NSTA 2024
Denver, CO

Eco Engineers: Building Wind Turbines with KidWind

Experiment

Project: Maximum Energy Output

- Go Direct Energy Sensor
- KidWind Advanced Wind Experiment Kit
- Vernier Variable Load

Workshop Presenter

Josh Ence
physics@vernier.com

Vernier Science Education • 888-VERNIER (888-837-6437)
info@vernier.com • www.vernier.com

Project: Maximum Energy Output

Generating electricity from fossil fuels (primarily coal and natural gas) produces carbon dioxide (CO_2) and an array of other pollutants that are injected into the atmosphere each year. The Intergovernmental Panel on Climate Change (IPCC) estimates that 20–25% of the CO_2 produced by humans comes from the generation of electricity around the world. Increasing CO_2 concentrations in the atmosphere is one of the key drivers of climate change.

While electricity generation produces a significant amount of the CO_2 released by humans, there are millions of people around the world who do not currently have access to electricity. When individuals or communities seek out reliable electricity, they have a variety of options, including generators that run on gasoline or diesel. Developing ways to efficiently produce electricity from renewable sources, such as wind or solar power, can greatly improve people's quality of life and ability to sustainably support themselves and their communities.

Wind turbines are a rapidly maturing technology that can help reduce the carbon footprint of electricity generation and bring electricity to even the most remote communities. In this project, you will construct a small wind turbine that maximizes energy output at low and high wind speeds. This turbine could be used to provide energy that would charge small electronics or provide lighting. During the project, you will work with your group to design, test, and then optimize your wind turbine design. At the end of the project, you will submit a set of deliverables.

DESIGN REQUIREMENTS AND CONSTRAINTS

- Turbine diameter: No larger than 50 cm
- Wind speed range: 2–6 m/s
- Output: Unregulated Direct Current
- Generator: Any available DC generator or you can build your own generator
- Turbine must be robust enough to withstand outdoor conditions over time
- Turbine should track the wind direction (yaw)
- Do not exceed the project budget

DELIVERABLES

- Prototype
- Detailed design specifications (so the unit can be replicated)
- Expected energy output over a 24 hour period at wind speeds of 2 m/s, 4 m/s, and 6 m/s
- Social and environmental impact statement on the benefit of your design

Project: Maximum Energy Output

The goal of this project is for students to design and build their own wind turbines. You may or may not decide to let them use KidWind kit parts. We have capped velocity at 6 m/s as this is the wind speed of a standard household box fan. We also set the maximum rotor diameter at 50 cm, which is appropriate because it is the size of most household box fans. You may wish to edit the parameters to fit your situation.

Students will need to consider the following as they construct their wind turbines:

Towers: Students can make a tower out of practically anything. They must make sure the turbine has a firm base or that it can be attached securely to a base. The tower must be tall enough that the blades do not hit the base/ground/table top and sturdy enough that it can withstand stress from the wind.

Generators: A generator is the device that converts mechanical energy into electrical energy. Student turbines will generate electricity using a generator of their choice. Students can choose any commercially available DC generator or even build their own.

Drivetrain: Students must decide to build a direct drive or a geared drivetrain. Gears can significantly increase the rotational speed of the generator and therefore power output, but gear boxes can be challenging to build. Students can use gears or pulleys for the systems.

Blades: Blade design has a huge impact on turbine power output. As students build their turbines, they will want to perform experiments to see which blades work best.

In the Electronic Resources you will find multiple versions of each student experiment—one for each supported data-collection program (Graphical Analysis, Logger *Pro*, or LabQuest App). Deliver to your students the version that supports the software and hardware they will use. Sign in to your account at **www.vernier.com/account** to access the Electronic Resources. See Appendix A for more information. **Note**: The printed book and the PDF of the entire book (found in the Electronic Resources) include only the Graphical Analysis (Go Direct sensors) versions of the experiments.The experiments in this book were selected to provide a sampling of Vernier experiments that cover several subjects and key scientific concepts. The downloaded zip file contains PDF files of the student experiments. You can print the PDF, distribute it to students electronically, or post the file to a password-protected class web page or learning management system.

ESTIMATED TIME

We estimate that this project can be completed in 7 to 10 class periods. Students may need 4 to 5 class periods to construct a good turbine. They will need one class period to collect data and then one to two periods to refine their design. Finally, students will need one class period to complete their report and calculations.

You can vary the complexity and time to complete the project through the materials you provide. For example, if you have KidWind Advanced Wind Experiment Kits, you could use the generators, gearboxes, and towers that come with the kits. This would allow you to focus on maximum energy output related to the design of the blades and spend less time on tower and generator design.

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations and designing solutions Engaging in argument from evidence Obtaining, evaluating, and communicating information	PS3.A Definitions of Energy (HS-PS3) PS3.B Conservation of Energy and Energy Transfer (HS-PS3) ETS1.A Defining Engineering Problems ETS1.B Developing Possible Solutions ETS1.C: Optimizing the Design Solution	Patterns Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter Structure and function Stability and change

SUGGESTED PROJECT PLAN

1. Assign students a research project in which they are expected to research the purpose of a wind turbine. Students should be able to define the problems addressed by a wind turbine, including global, social, and environmental issues that would be affected by using wind energy as an energy source. A great way to start this activity is by reading the book, *The Boy Who Harnessed the Wind*, by William Kamkwamba. It is a true story of a young boy in Malawi who builds his own turbine to charge small electronics in his house.

2. It can be very useful to perform some basic turbine experiments on blades, generators, and gearboxes to understand how they affect turbine performance. This can be in done in a more structured or a more inquiry-based fashion before students try to build a final turbine to test for this project. Other experiments in this book that use wind turbines can be good tools.

3. Give students time to design and build the wind turbine based on the design requirements (The student experiment includes a list of requirements and constraints, but you may have additions or changes based on how you do the project.). You will want to consider providing materials and/or setting a budget to limit how much students can spend on materials.

4. Once students have constructed a wind turbine, they will need to do performance testing. As wind turbines can rotate at a high rate of speed and things can come off if not well attached, the testing area should be set up with strict safety rules. Based on testing, students will need time to make refinements to their turbine.

5. After refinements, students will need to collect data for their best turbine setup. Based on this data they will need to extrapolate and determine how much energy their turbine could generate based on the wind speed they are testing.

6. Give students an opportunity to develop and present a social and environmental impact statement on the benefits of their design. In the report, ask students to share ideas on what they would improve if they had more time. This can give you insights into how they are interpreting their data.

PROJECT TIPS

1. The KidWind organization has developed a national competition, called the KidWind Challenge, that offers students hands-on opportunities to apply their knowledge of renewable energy through friendly and challenging competitions. To learn more about the KidWind Challenge, visit **www.kidwind.org/challenge**

2. Consider developing a rubric with which to grade students' projects. Possible criteria include:

    - Energy production at low speeds and high speeds
    - Quality of construction
    - Cost of construction
    - Durability
    - Aesthetics
    - Evaluate quality of each component: blades, drive train, and/or tower
    - Integration of wind turbine design theory

3. Perfecting blade performance can take quite a while because of the number of variables. Students will need a significant amount of time to "discover" an optimal design if they have not experimented with blade variables in earlier activities. See Appendix B for additional tips about designing blades.

4. By far the most complicated part of building a wind turbine from scratch is creating the gearbox. If this is the first year you are doing this project or your students are relatively new to the design process, we recommend either using KidWind Advanced Wind Experiment Kits or allowing only direct drive systems with different generators. As you and your students become more experienced, you can add in more complexity.

5. Power output from the generator is dependent on the load that is applied to the turbine. Maximum power will depend on the load. For this project, instruct students to use the ideal load for their generator.

6. The generators that come with the KidWind Advanced Wind Experiment Kits have maximum outputs of approximately 2 W (10–15 V at 100–150 mA, when spinning at very high RPM (8,000–12,000 RPM)). There are many other DC motors available that you can use as generators. They will all perform differently under load and have varying torque requirements. Experimenting with generators can be very interesting.

7. As it can be challenging to measure energy output for 24 hours, students will need to collect data for a specific amount of time and extrapolate. This type of experimentation also assumes that the wind will blow at the same speed all day, which would rarely happen in real life.

8. To produce a more realistic testing environment you could have students set up their turbines outside for a number of hours and see how much energy they produce. This can be challenging and show students the weaknesses in their design as the device needs to react to different wind speeds, wind gusts, and rapid changes in wind direction.

9. If you want to improve your knowledge, considering reading the books, *Wind Power for Dummies*, by Ian Woofenden and *Homebrew Wind Power,* by Dan Bartmann, Dan Fink, and Mick Sagrillo.

EQUIPMENT TIPS

1. Set up a safe testing area.
    - Clear the area of debris and materials.
    - Instruct your students to not stand in the plane of rotation of the turbine blades. Also tell them that they should not touch the blades while they are spinning. Blades can be moving very fast and can hurt if they hit someone.
    - Provide safety goggles for your students. Students should wear safety goggles when they are working with a turbine that is spinning.
2. An energy sensor makes it very simple for students to determine power and energy output. Keep in mind that Vernier energy sensors have an input limit of ±30 V and ±1 A. KidWind generators almost always stay below these limits, but if you are using other generators, test them with a multimeter so you do not damage the sensor. The Go Direct Energy Sensor has a 1 W internal 30 Ω resistor. We recommend using a power resistor connected to the External Load terminals if students are regularly exceeding 1 W of power production.

3. We recommend the Vernier Variable Load (order code: VES-VL) as a way to determine the optimal resistance for the generators, especially if you are allowing students to experiment with different generators. See Experiment 9, "Effect of Load on Output." The Vernier Resistor Board can also be used to relatively easily determine the optimal resistance for each generator. We recommend the Vernier Variable Load (order code: VES-VL) as a way to determine the optimal resistance for the generators, especially if you are allowing students to experiment with different generators. The Vernier Resistor Board can also be used to relatively easily determine the optimal resistance for each generator.

4. If you are requiring students to present energy output projections at different wind speeds, we recommend using an anemometer to collect wind speed measurements and tailoring the requirements to wind speeds you are able to produce.

5. If you have a mix of KidWind Advanced Wind Experiment Kits and Basic Wind Experiment Kits, you can combine materials if building turbines from scratch. Hubs, gears, and drive shafts from all KidWind wind experiment kits will work together.