PROJECT REPORT

Northern Wyoming Community College District / National Science Foundation
Summer Energy Education Program 2012

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June 27, 2012

TITLE

Where we're going, we don't need coal.

SUMMARY

This project serves to connect Newtonian Mechanics, electromagnetism, and environmental concerns in an engineering design process. Students will research and design an operational wind turbine and derive a scientific comparison to coal and its viability as an energy resource.

ENERGY CONTEXT

Wind turbines convert the kinetic energy of the wind into rotational mechanical energy in the turbine blades and electric energy through a generator in the nacelle. They are presented as an alternative and now more commonly as a replacement to coal-burning power plants.

ANTICIPATED TIME REQUIRED

Expected time of completion: 1 week

3 days for research, design, and testing of wind turbines
2 days for reporting
Optional additional outside class time for Campaign video

INTENDED STUDENT LEVEL

This curriculum is intended for 11th-12th grade students in an advanced physics or engineering design course.

ASSUMED PRIOR KNOWLEDGE

Students must have:

- Thorough understanding of Newtonian Mechanics, especially rotational kinematics
- Thorough understanding of Electrical Power
- Basic understanding of generators, motors, and applicable Electromagnetism concepts
- Thorough understanding of the Law of Conservation of Energy

LEARNING OBJECTIVES

1. Students should understand and be able to apply the work-energy theorem, so they can calculate the change in kinetic energy or speed that results from performing a specified amount of work on an object.

2. Students should understand the concepts of mechanical energy and of total energy, so they can
(1) State and apply the relation between the work performed on an object by non-conservative forces and the change in an object's mechanical energy.
(2) Describe and identify situations in which mechanical energy is converted to other forms of energy.
(3) Analyze situations in which an object's mechanical energy is changed by friction or by a specified externally applied force.

3. Students should understand conservation of energy, so they can identify situations in which mechanical energy is or is not conserved.

4. Students should understand the analogy between translational and rotational kinematics so they can write and apply relations among the angular acceleration, angular velocity, and angular displacement of an object that rotates about a fixed axis with constant angular acceleration.

5. Students should understand the dynamics of fixed-axis rotation, so they can:
(1) Describe in detail the analogy between fixed-axis rotation and straight-line translation.
(2) Determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque or force.
(3) Determine the radial and tangential acceleration of a point on a rigid object.
(4) Apply conservation of energy to problems of fixed-axis rotation.

6. Students should understand the motion of a rigid object along a surface, so they can calculate the total kinetic energy of an object that is undergoing both translational and rotational motion, and apply energy conservation in analyzing such motion.

MATERIALS

Each group needs:

- Generator or DC motor
    - OPTIONAL: DC motor with built-in gear ratio
    - ADVANCED: Students construct generators
        - Copper wire
        - Magnets
- Access to construction materials including but not limited to
    - Wooden dowels
    - Balsa wood
    - Foam board
    - Paper plates, cardstock, etc.
    - X-ACTO/Utility knife
    - Cutting surface
    - Hot glue
    - Nails/screws
    - Power drill
    - Mitre box and saw

- Multimeter
- OPTIONAL: Gear kit
- ALTERNATIVE FOR GENERATOR AND GEARS: Use a disassembled hand-crank flashlight

Classroom needs:

- Box fan or directional air output
- Handheld anemometer

INTRODUCTION / MOTIVATION FOR STUDENTS

In 2005, Texas ranked 3rd in coal production in the United States. Texas is the highest emitting state/province in the world for CO_2 emissions.

Coal is being pushed out of energy production due to stricter EPA guidelines and political pressure. Energy experts estimate more than 60,000 MW of coal-generated power will be taken offline by 2017. Renewable energy production is becoming more prevalent and necessary. Are we ready for the transition? Are there other alternatives we are disregarding? Does coal need to be replaced?

Environmentalists would argue that the most cost-effective and environmentally responsible approach would be to reduce demand through more efficient use of electricity. Could we operate off of only renewable energy resources? What is the real cost of renewable energy resources and production?

PROCEDURE

The class should be divided into groups of 2- 3. Each group is to construct a wind turbine using any materials that are not pre-fabricated for wind turbines.

Students will have a “wind tunnel” to test their designs and modify as necessary in order to construct the most efficient design possible. Class discussion should include considerations including, but not limited to, turbine blade length, pitch, shape, materials, weight, and number of blades.

Students must complete an energy analysis on their wind turbine taking into account energy losses. Their calculations must include kinetic energy of the wind, rotational kinetic energy of the wind turbine, and electric energy produced by generator. Then students should derive an efficiency factor for their wind turbine. Report must include at least one graph relating two variables of their wind turbine.

Students will then complete the same analysis on a commercial wind turbine and farm using the video provided by the teacher.

Students will post their work and energy comparison between coal and wind following standard lab report guidelines to their blog or class wiki (wiki.wrightphysics.com). Comments must be posted before last day of project.

Report considerations must include, but are not limited to:

- Austin energy sources
- Total cost/MW for construction, installation, and operation for energy sources
- Environmental considerations (pro and con)

Students will produce a live-action or animated commercial campaigning in favor of or against wind power as a viable energy resource and replacement for coal.

SAFETY ISSUES

Standard lab safety equipment should be worn at all times during construction and testing.

TROUBLESHOOTING TIPS

Some higher voltage generators may require gears or a push start.

ASSESSMENT

Pre-Assessment

Does the power generated affect the speed of the wind?

Learning Check

1. A typical commercial wind turbine has three blades that are about 100 feet long and rotate at 30 rpm. Calculate the rotational kinetic energy of this wind turbine if we approximate each blade as a uniform rod with a mass of 300 kg. (ANSWER: 1.3 MJ)
2. If this much energy is extracted each second, what is the maximum theoretical power output of this wind turbine? (ANSWER: 1.3 MW)

Post Assessment

Consider a wind turbine that is rated at 1.5 MW. This means that with sufficiently high winds, it will produce 1.5 MW or 1,500 kW of power. The installed cost of this turbine is $1.5 million.

1. If this turbine runs at its rated power 100 percent of the time for a full year, how much energy would it produce in a year?
2. This wind turbine has a capacity factor equal to 0.38. This means that over a year, it will produce only 38 percent of its theoretical maximum energy production. How much energy does this turbine actually produce in a year? ____ (million kWh/year)
3. Over the next 20 years, U.S. annual electric energy consumption is projected to increase by 1.5 trillion kWh/year. How many 1.5 MW wind turbines would be needed to supply 10 percent of this additional energy? _________________________
4. Calculate the cost of installing these wind turbines._____________________________________ ($)
5. Assuming the electric energy produced by these turbines is worth 5 cents per kilowatt-hour, these turbines would generate electric energy worth $7.5 billion per year. Calculate the simple payback period for these turbines. (Payback period is the time it takes for a system's net benefits to equal its cost.) ____ (years)

[From AP Central]

Lab Report evaluated by Lab Report Guidelines from class syllabus.

SUGGESTED EXTENSIONS

Based on the group-work and class collaboration, have the class construct a long-term wind turbine/solar panel and research the best location on campus for the construction.