Hands-on Activity: **Water Power**

Quick Look

Grade Level: 4 (3-5)
Time Required: 45 minutes
Expendable Cost/Group: US $1.00
Group Size: 4
Activity Dependency: None
Subject Areas: Earth and Space, Science and Technology

Summary

Students observe a model waterwheel to investigate the transformations of energy involved in turning the blades of a hydro-turbine. They work as engineers to create model waterwheels while considering resources such as time and materials, in their designs. Students also discuss and explore the characteristics of hydropower plants.
This engineering curriculum aligns to Next Generation Science Standards (NGSS).

Engineering Connection

Dams capture energy from a renewable energy source - water - and can reduce the amount of fossil fuels used to generate electricity. Civil, structural, mechanical, electrical, software and environmental engineers design and re-design hydroelectric dams to make them more environmentally-friendly and generate more electricity.

What energy transformations are involved with a waterwheel?

Learning Objectives

After this activity, students should be able to:

- Identify dams as a source of hydropower.
- Explain the advantages and disadvantages of human-made dams.
- Explain how engineers design and redesign hydropower technologies.
- Use counting to measure the rate of revolution of a waterwheel.

Educational Standards

- NGSS: Next Generation Science Standards - Science
- Common Core State Standards - Math
- International Technology and Engineering Educators Association - Technology
- State Standards

Materials List

Each group should have:

- 1 empty, clean 2-liter plastic soda bottle (or a 20-oz bottle, depending on availability) with holes drilled in the cap and the bottom of the bottle so that a wooden dowel fits through length of the bottle like an axle
- 1 pair of scissors
- duct tape
- wooden dowel (~¼ inch diameter and longer than the soda bottle length)
- string
- fin material, such as cardboard, index cards, straws, toothpicks, popsicle sticks, walls of plastic bottles, etc., that students can use to make turbine fins
- water-proofing materials (such as aluminum foil, plastic wrap, etc.) to wrap over any paper fins to keep them from disintegrating in the water
- water
- sink tap and drain access
- stopwatch

Introduction/Motivation

Humans have been using water for power for a long time. More than 2,000 years ago, farmers used waterwheels to grind wheat into flour. A waterwheel spins as a stream of water, which is being pulled down by gravity, hits its blades. The gears of the wheel drive heavy, flat, rotating stones that grind the wheat into flour. Hydropower plants use the same action of falling water to generate electricity. A turbine and a generator convert the energy from the falling water to mechanical and then electrical energy. The biggest advantages of using hydropower for electricity are that it is a renewable resource and it does not give off air pollution during operation.

Figure 1. Hoover Dam in Boulder City, NV.

Dams also use the waterwheel concept for generating electricity. Dams are some of the largest human-made structures on Earth. In fact, the Hoover Dam on the Colorado River in Nevada is 221 meters high, 379 meters long and 14 meters wide at the top. That is pretty big! It has 17 electric generators and provides electricity for about 500,000 homes in Nevada, Arizona and California.

Engineers design and improve dams in order to capture energy from a renewable source—water. Using dams is a way to generate electricity without burning fossil fuels. Engineers also re-design existing dams to be friendlier for fish and to work better at making hydroelectric power.

Procedure

Background

Hydropower Plants

The basic components of a hydropower plant are a dam, intake, turbine, generator, transformer, power lines and outflow. Most hydropower plants rely on a dam that holds back water, creating a large *reservoir*. Large dams are vital for large-scale hydropower, but dams of all sizes are also used for flood control, water storage and irrigation throughout the world. Gates on the dam open, and gravity pulls the intake water through the penstock, a pipeline that leads to the turbine. Water builds up pressure as it flows through this pipe. The water strikes and turns the large blades of a turbine, which is attached to a generator above it by way of a shaft. As the turbine blades turn, so do a series of magnets inside a generator. Giant magnets rotate past copper coils, producing alternating current (AC). A transformer inside the powerhouse takes the AC and converts it to higher-voltage current that is carried on high-tension power lines. The used water is carried through pipelines, called tailraces, and this outflow re-enters the river downstream.

The water in the reservoir is considered stored energy. When the gates open, the water flowing through the penstock has kinetic energy because it is in motion. The amount of electricity that is generated is determined by several factors. Two of those factors are the volume of water flow and the amount of *hydraulic head*. The hydraulic head refers to the distance between the water surface of the reservoir and the turbines, and it is dependent upon the amount of water in the reservoir. As the head and flow increase, so does the amount of electricity generated.

Figure 2. Hydropower dam.

Most people are familiar with large-scale hydropower; however, the energy of moving water can be captured on a much smaller scale, called *micro-hydropower*, in which small to mid-size generators are placed in rivers and streams to provide electricity for a few buildings or other smaller applications.

Worldwide, hydroelectric power plants produce about 24% of the world's electricity and supply more than 1 billion people with power. Utilities in the U.S. operate about 2,000 hydropower plants, making hydropower the nation's largest renewable energy source.

Dams

In the U.S., engineers have been involved with the construction of about 75,000 dams. This is an average of one dam completed each day since the signing of the Declaration of Independence. This rate of construction has slowed dramatically in recent years. In fact, civil engineers, structural engineers and environmental engineers are more likely to be redesigning or dismantling dams. Existing dams may be redesigned to be more fish-friendly and more efficient in generating hydroelectric power.

While dams are important for flood control and the generation of electric power, they have a significant effect on fisheries and river ecosystems. Dams can disrupt migratory fish patterns and spawning habits, especially for migrating species such as salmon. This can have devastating effects on both the fish population and people whose livelihoods depend on these fish.

Early engineering efforts to help salmon focused on designing systems that would allow fish to bypass either the turbines or the dam itself. The most common method of bypassing the turbines is by releasing water over the dam to provide an alternate path for fish moving downstream. The less-than-spectacular results of these early salmon conservation efforts have led engineers to design more fish-friendly dams. Because the greatest numbers of salmon deaths occur as the fish pass through the turbines, this is where engineers have focused their efforts.

In the last few years, several dozen dams have been removed in order to restore wildlife habitat. Engineers play a critical role in helping to decide if a dam is worth keeping. If not, they have to plan the best way to remove a dam. After a dam is removed, environmental engineers must monitor silt and debris as it flows downstream and they are involved with restoring the habitat.

Advantages and Disadvantages of Large-Scale Hydropower Dams

Advantages of large-scale hydropower dams include the following: reduces non-renewable fossil fuel consumption as well as production of greenhouse gases and pollution, can prevent flooding, and provides irrigation and recreation areas (such as boating and fishing). Disadvantages include the following: very expensive to build; can force people to leave their homes; interferes with natural flow of water; large-scale habitat destruction, especially where reservoirs form; interferes with natural migration patterns of some animal species; reduces areas for certain types of recreation including hiking, fishing, camping, hunting; can affect natural fisheries, which harms people who rely on those fisheries to make a living; all dams silt up; requires maintenance; and can fail catastrophically.

Before the Activity

- Prepare and test a model waterwheel before demonstrating it to the class.

With the Students

1. Discuss what students already know about hydropower. To warm up the class, ask the following series of true/false questions and have students vote by holding thumbs up for true and thumbs down for false. Count the number of true and false and write the number on the board. Give the right answer.
    - True or False: Hydropower dams reduce pollution (Answer: True)
    - True or False: Hydropower dams are cheap to build (Answer: False: they can be very expensive to build.)
    - True or False: Hydropower dams rarely interfere with natural wildlife (Answer: False: dams can disrupt migratory fish patterns and spawning habits, especially for species like salmon. This can have devastating effects on both the fish population and people whose livelihoods depend on these fish.)
2. Show students the model waterwheel.
3. As a generic test, pour a fixed amount of water over the waterwheel and count the number of turns it makes. Have a student time this test by using a stopwatch to record the elapsed time.
4. Ask students how might the rate of rotation be found. Then with the class, determine the rate of rotation (divide the number of turns by the elapsed time).
5. Ask students how hydromills and windmills are similar. (Answer: both have "vanes" and a turbine shaft, and both use energy that is renewable.)
6. Fasten a string to the neck of the 2-liter bottle. Tie objects to the other end of the string, and use the mill to pull them up as the string rolls up around the neck of the bottle. Investigate what size objects the waterwheel is able to move.
7. Divide the class into groups and tell them that they are working for H2O Solutions, an engineering design firm that works mostly with waterwheels and water energy. The city has asked them to design a more efficient watermill. The firm has been split into several engineering teams (student groups). Tell the teams that they must design a functioning waterwheel that turns and their constraint is to use only the materials provided for their designs. Ask them to sketch their new design and test their designs. Have a few groups present their designs to the rest of the class indicating what elements worked well and what they could improve on.

Assessment

Pre-Activity Assessment

Voting: To warm up the class, ask the following true/false question and have students vote by holding thumbs up for true and thumbs down for false. Tally the votes and write the numbers on the board. Give the right answers.

- True or False: Hydropower dams reduce pollution (Answer: True)
- True or False: Hydropower dams are cheap to build (Answer: False: they can be very expensive to build.)
- True or False: Hydropower dams rarely interfere with natural wildlife (Answer: False: dams can disrupt migratory fish patterns and spawning habits, especially for species like salmon. This can have devastating effects on both the fish population and people whose livelihoods depend on these fish.)

Activity Embedded Assessment

Question/Answer: Ask students how hydromills and windmills are similar **(Both have "vanes" and a turbine shaft and both generate energy that is renewable)**.

Post-Activity Assessment

Engineering Design project: Divide students into groups and tell them that they are working for H2O Solutions, an engineering design firm that works mostly with waterwheels and water energy. The city has asked them to design a more efficient watermill. The firm has been split into several engineering teams (student groups). Tell the teams that they must design a functioning waterwheel that turns and their constraint is to use only the materials provided for their designs. Ask them to sketch their new design and test their designs. Have a few groups present their designs to the rest of the class indicating what elements worked well and what they could improve on.

- Ask students to describe, in general terms, how hydropower works. They can use some information from the demonstration/activity to support their ideas.
- Ask the students to brainstorm how they think they could make their watermill more efficient if they had even more resources (materials, time) available.
- Ask the students to compare other teams designs based on how well each meets the criteria and constraint of the problem. Decide which new design is the best and why?

Troubleshooting Tips

Prepare and test the waterwheel before demonstrating it to the class.

If a sink is not available, take students outside so they can pour cups of water from a bucket over their hydro-mills.

Insert the dowel into the neck of the bottle as an axle. Cut a circular opening in the center of the bottom of the bottle to let the dowel extend outside of the bottle.

Activity Extensions

- Divide the class into a few groups and provide each group with a different type of bottle (different shapes and volume capacities) with which to make hydro-mills. Ask each group to come to the sink where the tap water is running at the same flow rate for each water mill. Have students compare their water mills to their peers' based on the number of turns per minute for a given and constant water flow rate. Ask the students why their water mill performs differently than other groups' mills. Which type works the best? Why?
- Make some other turbine models. http://www.energyquest.ca.gov/projects/turbine.html or http://www.energyquest.ca.gov/projects/hydro-power.html
- Have students conduct research: How much water do Americans use daily? For what purposes? Do people in other countries use as much water? What are some ways to conserve water?

Activity Scaling

For lower-grade students, conduct this activity as a class demonstration.

For upper-grade students, add more constraints for their designs (i.e., cost of materials, time).

For upper-grade students, ask them to evaluate the hydro-mill as an energy source. This evaluation would involve measuring the amount of water that is needed to turn the mill a certain number of turns with a load. To do this, place a large bucket under the mill to capture the water as it falls off the mill. Then, see how many turns it takes to lift an object a given distance by turning the string around the neck of the bottle. Compare this ideal to real energy costs. (Calculate the percent efficiency by dividing the weight of the object by the weight of the water required to raise the object the same distance the water fell—about 1 foot—then multiply the result by 100.)

Have students also investigate with different variables: types/shapes of the turbine, number and position of fins on the turbine, etc.

References

- American Rivers, www.amrivers.org
- California Energy Commission, www.energyquest.ca.gov
- How Stuff Works, www.howstuffworks.com/hydropower-plant.htm
- Foundation for Water and Energy Education, fwee.org
- PBS Online, www.pbs.org/wgbh/buildingbig/dam/index.html
- U.S. Geological Survey, Water Science for Schools, ga.water.usgs.gov/edu
- U.S. Geological Survey, Water Resources of the U.S., water.usgs.gov

Other Related Information

Search for images at NREL at www.nrel.gov.

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