Berkeley Engineers and Mentors

Lesson Name: Wind Turbines
Lesson Type: Exploration/Project
Author: Michael Song (Michael.song@berkeley.edu)
Last Updated: 1/19/11

<u>Materials</u>
Cardboard, construction paper, aluminum foil
Masking tape, duct tape, glue, paper clips
Scissors
Small dowels or sticks, toothpicks
Cheap electrical generator (can build from magnets, copper wire and cardboard) or operate small motor in reverse
Voltammeter
Blow dryer or fan

<u>Agenda</u>
Suggested length: One week for lesson plus activity.

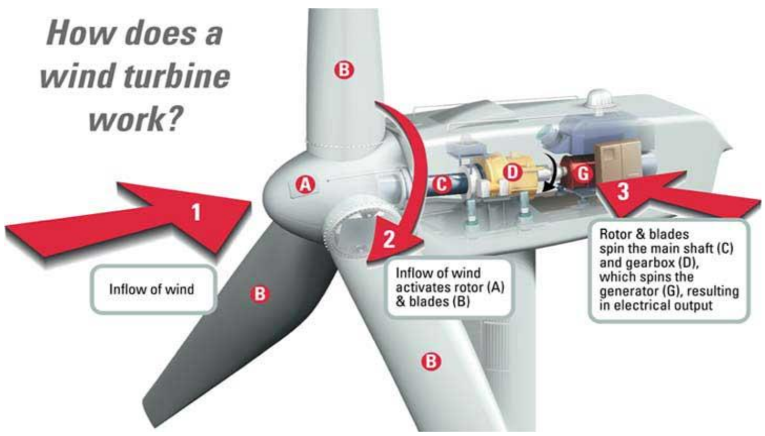
<u>Introduction</u>:
This lesson plan aims to instruct students about the uses and means of converting wind energy for practical human usage. First, we discuss the origins of wind power and how the wind is able to carry energy. Next, we discuss the design and workings of wind turbines and how exactly they convert energy between its different forms. Finally, we investigate the advantages, disadvantages and features of wind power as an alternative to other forms of power generation. Wind energy, like solar energy, tide energy, bio-fuels and geothermal energy, is a **renewable resource** in that it is replaced by natural processes. The activity for this lesson will be for the students to construct their own wind turbines based on a template, to power a crude electrical generator!

<u>Suggested Discussion Questions</u>
Note: These questions can be asked at any point during the lesson: before the lesson to motivate discussion of the topic, after the lesson to review what the students learned, or during the lesson to emphasize various points. It would be good to emphasize the "big picture" stuff for the students to think about.

1. Why do we need a wind turbine to use the energy from wind? What are some common forms of energy and what are their advantages/disadvantages? Can we use them directly?
2. Why is wind power considered an "alternative" energy source? What are some other sources of alternative energy?
3. What are some advantages of wind power? What are some issues?

4. Make your own hypothesis! What effect do you think changing a major design parameter will have on the power output of the turbine? (Maybe conduct small scale tests as an activity before moving on to the main activity.)
5. During the activity, what worked and didn't work for designing an efficient wind turbine?

Activity:
In the activity, students will essentially build their own wind turbines and vary parameters such as the angle, number, size and weight of the rotor blades, as well as the length of the turbine shaft to see which parameters are most important in affecting a turbine's efficiency and power generation. The rotor blades can be constructed from different materials such as cardboard, aluminum foil or construction paper, and can be angled relative to their point of attachment to the turbine shaft using toothpicks or small dowels as connectors.



Note: Normally, wind turbines are turned by wind flowing parallel the shaft axis (see picture). However, for our simplified activity we will have the wind blowing into the rotor blades perpendicular to the shaft axis, since we aren't so sophisticated… (see green arrows)

The turbine shaft is allowed to rotate freely when blown by wind so that it turns an electrical generator. We can use a fan or a blow dryer to simulate wind driving the students' wind turbines from different directions and angles.

For students to visualize the output of their design, an electrical generator can be used to power small light bulbs or the voltage output can be measured using a small voltammeter. Alternatively, the wind turbine can be used to pull up a small load such as a tennis ball or water container via coiling up a string. Emphasize that the best design should be able to generate energy efficiently under any set of wind conditions! Afterwards, the students can take their wind turbines outdoors to see if their creations can harness the energy of the wind in their own school environment!

Note: Additional testing will be required to evaluate the feasibility and fun factor of this activity. The generator can be constructed from cheap components such as a few magnets, thin copper wire and copious amounts of cardboard and tape.

placeholder for pictures of pilot turbine

Post-Discussion:

What worked or didn't work for building the wind turbines? Students can discuss alternative energy in general, what they learned from designing their wind turbines, issues with wind power, any ideas they might have for wind power, etc., up to the mentors.

Background for Mentees:

Today we are going to learn about energy! What are some ideas you have about energy? Why is energy so important and what are some common examples of energy? What are some examples of energy in this room right now?

It turns out that in nature, there are many things can carry energy in its different forms. Electricity is one very common form of energy that we always talk about, and it makes it very convenient for us to power our lights and appliances that we use every day! Another very common form of energy is kinetic energy. Has anyone heard this term being used before, kinetic energy? What exactly is kinetic energy?

Kinetic energy is the energy that moving things possess. The faster something moves, the more kinetic energy it has. You can imagine two balls rolling down a hill. The ball that rolls more quickly down the hill we intuitively see would have more energy than the other! This is kinetic energy!

Now when real scientists and engineers think about how energy is important to society, they have to think about how to create the energy that all of us use up from day to day. Think about how much energy we use every day! We drive cars, we heat or air-condition our houses, we use lights so we can see—humans use a staggeringly large amount of energy! Well, it turns out there is energy all around us! Remember what we said about kinetic energy being the energy of things that moved *fast*? What are some things in nature that can move very fast, and yet there is a very large amount of it?

If you guessed wind or water, you are right! This is what we are talking about when we talk about wind or water energy. There is so much water and air moving in the oceans and our atmosphere that there is a ton of energy for us to harvest for societal use! The trick is, how do we get that energy in a useful form? How does a raging wind on a stormy day help us power our computers and cars? This is where wind turbines come in! In our activity today we will learn about and discuss wind turbines, and then we will build our very own to power a small light bulb!

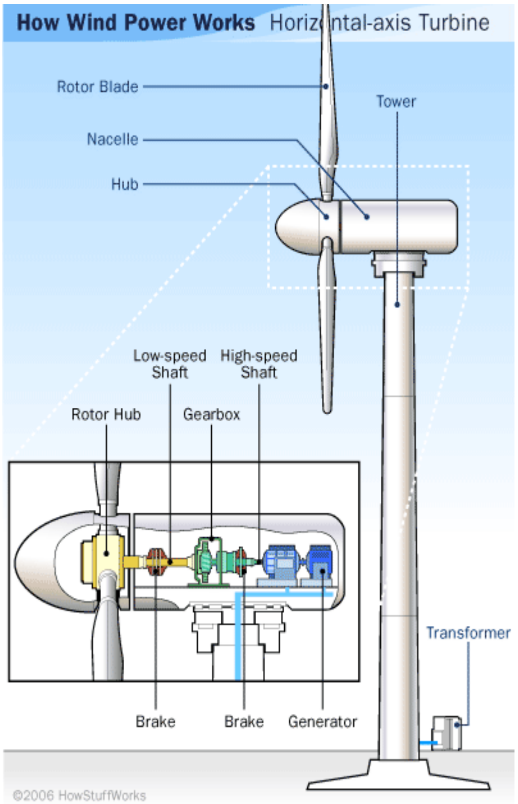
Background for Mentors[1]:

Wind turbines are devices that convert **kinetic energy** from the wind into **mechanical energy** that can be used to generate electricity, run machinery, or serve some other working purpose, e.g. pumping water. As wind is just the bulk flow of air molecules, it is these moving air molecules which carry the kinetic energy turbines arrest and harness for storage or use. It is exactly analogous to a water mill which derives its energy from a current of water—this is because air and water are both **fluids**, albeit one is gaseous and the other is in a liquid form.

placeholder

[1] *Note:* Most of this material is just background information and should not be vital for teaching the lesson. Basically, we just want to introduce wind power as a renewable, alternative source of energy and have our mentees see a wind turbine they built in action, generating electricity and powering a small light bulb.

How Wind Turbines Work:



Shown here is a basic schematic of a "horizontal axis" wind turbine. The three most important components are the **rotor blades**, the **turbine shaft**, and the **electrical generator**.

The rotor blades, which are connected to a common turbine shaft (horizontally-oriented in this case), are rotated as they are blown by the wind. This in turn spins the turbine shaft, and so the kinetic energy of the wind is converted into an energy of rotation.

Finally, the rotating shaft produces an electrical voltage via a generator attached to the shaft, courtesy of *electromagnetic induction*. This electricity is carried elsewhere by an electrical grid for storage or use. The important thing to note is that a generator requires **rotary motion of a shaft** to produce a voltage, and that a turbine shaft neatly produces this rotary motion.

Alternatively, the turbine can itself power machinery without requiring an electrical generator (think windmills which mill grain or pump water).

There are also "vertical axis" wind turbines. Real wind turbine design is driven using complex aerodynamic models and takes in a large number of variables such as the location and environment, local demand for electricity, and available wind resource at different heights.

In the activity, where the mentees will optimize the basic design of a wind turbine, they can adjust parameters such as the angle, number and size of the rotor blades, the weight of the rotor blades, as well as the length of the turbine shaft to see what sets of parameters might optimize power generation as measured by a voltammeter.

The “design equation” for a wind turbine is

*Power = density of air * rotor swept area * wind velocity*^3

where power is defined as energy per unit time (think running up the stairs quickly versus walking up the stairs, or pushing a book quickly versus steadily moving the book across the same distance).

Physics Background:
In the activity, the wind turbines can be connected to a circuit containing a *voltammeter* to measure the voltage produced by the rotating shaft and induction motor. A voltammeter is designed to measure either the voltage or current in an electrical circuit. The **voltage** is just a measure of the *energy carried by the electrons* in the circuit, while the **current** is a measure of *how many electrons are flowing* through the circuit[2]. The greater the voltage produced by the students’ wind turbines, the more energy they are producing at any given moment, but note that the voltage can fluctuate over time!

Another common measure in physics is *power*—how much energy is being produced in a given amount of time. The total power generated in a circuit element is simply given by the current multiplied by the voltage ($P = I*V$), and so if you are producing 10-watts of power for 5 seconds, you have in total produced 50-Joules of energy (a Joule is a watt-second). This is important because a wind turbine might be rated based on its power output or **capacity** (the largest capacity for a wind turbine is currently 7.58-megawatts or 7.58 $*10^6$-watts) or rated based on its total energy output per year (3066-megawatt-hours produced in a year).

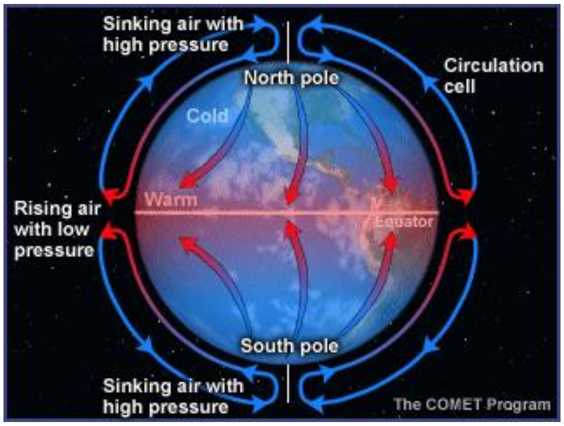
Note the differentiation between “kilowatts” (power) and “kilowatt-hours” (energy)—a power plant that has an average capacity of 1000-kilowatts will produce 1000*365*24 = 8760000-kilowatt-hours worth of energy per year.

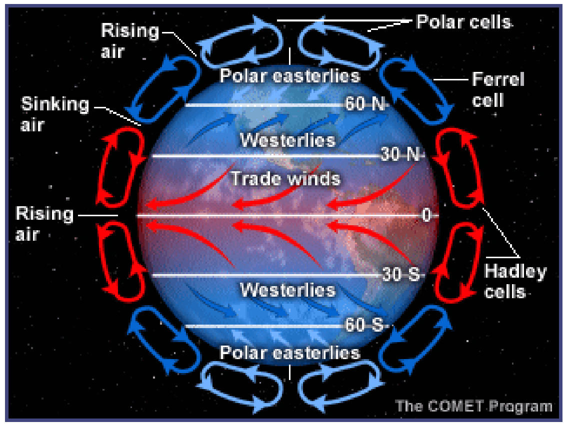
Issues with Wind Energy:
Energy production from wind has doubled in the past three years and approaches 350-terawatt-hours produced, or 2-% of worldwide energy consumption (tera = 10^{12}). An estimated 72-terawatts (TW) of wind power is available on Earth whereas the average global power consumption is only 15-TW. Currently, we have only tapped 0.16-TW worldwide, or a <u>fifth of a percent</u> of the estimated capacity! Now granted, only sixty percent of this estimated capacity is attainable under optimal conditions (see *Betz’s Law*), but it is a rapidly growing industry for harnessing this renewable wind energy for use!

Why is wind energy considered a **renewable resource**? Wind energy and air currents arise from uneven heating of the Earth by the sun, with the equator receiving much more solar energy than the poles, for

[2] They are related by a constant of proportionality called the *resistance* ($V = I*R$).

example. This differential heating results in a **global convection system** where air in our atmosphere starts circulating, creating movements of air at higher altitudes, ones that we can tap for energy! Therefore, natural radiative heating by our sun is the ultimate provider of wind power, and as with solar or geothermal power, we don't have to worry about consuming a limited resource.





The origin of air currents in the atmosphere—the uneven heating of the equator over the poles creates a global convection system and replenishes the energy carried by the wind.

Wind energy is also a clean form of energy as it does not generate **greenhouse gases** (gases such as water, methane and carbon dioxide which stay in the atmosphere and trap infrared light, otherwise known as heat, around the Earth) or emit toxic byproducts into our environment. As examples, compare clean energies such as solar and wind with burning fossil fuels and nuclear power.

Some issues with wind energy however are its high capital costs, its inherent **intermittency** and the importance of choosing an acceptable, out-of-the-way location for efficiently generating power. A major issue with utilizing wind power is that any power that is generated must be consumed by immediate electrical demand, otherwise it will go to waste or even destabilize the electrical grid, which has a characteristic capacity maximum. Because the electricity generated by wind power is so variable from hour to hour and from day to day (intermittency), accurate wind forecasting must be available to properly manage and distribute the power through the electrical grid. Imagine a super hot, dry day in Texas. The electricity generated by wind power would be minimal but the demand would skyrocket due to increased use of air conditioning. Solutions might be smarter electrical grids that can distribute power across large distances to areas of increased demand, or ways to store the energy for use when its demand has increased (e.g. pumped-storage hydroelectricity).

In summary, these are some of the reasons why wind energy has not become as popular or economically viable as it might have become, and students can have a lengthened discussion on other forms of alternative energy and whether or not these same issues might be applicable for other forms of energy production, etc.

References:

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