Lesson Plan – Cal Prep

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Teaching Plan:

As citizens of Berkeley, understanding how wind turbines work can help students think beyond just solar, electric and other forms of power generation. The turbine mentoring session should take up the whole period.

(6-8 Minutes)- Introductory PowerPoint "Student Engaged" Presentation on Wind Turbines

- Scientific, mathematical and crucial design features of a wind turbine etc.

(5-7 Minutes) We will divide into groups of three (depending how large the group is) so each student can engage in the activity as much as possible. We will have each student to conceptually think, draw and discuss their ideas about what can maximize the rotation of the turbine using the limited materials we have.

(Approx. 15 Minutes per Prototype) We would want the students to build at least 2 prototypes but overall understand the more complicated design features of a wind turbine.

(Last 10 minutes) Time to reflect, identify design failures or successes. Think about possible improvements that could have been implemented and final concluding thoughts.

Mentor Scientific Background

Functional Principle Wind turbines function to convert the kinetic energy of wind into mechanical and then electrical energy in the turbine. Wind turns the turbine blades, which turn a geared shaft that spins a generator, producing electricity.

Overall Design Turbines can either be oriented with a vertical axis of rotation or a horizontal axis of rotation, though effectively all commercially produced turbines now have a horizontal axis, as the design allows for better maximum efficiency. Additionally, horizontal axis blades can either be oriented upwind or downwind of the turbine tower. Downwind blades have the advantage of self-aligning with wind direction, however the blades experience damaging stress every time they pass behind the tower, due to the sudden loss of airspeed in its shadow. Almost all blades are thus located upwind and require sensors and motors to keep the nacelle aligned with optimal wind direction.

Blade Design Turbine blades are shaped as airfoils and wind flowing over the curved top and bottom surfaces thus create a pressure differential, producing the lift (by Bernouilli's equation). As with aircraft, the presence of the airfoils also creates drag, and turbines are thus partially designed to optimize the ratio of lift to drag.

Power Equation The theoretical power available in a given fluid stream is the amount of kinetic energy ($^1/_2 mv^2$) introduced by the fluid in a given time. The mass, m, is equal to the density of air multiplied by the volume of air ($m=\rho V$) and the volume of air, V, is equal to the area swept by the blades, A, times the wind velocity, v, times the length of time t, ($V= Avt$). Thus the energy in a wind stream is $KE = {^1/_2}\rho Av^3t$ and the power is $P = {^1/_2}\rho Av^3$. The salient points to take away from this equation is that theoretical power increases with the cube of wind speed and the square of blade radius.

Theoretical Limitations The key theoretical limit to the effectiveness of converting energy from wind energy is the Betz' Limit, which exists because extracting all of the wind's energy would require the wind to have zero velocity after passing by the turbine which is infeasible. The theoretical maximum efficiency is thus calculated to be 58.3% (the Betz limit). Actual efficiencies are significantly less due to factors drag on the blades and generator and frictional losses.

Practical Limitations Additional limitations on wind power generation stem from the inherent intermittency of the power source (i.e. the wind does not blow at a constant speed). As a result, wind turbines frequently operate at less than their maximum capacity. Averaged over a year, they often only produce about 20% or less (the so-called "capacity factor") of their theoretical design output.

Implementation Considerations Other considerations include the difficulty in siting wind farms, as high-quality (consistent, high-velocity) winds are often located away from population centers and/or offshore. Finally, the intermittency can make it difficult for large amounts of wind generation to be implemented into the grid without special considerations to compensate for rapidly changing power output.

Introduction for Mentees

Wind power is perhaps the cleanest, easiest means to generate electricity without producing greenhouse gases that can lead to climate change. The technology is much older and more well-developed than other promising prospect like solar power.

The basic principle behind wind power is to use the kinetic energy (energy of motion) of air to turn an electrical generator, which converts this mechanical energy into electrical energy.

This can be conceptualized as a household fan running in reverse, where electrical energy is converted into mechanical energy to spin the blades, moving air.

Wind energy generates power according to the equation $P = {}^{1}/_{2}\rho A v^3$, where P is power (the same power as in the electricity lessons, which equals current times voltage OR energy per time), ρ is the density of air, A is the area swept by the spinning blades, and v is the velocity (speed) of the wind.

(The remaining discussion of limitations, design considerations, etc.will be part of an interactive discussion with the mentees).

Project

Mentees will have an opportunity to design a mock wind turbine and measure the “power output” by timing how long it takes for the their designs to lift a weight off the ground.

Closing Activity and Discussion

-How do you improve the effectieness or efficiency of wind turbines?

-What are some advantages to using wind turbines for power?

-What are some limitations to using wind turbines?

-Overview of different factors (size, type, location, etc.)

---Vertical versus horizontal axis turbines?

Wind Turbines

Open Questions

1. What are turbines? Where in daily life do you see turbines?
2. What locations are optimal for these designs?
3. What factors help wind turbines work more efficiently?
4. Can you think of some ways of generating power?
5. Are these forms optimal for the environment?

Materials:

- Tinker Toys
    - Used as a hub to hold blades
- Cardboard tube
    - Used as the tower that will hold the rest of the mechanism.
- Foamboard/cardboard
    - For blade design
- Fan
    - Used for testing each model
- Tape
- Scissors
- Yarn
    - For measurement purposes.

References

Casillas, Christian. “Wind and Hydro Generation.” Energy and Resources 100 Lecture. 9 November 2010. <http://er100200.berkeley.edu/lectures/L19_wind_hydro.pdf>

“Wind.” Wikipedia.org. <http://en.wikipedia.org/wiki/Wind>.