SUSTAINABILITY WORKSHOPS
for Middle School & High School Teachers

Wind Turbine Technology: A Research, Design, Build & Test Challenge

Argonne's Sustainability Workshops for Middle School and High School Teachers were conceived, designed and implemented as part of the Laboratory's educational outreach. The goals of these workshops include knowledge and awareness of alternative energy technologies, their advantages and limitations; the key issues and impacts of technologies related to climate change; to extend the resources of sustainability; and to encourage energy literacy. Participating teachers are asked to synthesize their experiences and knowledge gained into a useable lesson plan. The plans presented in this unit are a compilation of those lessons.

Grade Level

Highly adaptable for Grade 3 through College

Time Needed

Highly adaptable for Grade 3 through College

Activity Description

Action begins with the "creation" of a hypothetical wind turbine company. The initial tasks for the new company involve collaboratively designing and performing experiments and clearly communicating findings on the variables that could contribute to the optimal performance of a wind turbine (Phase I). Next, each "variable" team designs and builds what they believe to be the optimal combination of factors to achieve the most efficient production of electrical power (Phase II). Finally, each design is tested and the results are used to determine the most efficient design (Phase III).

Background Information

"It makes no sense for China to have better rail systems than us and Singapore having better airports than us. And we just learned that China now has the fastest supercomputer on earth -- that used to be us!"
--President Barack Obama, 11/3/10

Here are three current books that all agree upon the direction education needs to evolve toward while urgently admonishing us to take action soon if America is ever to regain its preeminent position in the world:

***That Used To Be Us* (2011) by T. Friedman & M. Mandelbaum.** This work maintains that this country's success was built upon Five Pillars, the first of which is providing public education for more and more Americans. We now need to create "more innovation powered by better education for every American." A productive, modern education means addressing the Seven Survival Skills: 1) critical thinking and problem solving, 2) collaboration and leading by influence, 3) agility and adaptability, 4) initiative and entrepreneurship, 5) accessing and analyzing information, 6) effective oral and written communication, and 7) curiosity and imagination. (This wind turbine design activity can do an exceptional job of comprehensively encompassing just about all of these skills.)

Argonne's 10 kW wind turbine is used by scientists and engineers to study the interaction of wind energy, electric vehicle charging and grid technology. It is estimated to save $1,000 on electricity and more than 10 metric tons of greenhouse gas emissions annually.

***Drive* (2009) by Daniel Pink.** This book is all about what truly motivates us; the key is intrinsic motivation engendered by type I (intrinsic) challenges characterized by autonomy, mastery and purpose. As far as the current state of education is concerned: "We are bribing students into compliance instead of challenging them into engagement." (This wind turbine design activity has never failed to challenge and engage participants of all ages, from 10 on up.)

***Creating Innovators* (2012) by Tony Wagner.** This book maintains that play, passion and purpose are the keys to creating and nurturing innovators. Even the U.S. army realizes that its competitive advantage directly relates to its capacity to learn faster and adapt more quickly, so in its ALC 2015 recommendations, number one is to "convert most classroom experiences into collaborative problem-solving events led by facilitators who engage learners to think and understand the relevance and context of what they learn." (This is exactly the environment that the wind turbine design challenge can create.)

Each of these books includes large sections devoted to meeting the educational challenges of the 21st century; this challenge has the potential to put all the authors' insights and suggestions into action and illustrate an inspiring example of what 21st century education can and should be.

Materials

The best, most comprehensive kit for wind energy experiments and activities is *Kidwind's Advanced Wind Experiment Kit*, which also comes in a classroom pack. A less expensive option is called the *Basic Wind Energy Kit* (see *Resources* for information). These kits contain wind generators, blade materials, hubs, pitch protractors, a small digital multimeter and more.

In addition, protractors, glue guns, large graph paper and scissors/cutters are needed. Yard signs can also be "harvested" for blade material. Each test station should also have one three-speed fan; larger diameter and more blades are better.

Teacher Note: Using the kit, a "standard" blade can be a rectangular 1.5" x 8" piece of corrugated plastic glued to a 1/4" x 5" dowel rod. Four of these can be cut from one 3"x 16" piece. These are used to explore the number and pitch variables. Widths can range from 1" to 3" in 1/2" increments (8" long) and lengths can range from 6" to 16" in 2" increments (1.5" wide). Various shapes can be made, paying attention to keeping the area about the same. Other blade materials can be explored, as well.

Vocabulary

airfoil
drag
generator
multimeter
voltage
ammeter
efficiency
kinetic energy
power
voltmeter
ampere
electricity
lift
renewable
watt
Betz's Law
energy
load
turbine
current
friction
mechanical energy
variable

Procedure

The background information above can be by educators to "set the stage," A September 2012 article in *Scientific American* on wind energy potential (cited below in the *Resources* section) can be used with both teachers and students to "motivate" the creation of a hypothetical wind turbine company that can be named by the group.

Step 1. Research

(3-4 class periods)

The new company's first task is to collaboratively perform experiments and clearly communicate their findings on the variables that could contribute to the optimal performance of a wind turbine. These variables are elicited by the facilitator and recorded during group discussion (perhaps with a sample model turbine in view); usually five or more ideas result from this phase (number, pitch, length, width, shape, material, etc.). The "power in the wind equation" ($P= 1/2\ \rho\pi r^2 v^3$) can also be analyzed and discussed to reveal how the language of mathematics encodes key information and informs decisions. In addition, the facilitator should initiate a discussion of symmetry and balance given that the hub has 12 positions where blades can be attached.

Divide the group into five or more teams of 2 or 3 members; one team per variable to be explored. Each team selects the variable it will tackle. Before the experiments commence, everyone needs to agree upon the "standard turbine" and

testing parameters: fan speed/s, distance from fan to turbine, etc. If the *KidWind* kit material is used, the facilitator should try to steer the group toward three or four 1 1/2" x 8" rectangular blades and a pitch between 10-15 degrees since this combination is in the "middle" of what can be changed.

Each team selects and/or constructs a set of blades that will be used to test the effect of changing its variable (attention needs to be paid to how far along the 5" dowels the blades are attached with hot glue guns; halfway recommended). The teams proceed to carefully repeat and record voltage measurements according to the agreed upon test parameters, changing their variable at least five times. Readings can be done at both low and high fan speeds in order to measure performance across a range of wind speeds; these data can then be averaged.

When all the teams have finished their experiments, they are to organize their information in graphic form and clearly share what they learned with the entire group, along with any hypotheses on what may have caused the voltage variations they found. Each team records the findings of all the others to be used to synthesize their own optimal competition combination. These presentations can be done to close the experimental section of the challenge or at the beginning of the design/build /test phase depending on preference and/or timing. This will take about one class period.

Teacher Note: Step I (Research) takes about two class periods, with a completed set of blades for each variable and two test stations, each with a fan and turbine tower. Initially, sets of blades will have to be constructed to test the variables. If this is done in class, add another period. This only needs to be done once, since these sets can be used indefinitely each time the research phase is done.

Step 2. Design, Build and Test

(1-2 class periods)

Using their notes from the presentations, each team collaboratively attempts to design the best/most efficient wind turbine by negotiating with each other and balancing variables culminating in a blade design drawn on scaled graph paper (this blade design will be approved by the facilitator and serve as the blueprint for the construction of a set of uniform blades). When the design is approved, each team receives the materials they need to build their design. Construction is accomplished by cutting out the blueprint, tracing it onto the blade material, carefully cutting this shape out and gluing the blade onto dowels that fit into the hubs. As each team completes the assembly (using hot glue guns) and adjustment (using special protractors) of their design, the testing can begin. The exact same parameters should be used during this competitive testing phase, including the same fan, tower and gearbox/generator combination. If time allows, both the maximum voltage and current (amperage) should be measured at both low and high fan speeds, averaged and multiplied together to calculate the average power output (watts). If time allows and the teams agree, they can observe each other's designs, fine-tune their designs, and measure again. The winning team can be determined by taking the top voltage generated (for limited time or younger groups), or top average power output all the way up to top efficiency (divide turbine "cost" by average maximum power generated).

Teacher Note: Step 2 requires about one class period depending on the number of teams.

Assessment

The team presentations at the end of the research phase can serve as a formative assessment of team performance and conceptual understanding.

In a real engineering firm, each team would have to document the entire process of experimentation, sharing findings, design, construction and test results. Each student team should be encouraged to do this in the most creative fashion they can come up with as a final, summative assessment of their work.

Extensions

After designing their blade configuration, each team can "buy" the materials they need to build their design. Each piece of material can be "priced" and the total "cost" can be used to calculate the efficiency of the turbine in $/watt or watts/$ (efficiency). This economic result can then be used to determine the winning combination.

Many other experiments are possible with the *Kidwind* advanced kit, including changing gear ratios, pumping water and lifting weights/weight lifter drag racing.

Resources

- KidWind, accessed June 30, 2013. A long-lived, evolving and deep web resource for everything educational on wind energy – including excellent kits. This website is probably the number one resource for wind energy education with a really comprehensive collection of ready-to-use materials across the curriculum including background information, lesson plans, power point presentations, etc.

- Biello, David. *The Sky Is the Limit for Wind Power*, Scientific American, September, 2012.

- Watson, David E. *Wind Turbines and the Energy in Wind*. FT Exploring Science and Technology, 2010

Goals and Objectives/ Connections to Next Generation Science Standards (NGSS)

The overall goal of this challenge is to provide a balanced and engaging STEM experience while comprehensively addressing as many NGSS performance expectations (PE) as possible while learning all about wind energy.

Science and Engineering Practices

- **SEP1:** Asking Questions & Defining Problems
- **SEP2:** Developing & Using Models
- **SEP3:** Planning & carrying out investigations
- **SEP4:** Analyzing & interpreting data
- **SEP5:** Using mathematical & computational thinking
- **SEP6:** Constructing explanation & designing solutions
- **SEP7:** Engaging in argument from evidence
- **SEP8:** Obtaining, evaluating and communicating information

Crosscutting Concepts

- **CC1:** Patterns
- **CC2:** Cause & Effect: Mechanism & Explanation
- **CC3:** Scale, Proportion & Quantity
- **CC4:** Systems
- **CC5:** Energy& Matter: Flows, cycles & conservation
- **CC6:** Structure & Function

Disciplinary Core Ideas

- **PS1.A:** Structure & Properties of Matter
- **PS2.A:** Forces & Motion
- **PS2.B:** Types of Interactions
- **PS3.A:** Definitions of Energy
- **PS3.B:** Relationship Between Energy & Forces
- **PS3.C:** Energy in Everyday Life
- **ESS2.A:** Earth Materials & Systems
- **ESS2.D:** Weather & Climate
- **ESS3.A:** Natural Resources
- **ESS3.C:** Human Impacts on Earth Systems
- **ESS3.D:** Global Climate Change

Need more information or help with this lesson?

Contact Argonne National Laboratory by e-mailing SustainabilityEd@anl.gov.

Find out more about Argonne's Sustainability Program at blogs.anl.gov.