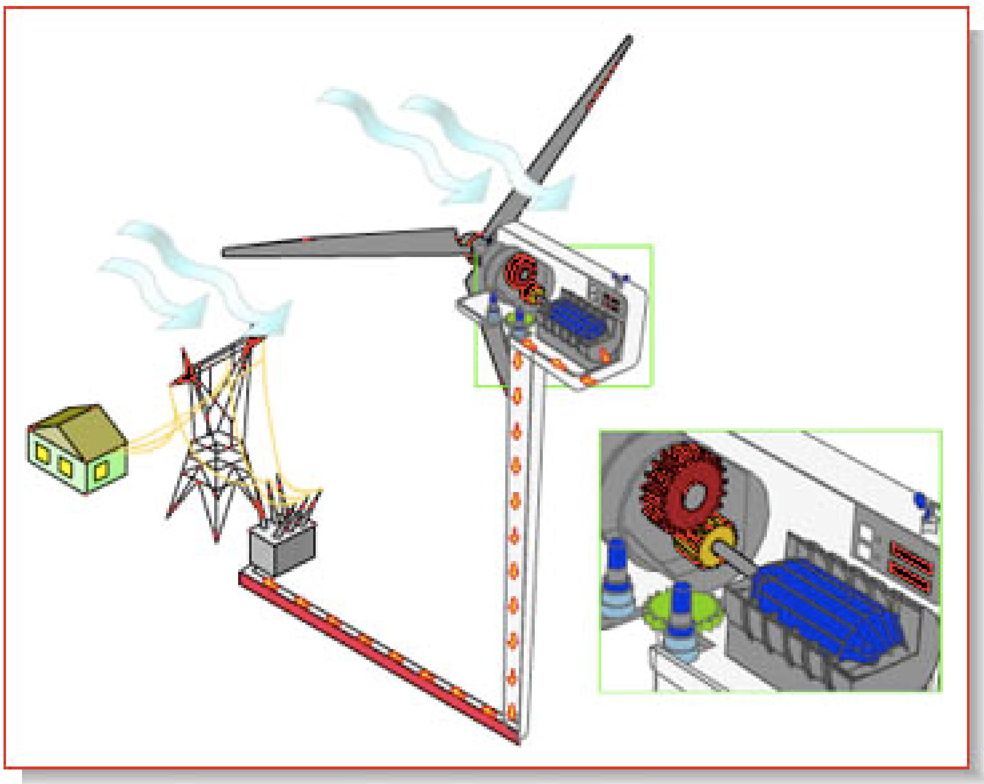
Stand-alone wind turbines are typically used for water pumping or communications. However, homeowners, farmers, and ranchers in windy areas can also use wind turbines as a way to cut their electric bills.

Small wind systems also have potential as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

From the National Renewable Energy Lab: www.nrel.gov/learning/re_wind.html

How Wind Turbines Work
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 terms wind energy or wind power, describe the process by 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.



So how do wind turbines make electricity? Simply stated, 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. The electricity is sent through transmission and distribution lines to homes, businesses, schools, and so on.

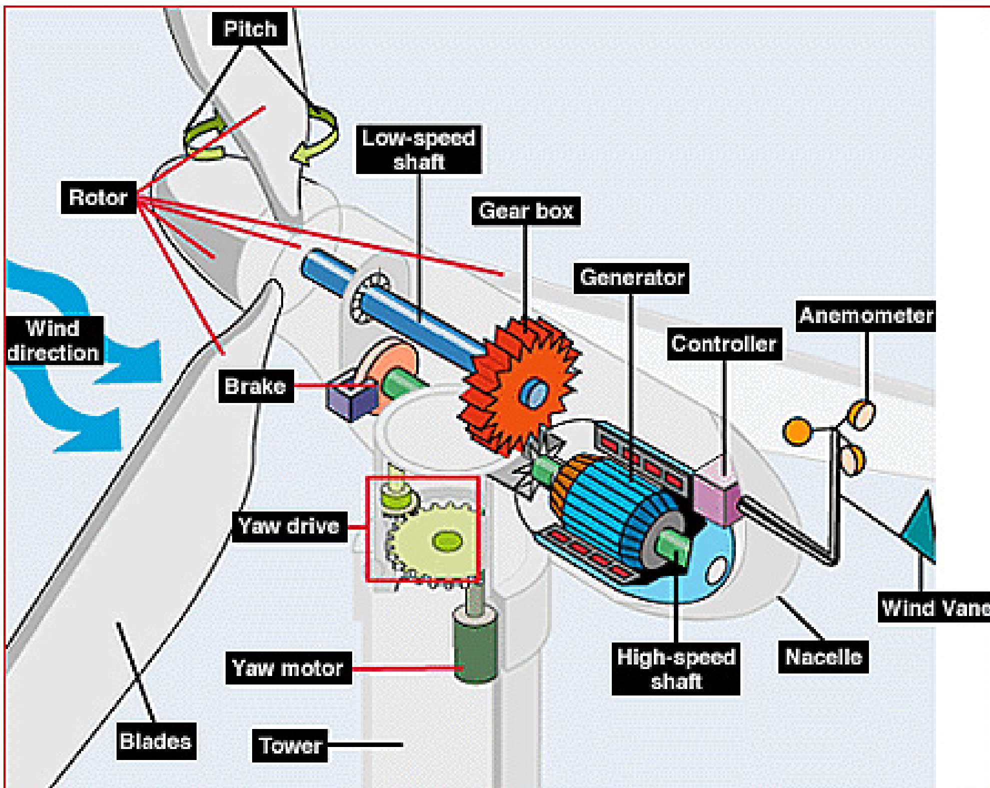
From the U.S. Department of Energy, Energy Efficiency and Renewable Energy website:
www1.eere.energy.gov/windandhydro/wind_how.html

Sizes of Wind Turbines

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts. Larger turbines are grouped together into wind farms, which provide bulk power to the electrical grid.

Single small turbines, below 100 kilowatts, are used for homes, telecommunications 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.

Inside the Wind Turbine



Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake: A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle: The nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.

Pitch: Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

From the U.S. Department of Energy, Energy Efficiency and Renewable Energy website: www1.eere.energy.gov/windandhydro/wind_how.html

Wind turbines come in many shapes and sizes: (images from: http://commons.wikimedia.org/wiki/)

1. This windmill on the Isle of Wight, UK dates back to 1700

Photo: Danny Hope

2. Modern 3-blade Wind turbines in Albuquerque, New Mexico

Photo: Sandia National Laboratory

3. Windstar vertical-axis turbine in Palm Springs, California

Photo: Kevin Wolf

4. 30 m vertical-axis Darrieus wind turbine in the Magdalen Islands

5. Small-scale wind turbines power this floating Science Barge classroom in Brooklyn, NY

Photo: Anne Pope (for Sustainable Flatbush)

Wind Energy Controversy
Engineers have developed efficient systems to use wind to create electricity to power our towns and cities without generating greenhouse gases as byproducts. Why then are we still dependent on fossil fuels for energy?

Not everyone is in favor of wind farms in their “backyard.” Detractors claim that the wind turbines are visually unappealing, often blocking views of natural beauty, and that when operating they make an unpleasant sound. Furthermore, these opponents worry about the effect the farms will have on their property values. Some naturalists fear that wind farms will harm migrating birds and destroy ecosystems. Below is an article from the Associated Press that describes the debate for and against the building of wind farms that took place in Massachusetts in 2004. Similar arguments occur in regions and states across the country.

> **Several Massachusetts Communities Eye Wind Power**
> By Martin Finucane, Associated Press
> posted: 06 September 2004 9:00 AM, ET
> www.livescience.com/environment/wind_power_040906.html
>
> HULL, Mass. (AP) – Wind power projects are in various stages around the state, from the Atlantic coast in the east to the wooded slopes of the Berkshire Mountains in the west, gigantic towers whose hurtling blades are designed to create clean energy.
>
> The most prominent of the projects calls for 130 turbines in Nantucket Sound. It's the project that has grabbed headlines, stirring fierce debate about the aesthetics versus the need for clean energy, drawing in some prominent Cape Cod residents, including broadcaster Walter Cronkite and U.S. Sen. Edward M. Kennedy. (Cronkite started out opposed and now maintains a neutral position, while Kennedy has opposed it.)
>
> The proposal has become a major point of conflict on Cape Cod with opponents saying it would wreck a beautiful seascape, be harmful to bird life and undermine an important ecosystem.
>
> The wind turbines – each hundreds of feet high and located about five miles offshore – could generate 420 megawatts of energy at peak times. Supporters say it would supply nearly three-quarters of the electricity used on the cape and islands, without producing greenhouse gases.
>
> Other projects are also in the works around the state, including the 10 turbines planned on Brodie Mountain in the western Massachusetts towns of New Ashford and Hancock and a proposal to erect 20 turbines on mountains in the western Massachusetts towns of Florida and Monroe.
>
> In addition, more than 40 of the state's cities and towns have expressed an interest in wind power. And the Massachusetts Technology Collaborative, a quasi-public agency that promotes renewable energy, is actively working with 23 of them, including Orleans, Lynn, Kingston, Falmouth, Lenox, Dartmouth, said Warren Leon, director of the agency's clean energy program.

"I think most towns would like to do right for the environment. Most towns know the serious problems that are caused by our current dependence on fossil fuels," Leon said. "And on top of that, there's the potential for helping the town's bottom line."

The agency, which commissioned a study of wind speeds in places around the state, found that the most conducive areas are in the Berkshires, some central areas of the state, and, of course, the coast.

Over the past five years, wind power capacity in the United States has tripled nationally. As technology has improved, the price of generating power by wind has declined.

The country gets three-tenths of 1 percent of its electricity from wind. The American Wind Energy Association, a trade group, predicts no more than 6 percent by 2020, a far cry from the 50 percent of electricity currently produced by burning coal.

Wherever they go, wind power proposals have to overcome the qualms of residents over the turbines' appearance, the sound they make, their effect on the environment, and the possible effect on their property values.

In Hull, where the rotor hub is 164 feet off the ground and the rotors themselves reach another 77 feet into the sky, the gigantic steel tower, which stands next to the high school and its football field, was spinning busily on a recent bright summer day with an eerie, but not unpleasant, supersonic whistle.

At a nearby clam shack, an older woman said she wouldn't mind having one in her backyard, while two young girls joked that their father, a wind power believer, made them periodically "worship" the turbine.

The town's municipal light board is moving forward with plans for a second turbine at the town landfill and is now interested in building a wind farm offshore, said John MacLeod, operations manager for Hull Municipal Light.

"We think it's a good thing and people in town seem to want to continue pursuing it," he said.

Whitcomb, however, said it wasn't easy to live with the huge machine.

Even more than 1,000 feet away, Whitcomb said, she can hear it. The aircraft warning lights on top sometimes bother her at night and, at certain times of the year, the sun sets right behind the rotor, creating a colossal strobe effect.

"It's just one more time you want to look at the windmill and shoot it," she said. "Would you want to move into Windmill City?"

Photo: Jenna Sicuranza **http://flickr.com/photos/jennasic**

The bumper sticker above is part of a campaign to encourage citizens to vote "Yes" on a special referendum about whether or not to go forward with the Cape Wind project.

Your Design Challenge

Work with your group to design and build a prototype wind turbine for a wind farm in Nantucket Bay. You will be designing and building a simplified turbine that uses wind energy to do work, but there will be no gears, coils or magnets to transform kinetic energy into electricity. Your prototype must be efficient – the apparatus must be able to lift a 5g weight a height of 1 meter in less than 60 seconds and your design must take into account one or more of the concerns of the opponents to the wind farm project.

BRAINSTORMING TIPS

- No criticism allowed! All ideas are welcome. Do not judge ideas at this stage.
- Work for quantity: aim to record 50 different ideas
- Hitch hiking is welcome: try riffing on, modifying and expanding other's ideas.
- Silly and outrageous ideas are encouraged: often the zaniest ideas contain some hint that will inspire or help solve a problem.
- Use words, pictures, doodles, analogies and diagrams to describe your ideas.
- If you get stuck, start another list to come up with the WORST design ideas possible.

Optional Templates for Turbine Blade Design

Pinwheel Design

1. Cut the largest square you can out of cover stock or a manila folder.

2. Draw 2 diagonal lines from corner to corner, making an X that divides the square into 4 triangles, connected in the middle (see Figure A).

3. Measure 2 cm from the center on each diagonal line and draw a mark (see Figure B)

4. Draw a dot in the right hand corner of each of the 4 triangles as shown in Figure B.

5. Use scissors to cut along the lines from the corners of the square towards the center. Stop cutting at the 2cm marks. Do this 4 times, once for each corner of your square (see Figure C)

6. Fold each triangle so that the dotted corner meets the center point and hold all four corners together at this point (see Figure D)

7. Using a push pin, carefully pin all of the dotted corners together in the center to make a pinwheel. Push the pin through the layers of paper and then into the eraser end of your pencil. (see Figure E)