# Investigating Conservation of Energy Using Wind Turbine Analysis (Resource Exchange)

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# INVESTIGATING CONSERVATION OF ENERGY USING WIND TURBINE ANALYSIS

(Resource Exchange)


## SUMMARY

Using miniature wind turbines and a variable-speed air mover, students collect quantitative data on wind speed using an anemometer and measure turbine blade rotation with a tachometer. Once the system reaches steady-state operation, students use the measured wind speed and turbine swept area to estimate the power available in the moving air. The turbine is then connected to a known electrical load, and students measure the voltage across the load to calculate the electrical power output. Students graph wind speed versus available wind power and compare it to the measured electrical power output. Through this analysis, students investigate the relationship between wind speed and power, evaluate how variations in rotor design affect turbine performance, and estimate the efficiency of energy conversion from wind energy to electrical power. This hands-on model wind farm activity supports student understanding of energy transfer, system efficiency, and real-world applications of renewable energy.

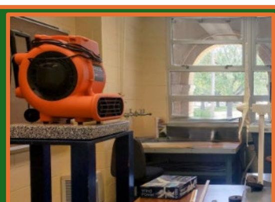
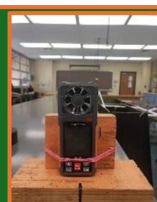
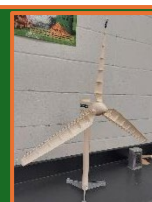

## PROCEDURE

**Introduce the Module**

- Explain wind turbines and wind farms, emphasizing physics principles involved in harnessing wind energy.
- Discuss the concepts of kinetic energy of the wind and its relationship to power input.
- Discuss the concepts of voltage and resistance and their relationship to power output.
- Discuss the importance of steady state rotation and optimizing energy conversion for wind farm efficiency.

**Setup Model Wind Farm**

- Place the wind turbines at various set distances from the air-mover (to produce varying wind speeds at the wind turbines).
- Measure the distance from the hub center of the turbine to the highest blade to acquire the radius of the blade swept area.

## OBJECTIVE

Students will collect and analyze data from a wind turbine model to calculate power input via wind speed and electrical power output. Graphs will be used to explain the relationship between wind speed, power, energy transfer, and turbine efficiency.

## TARGET GRADE AND COURSE:

High School (Grades 9-12) Physics or AP Physics

## TIME

2-3 class periods
45 minutes each

## MATERIALS

- Anemometer
- Model wind farm setup (constructed with miniature wind turbines)
- Air mover / Wind generator
- Measuring tape or ruler
- Voltmeter
- Resistor
- Stopwatch or timer
- Camera (if needed)

## [STATE] STANDARDS ADDRESSED

112.45(c)(5)(c)
112.45(c)(7)(B)
112.45(c)(7)(C)

## NGSS ADDRESSED

HS-PS3-1
HS-PS3-3
HS-ETS1-3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**Measure Wind Speed and Power Output**

- Vary the air-mover speed (or distance to turbine) to produce different wind speeds at the wind turbines. For each wind speed, use the anemometer to measure and record the wind speed.
- Use the tachometer to measure the rotational speed of the wind turbine's blades. Record the corresponding rotational speed for each wind speed. Adjust blades to evaluate how variations in rotor design affect turbine performance.
- Connect a known resistor to the terminal at the back of the turbine. Using a voltmeter across the resistor, measure the voltage output by the turbine once it reaches a steady state of rotation.

**Calculate Power Input by the Air**

- Calculate the power of the moving air, $P_{wind}$ using the measured wind speed ($v$) values using the equation:

$$P_{wind} = \frac{1}{2}\rho A v^3$$

Note: Density, $\rho$, of the air is assumed to be at sea level ~1.225 kg/m$^3$. The area, $A$ represents the blade swept area of the wind turbines.

**Calculate Power Output by the Turbine**

- Calculate the power output by the turbine ($P_{electric}$) using the following equation:

$$P_{electric} = \frac{V^2}{R}$$

Note: R represents the resistance of the resistor connected to the turbine and $V$ is the voltage.

**Calculate Power Efficiency**

- Calculate the efficiency of the turbine ($\%Eff$) using the following equation:

$$\%Eff = \frac{P_{electric}}{P_{wind}} \times 100\%$$

**Calculate Rotational Kinetic Energy (May substitute other Angular Concepts)**

- Calculate the rotational kinetic energy of the wind turbine ($K_{rot}$) using the measured rotational speed ($\omega_{turbine}$) data and the moment of inertia of the turbine blades ($I_{blades}$) using the formula:

$$K_{rot} = \frac{1}{2} I_{blades}\omega_{turbine}^2$$

Note: Since students are not familiar with finding moments of inertia for irregularly shaped objects, wind turbine blades are treated as rods. This approximation provides a reasonable estimation of the moment of inertia for educational purposes, allowing students to understand the concept of moment of inertia and its role in rotational motion without getting bogged down in complex calculations.

**Graph the Data**

- Create a graph of displacement from air-mover vs wind speed (for reference).
    - This graph allows students to visualize how wind speed changes within the experimental setup.
- Create a graph of wind speed vs power input.

**Make Inferences from the Graph**

- Analyze the wind speed vs power output graph and draw inferences. Some possible inferences:
    - What is the relationship between the variables?
    - The graph may show a cubic relationship. How can this be linearized?

**Compare and Analyze/Discuss**

- Students compare the wind power and electric power to evaluate efficiency.
- Students compare tachometer speeds of various rotor designs to evaluate how effectively the wind interacts with the turbine affecting its rotational kinetic energy. Discuss reasons for speed losses such as friction in the turbine's components, aerodynamic losses, and electrical losses in the generator and transmission.
- Students brainstorm and discuss possible improvements to enhance the efficiency of the wind turbine system.

Remember to provide clear instructions, safety guidelines, and emphasize the scientific rigor of the experiment, encouraging students to apply their understanding of physics principles throughout the process.

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