Investigating How Electricity is Generated

Electrically Speaking: How Does it Get From There to Here?

Introduction

Here are the facts. First, civilization depends on electricity. Second, electricity incurs substantial environmental costs. Third, use of electricity is not optimized. Fourth, the way we generate and use electricity is not sustainable.

To create a balanced sustainable electrical generation system, society must develop carbon-neutral, low impact power sources, ideally using renewable resources. Although such a mandate is imperative for a safe and prosperous future, the reasoning behind it is subtle and complex, and often hard for middle school students to grasp.

This lesson helps students understand how electricity is generated. It highlights the environmental cost of different methods of generating electricity. To make the lesson relevant to students' daily lives, they examine ways in which electricity impacts them personally.

In the lesson's activity, students build a model turbine. The students investigate the primary method of electricity generation using mechanical force. This challenges them to consider two key aspects of the physics of electricity generation: efficiency and energy transfer.

By understanding that energy transfer is the basis for generating electricity, students will connect the different methods of power generation to their environmental impact.

Testable Question: How can you transform kinetic energy into mechanical energy?

Objectives

- Compare the different ways in which electricity is generated
- Differentiate between renewable and nonrenewable resources for electricity generation
- Examine ways in which electricity impacts daily lives
- Build a model turbine
- Investigate efficiency and energy transfer in the context of electricity generation
- Identify the environmental impacts of electricity generation

Materials

- Computer with Internet access
- Library and/or classroom resources
- Cardboard tube (e.g., as used for aluminum wrap or clear wrap)
- Cardboard for holder and fins
- Cork
- Craft knife
- Fan
- Household fan (3 speed)
- Large pins
- Marker pen
- Plastic or metal strips for fins (optional)
- Tape
- Timer

Vocabulary

- CO2 – carbon dioxide, the primary greenhouse gas
- Efficiency – difference between amount of energy put in and energy wasted as heat and is calculated by heat and is calculated by the energy output/energy input x 100%
- Electricity – energy available from the flow of charge
- Energy – capacity of a system to do work
- Environment – the habitats surrounding an area
- Fossil fuels – hydrocarbon compounds formed from organic matter
- Generator – device used to convert mechanical energy into electricity
- Heat – energy transferred by a temperature difference
- Natural resources – things that we use provided by the environment
- Non-renewable – natural resources that are not renewed by nature over time
- Renewable – natural resources renewed by nature over time
- Transmission – method to transfer electricity from generator to device
- Turbine – device used to convert kinetic energy into mechanical energy
- Watts – amount of energy used per unit time

Essential background for teacher

This section is need-to-know information for the teacher to teach the lesson effectively.

Key questions:

- Why should we care about how electricity is generated?
- How does electricity impact our daily lives?
- How is electricity generated?
- How does a turbine work?
- What are the different ways electricity is generated?
- What is the benefit of using renewable versus nonrenewable resources to generate electricity?
- How is energy wasted during electricity generation?
- What are the environmental consequences of electricity production?

Key facts:

- Electricity is essential to modern civilization.
- Electricity is measured with several units including: watts for power, amperes for current and volts for electromotive force of potential.
- We use electricity in numerous ways including: heating and cooling our homes, lighting, labor-saving devices, entertainment, and electric vehicles.
- Industry and business uses electricity for lighting heating and cooling office buildings, office equipment, manufacturing and industrial plants.
- When we lose electric power, we lose all of the essential functions it serves.
- Electricity is generated by converting mechanical energy into electrical energy. The mechanical energy turns coils inside a generator. The coils are located next to magnets. The turning induces current that is then transmitted to end users or storage.
- A turbine works by converting various sources of kinetic energy into mechanical energy. A generator converts mechanical energy (usually rotational) to electrical energy.
- More than 90 per cent of our electricity is produced using nonrenewable resources. More than three-quarters of our electricity is produced using fossil fuels. Nonrenewable resources will run out, so using them to generate electricity is not sustainable. If we do not switch away from nonrenewable resources our present way of life cannot be continued. Any measure to improve efficiency will lessen demand on nonrenewable resources and help sustain our way of life.
- Most nonrenewable resources consume large amounts of energy for extraction, refinement and transportation. Uranium for nuclear fuel is first hard rock mined and then requires significant energy for processing, transportation. Redundant engineering is in place for safety at all sites involved with the handling nuclear fuel. Mountain top removal for the mining of coal degrades terrestrial and aquatic ecosystems. Oil is transported across oceans and continents before we can use it to generate electricity.
- Use of renewable resources is sustainable since these resources will not run out. By using renewable resources we can sustain our civilization indefinitely. Renewable resources have a smaller "carbon footprint" and so contribute less to global warming than fossil fuel-based nonrenewables.
- Inefficiency in electricity production and transmission arises from wasted heat, friction during generation and resistance during transmission. About a third of the heat energy produced by burning fossil fuels is converted to electrical energy. Two thirds is wasted as heat. Electricity is transmitted at high voltages to reduce resistance.
- Mass production of electricity incurs environmental costs including pollution and land degradation. Fossil fuel plants pollute the atmosphere with carbon dioxide, which contributes to global warming, and sulfur dioxide, which causes acid rain. Nuclear power generation creates radioactive waste that needs special handling procedures and fortified storage facilities. Extraction of fossil and nuclear fuels also incurs a substantial environmental cost through pollution risk and land degradation. Health problems occur downwind of oil refineries, nuclear processing plants and coal fired power plants. The environmental impact of renewable sources of energy is much lower.
- Electricity production can impact on marine ecosystems in several ways. Greenhouse gases emitted by the combustion of fossil fuels impact the marine environment in two significant ways. First, CO_2, SO_2 and NO_x gases mix with water to make acids. The resulting acid rain and acid runoff can damage fragile ecosystems such as coral reefs. At the poles, CO_2 mixed into the water during winter storms also causing acidification. It can cause imbalances in water chemistry of lakes and oceans. The second effect of the addition of greenhouse to the atmosphere is the

warming of the atmosphere which in turn warms the oceans causing bleaching of corals and dead zones. Oil spills can devastate marine ecosystems and cause long-term damage to shoreline habitats. Discharge of warm water (a byproduct of cooling systems) can disrupt the ecology around a power station. Although renewable resources are desirable, there is little research on the environmental impact of large tide or wave power installations.

General Background for Teacher

How we generate electricity

Electricity is a fundamental physical force. Humans have learned to generate, and harness this natural force to use it in a multitude of ways.

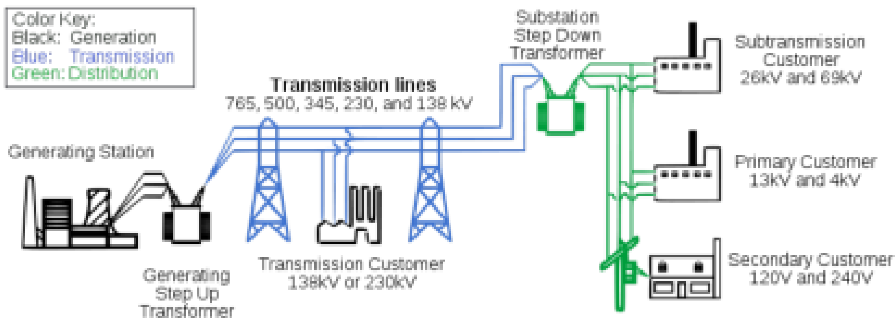
Most power generating systems involve using turbines to convert mechanical energy into electrical energy. Any moving medium can drive these turbines. The commonest is steam. Steam is produced by heating water. Fossil fuels are the primary way to produce such heat. Coal plants produce the majority of electricity in the United States. Nuclear, geothermal and biomass energy are other ways water is heated to produce steam to power turbines.

Of these, only biomass and geothermal energy are renewable resources. Fossil and nuclear fuels are nonrenewable. Some nonrenewable resources will run out in the next century or even sooner. Given the dependence of society on electricity, we must ensure that electrical power generation is sustainable. In addition, nonrenewables incur a heavy environmental cost. Fossil fuels produce CO_2, the gas principally responsible for global warming. Fossil fuels include coal, natural gas, and petroleum or crude oil. Burning fossil fuels also creates sulfur dioxide, which reacts with atmospheric water to form sulfuric acid. The resulting acid rain damages habitat and disrupts water chemistry of natural aquatic systems. Fossil fuel extraction is a source of pollution in sensitive marine and terrestrial environments. Although nuclear power does not produce CO_2, disposal of nuclear waste requires substantial resources. It continues to be an environmental and security risk for many decades afterwards.

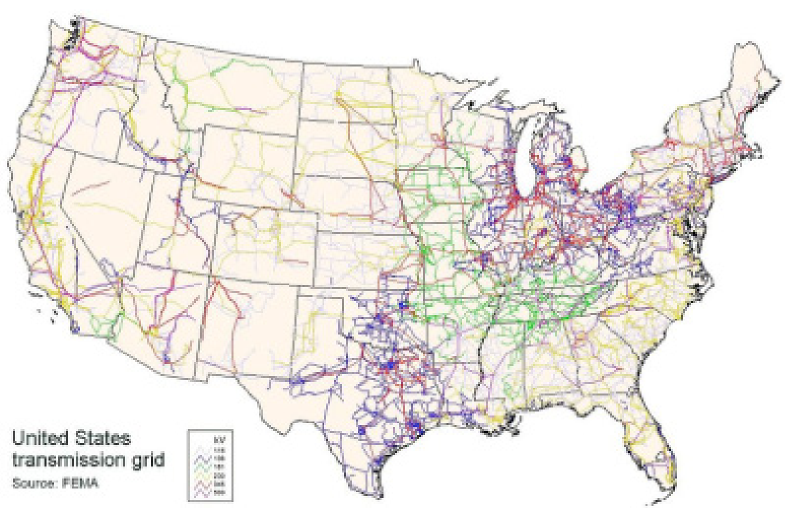
While not perfect, renewable energy has a much smaller environmental footprint. Solar power is the only method that does not use turbines. Solar cells directly convert light energy to electricity. They are reliable and efficient. The drawback is that they are expensive. Their deployment requires considerable land area. In urban areas, they can be used on new or existing roofs of buildings. There are many exciting advances being made to increase efficiency and reduce the costs of solar cells.. A variety of methods are used to tap geothermal energy. The commonest is to tap into steam from water heated deep underground. This is used to turn turbines. The drawback of geothermal is the lack of suitable sites. Biomass creates methane gas that is burned to create steam and power turbines. Several initiatives are underway to tap into the methane created in landfills. Biomass derivatives (such as alcohol) can be burned to create heat. The problem is to get sufficient biomass to create enough gas for commercial electricity generation. Wind power turns fans that directly turn turbines. Opponents argue that wind farms are an eyesore. Large areas are needed to generate electricity on a commercial scale. Sites are limited to areas where wind blows reliably. Solar, wind and hydroelectric are the only methods that do not use steam to turn turbines. Hydroelectric power relies on dams that store water. When the water is released, it drives turbines. Hydroelectric power necessitates the flooding of natural areas and can disrupt river ecology downstream.

How is electricity transmitted?

The diagram below shows how electricity generated at a power plant is transmitted to the enduser. In the United States commercial power stations transmit electricity into a national power grid. Visualize it as a net covering the country. Regional electric companies manage the distribution of electric power. At substations, transformers step down the voltage to a usable form, and businesses and homes can use the electricity.



http://en.wikipedia.org/wiki/File:Electricity_grid_simple-_North_America.svg



http://en.wikipedia.org/wiki/File:UnitedStatesPowerGrid.jpg

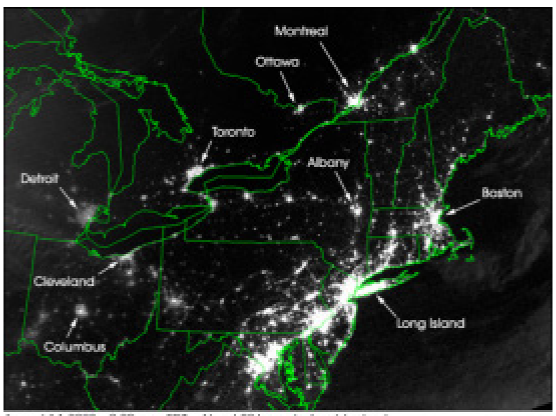
How does a generator work?

A generator is a device that converts mechanical energy into electrical energy. The process is based on the relationship between magnetism and electricity. In 1831, scientist Michael Faraday discovered that when a magnet is moved inside a coil of wire, electrical current flows in the wire. A typical generator at a power plant uses an electromagnet — a magnet produced by electricity — not a traditional magnet. The generator has a series of insulated coils of wire that form a stationary cylinder. This cylinder surrounds a rotary electromagnetic shaft. When the electromagnetic shaft rotates, it induces a small electric current in each section of the wire coil. Each section of the wire becomes a small, separate electric conductor. The small currents of individual sections are added together to form one large current. This current is the electric power that is transmitted from the power company to the consumer.

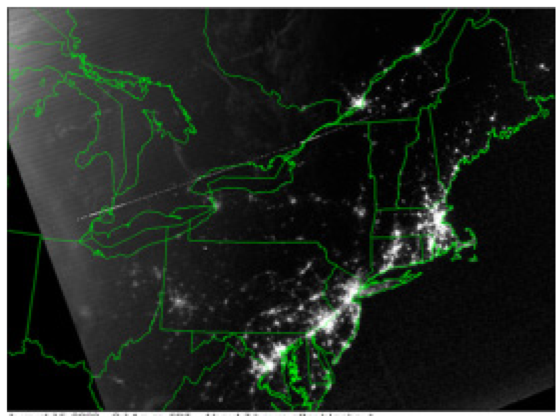
Source: http://www.eia.doe.gov/kids/energy.cfm?page=electricity_science-basics

Engage

1. Introduce students to the key concepts. (See Vocabulary.)
2. Ask students: Have you ever experienced a power outage or black out? What happened? How did you feel? Was it inconvenient? What did you miss the most during the power outage? What did you like about the power outage? Did you do anything fun and different during the power outage? How long did it last? What caused the outage? Was it widespread?
3. Ask students: What happens elsewhere during a blackout? (Prompt students with additional questions. What happens at the shopping mall? What happens to traffic? What happens at hospitals?) The aim is to get them to realize how much society depends on electricity.
4. Ask students: Investigate real time power outages at this website. http://progress-energy.com/shared/outages/car/default.aspx How many power outages are there? How is this information useful to the power company?
5. Ask students: Compare the two photographs below. They are satellite images of the biggest blackout in U.S. history. It occurred on August 14, 2003, leaving 50 million people without power. The first is 20 hours before the black out and the second is 7 hours after the initial blackout started. (Prompt them to observe which cities were most affected. Lights in Long Island, Detroit, Cleveland, Columbus, Toronto, and Ottawa are either missing or visibly reduced. Boston was relatively unaffected.



August 14, 2003 • 9:29 p.m. EDT • About 20 hours before blackout


August 15, 2003 • 9:14 p.m. EDT • About 7 hours after blackout

http://visibleearth.nasa.gov/view_rec.php?id=18796

6. Ask students: How does electricity get to your house or school? What is the point of origin for the transmission of the power? How is it transmitted? Where are the places an interruption of service could occur?
7. Prompt students with additional questions. How is electricity supplied to so many homes and businesses? Where does electricity come from? Do you have electricity transmission lines near your house?
8. How is electricity for your area generated? Is electricity generated the same way all across the country? What are some other ways to generate electricity and where in the country do you think these methods are most in use?

Lesson Lead-in

1. Explain that electricity is generated when a coil turns inside a magnet. This rotation is the basis for generating power on a large scale.
2. Explain that millions of homes and business, and large industrial and manufacturing plants are powered by electricity. We need big power plants to generate enough electricity to meet those needs.
3. To generate electricity, a turbine turns a generator. There are various ways this can be achieved. Explain that fossil and nuclear fuels heat water to create steam. In turn the steam turns the turbine.
4. Ask students: what other ways, besides steam, power stations could turn a giant turbine? (Prompt them with the following images:

http://www.fws.gov/digitalmedia/cdm4/item_viewer.php?CISOROOT=/natdiglib&CISOPTR=6861

http://apps1.eere.energy.gov/news/images//08_03_12_hoover_dam.jpg

5. Explain that they are going to build a turbine. This will demonstrate the principle for using mechanical energy to turn generators.

Explain (Sample Answers to Analysis Questions)

Use these answers to help explain the concepts and ideas behind the lab activity (Analysis in the Student Resource Section).

1. How fast in RPMs did your turbine spin with the first design on the slowest fan speed?
   Answers will vary.
2. How fast in RPMs did your turbine spin with the first design on the fastest fan speed?
   Answers will vary. (This figure should be higher than in 1 above)
3. What is the difference in your turbine RPMs between the slowest and fastest fan speeds with the first design?

Answer: Subtract answer 1 from answer 2.

4. How fast in RPMs did your turbine spin with the second design on the slowest fan speed?
   Answers will vary.
5. How fast in RPMs did your turbine spin with the second design on the fastest fan speed?
   Answers will vary.
6. What is the difference in your turbine RPMs between the slowest and fastest fan speeds with the second design?
   Answer: Subtract answer 4 from answer 5.
7. Was your second design an improvement on the first? Explain.
   Answers will vary. Sample answer: Since the RPMs were faster at the same fan speeds for the second design, it was an improvement.
8. In what ways could you improve further on your design?
   Answers will vary. Sample answer: Various approaches could be taken. A more solid framework would decrease movement of the cardboard holder. We could use better axle material to reduce friction of turning. We could experiment some more with the angle and shape of the fins.
9. You used wind to turn the turbine. What other ways could you use to turn the turbine?
   Answers will vary. Sample answer: The turbine could be turned with a flow of water, such as from a faucet. We could use steam blowing from a kettle to turn the turbine.
10. How would you generate electricity with your turbine?
    Answers will vary. Sample answer: To generate electricity we would have to rig a generator to the turbine. The turbine would rotate the generator and generate electricity.

Elaborate or extend

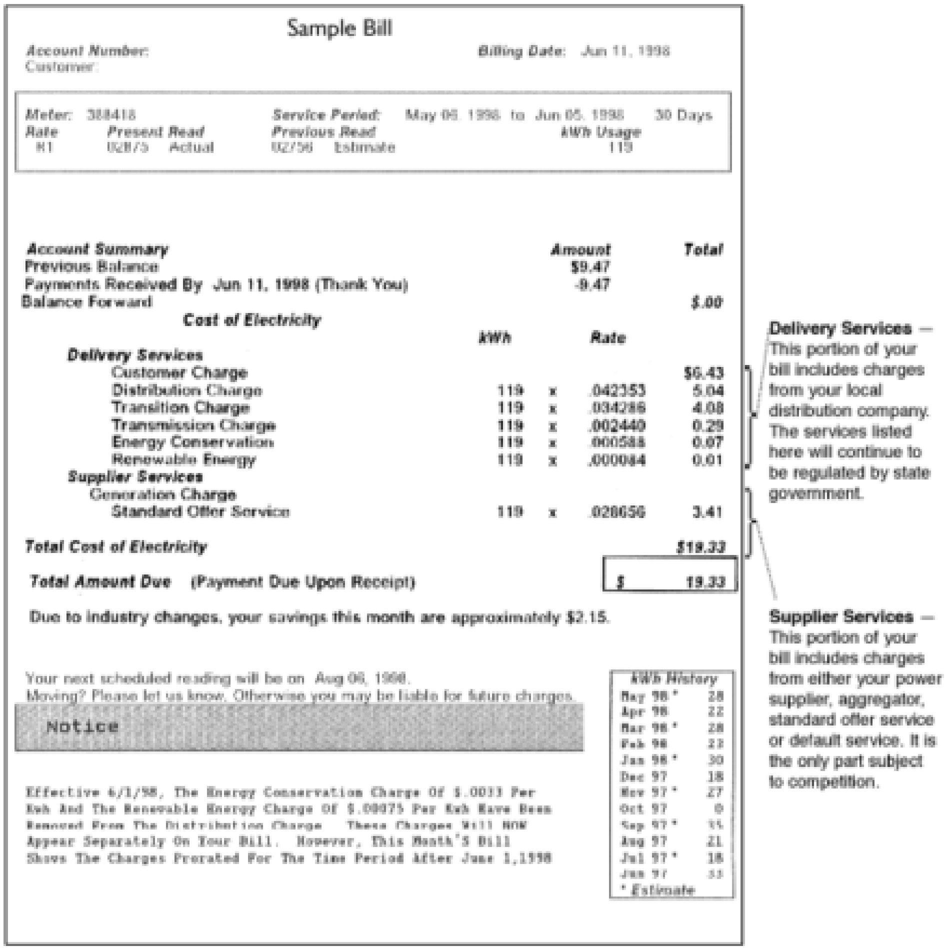
1. Ask students: Examine the sample electric bill. Why do we have to pay for electricity? What is kWh? Why do you think there are charges for transmission, energy conservation and renewable energy?
2. Ask students: Are there ways to reduce your electric bill? What are the economic and environmental benefits of a lower electric bill?
3. Ask students: If we lower our electric bill by using less electricity, how will that change the need for new or bigger power stations?
4. Ask students: Research resources used for electrical power generation using the websites provided. (Split the class into separate groups to research different types of power generation. Each group is responsible for reporting to the class the economic, environmental and political advantages and disadvantages of using different power sources: oil, coal, natural gas, nuclear, wind, hydroelectric, wave or tide, geothermal.) The total cost of the production of electricity needs to be considered from procurement and extraction of the resources used to the disposal of any waste products.
5. Ask students: If we can use less electricity, what kinds of resources can we use to meet our needs for electric power?

Evaluate

Discuss and write answers to the following questions:

1. How much did your turbine performance improve between the first and second design?
2. In what ways might turbine design be important for efficient generation of electricity?
3. What might go wrong in the steps to get electricity from the power station to your home?
4. What steps can you take at home to increase efficiency of energy use?

5. What are the advantages and disadvantages of using renewable and nonrenewable resources for electricity generation?
6. What are three environmental impacts of using fossil fuels for electricity generation?



Sample Bill

Account Number:
Customer:
Billing Date: Jun 11, 1998

Meter: 388418 *Service Period:* May 06, 1998 to Jun 05, 1998 30 Days

Rate	*Present Read*	*Previous Read*	*kWh Usage*
R1	02875 Actual	02756 Estimate	119

Account Summary			***Amount***	***Total***
Previous Balance			$9.47	
Payments Received By Jun 11, 1998 (Thank You)			-9.47	
Balance Forward				*$.00*

Cost of Electricity

	kWh		***Rate***	
Delivery Services				
Customer Charge				$6.43
Distribution Charge	119	x	.042353	5.04
Transition Charge	119	x	.034286	4.08
Transmission Charge	119	x	.002440	0.29
Energy Conservation	119	x	.000588	0.07
Renewable Energy	119	x	.000084	0.01
Supplier Services				
Generation Charge				
Standard Offer Service	119	x	.028656	3.41
Total Cost of Electricity				*$19.33*

Total Amount Due (Payment Due Upon Receipt) $ 19.33

Due to industry changes, your savings this month are approximately $2.15.

Your next scheduled reading will be on Aug 06, 1998.
Moving? Please let us know. Otherwise you may be liable for future charges.

Notice

Effective 6/1/98, The Energy Conservation Charge Of $.0033 Per Kwh And The Renewable Energy Charge Of $.00075 Per Kwh Have Been Removed From The Distribution Charge. These Charges Will NOW Appear Separately On Your Bill. However, This Month'S Bill Shows The Charges Prorated For The Time Period After June 1,1998

kWh History	
May 98 *	28
Apr 98	22
Mar 98 *	28
Feb 98	22
Jan 98 *	30
Dec 97	18
Nov 97 *	27
Oct 97	0
Sep 97 *	35
Aug 97	21
Jul 97 *	18
Jun 97	33

* Estimate

http://www.mass.gov/Eoca/images/doer/bill.gif

Online resources

http://www.eia.doe.gov/energy_in_brief/slideshows/renewable_energy.html
http://www.eere.energy.gov/kids/renergy.html
http://www.energy.gov/forstudentsandkids.htm
http://www.eia.gov/energyexplained/index.cfm
http://www.energystar.gov/index.cfm?c=kids.kids_index

1. National Standards

A. ESS Core Idea 4: Human activities are constrained by and, in turn, affect all other processes at Earth's surface. [Human Interactions with Earth] Human impacts on Earth Grades 6 – 8

Sub-question: *How do humans change the Earth?*

Humans have become one of the most significant agents of geologic change at Earth's surface. The activities that have built human civilizations have both positive and negative consequences related to the sustainability of these civilizations.

1.How do human activities alter Earth?

Most actions that change the Earth's environments have both costs and benefits.

Modest changes in individual and societal activities can significantly reduce pollution.

B. ESS Core Idea 4: Human activities are constrained by and, in turn, affect all other processes at Earth's surface. [Human Interactions with Earth] Grades 6 – 8

ESS4.D: Global Climate Change

Sub-question: *How will global climate change affect humans?*

Climate change, driven by both natural and human activities, has large consequences for all of Earth's surface systems, including humans. Humans can take actions to reduce climate change and its impacts.

1.How do human activities alter Earth's climate?

Humans alter global climate patterns by burning fossil fuels, releasing chemicals into the atmosphere, reducing forest cover, and by the rapid expansion of farming, development, and industrial activities.

PS Core Idea 3: Transfers of energy within and between systems never change the total amount of energy, but energy tends to become more dispersed; energy availability regulates what can occur in any process. [Energy and its Transformations]

PS3.B: Energy for Life and Practical Use. The Special Role of Food and Fuel.

Sub-question: *If energy is conserved, how can we use it?*

In everyday language we speak of producing, using or wasting energy. This is because energy that is in concentrated form is useful for running machines, generating electricity for heat and light etc, while dissipated energy in the environment is not readily recaptured. Most processes tend to dissipate energy. Food, fuel and electric power can be moved from place to place to provide energy where needed.

What processes produce the energy we use? What process makes things slow down and stop (lose energy)? Energy cannot be made or destroyed. When we talk about processes that produce it, we mean a process to store it in concentrated form or produce electrical energy, or chemical reactions such as burning that release energy.

Where do we get energy?

Electric power generation uses fossil fuels (coal, oil and natural gas), nuclear fission, or renewable resources (solar, wind, tidal, geothermal and hydro- power).

Transportation today chiefly uses fossil fuels but electric and alternate fuel (hydrogen, biofuels) vehicles are a growing sector.

All forms of electrical generation and transportation fuels have associated economic, human, and environmental costs and risks, both short and long term. Technological developments and regulatory decisions can change the balance of these factors.

What is energy efficiency?

While energy cannot be destroyed, it can be converted to less useful forms, such as noise and thermal energy lost to the surrounding environment. In designing any machine or any system for energy storage and distribution, maximized efficiency means maximized desired impact per input fuel. Efficiency is a major element to optimize because it reduces costs, waste materials and other environmental impacts.

Student Resource page

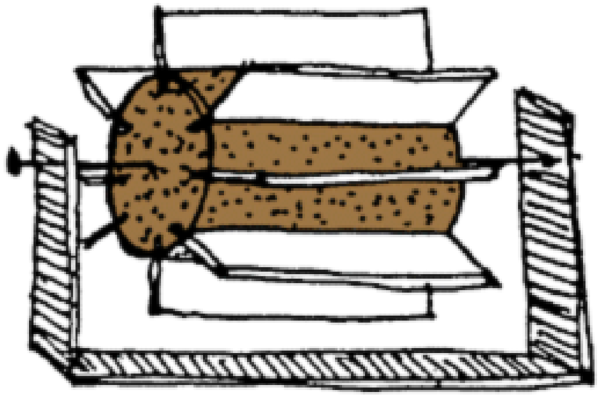
Explore: Hands On Activity – Build a turbine

Objective: Design a turbine turn that will turn the fastest using the least amount of energy.

Power stations use turbines to convert kinetic energy into mechanical energy. In this lab you will build a model turbine. Then you will change the design to see if you can improve the performance of the turbine.

Materials:

- Cardboard tube (e.g., as used for aluminum wrap or clear wrap)
- Cardboard for holder and fins
- Cork
- Craft knife
- Household fan (3 speed)
- Large pins
- Marker pen
- Tape
- Timer



Procedures:

1. Use the picture below as a guide to how to build your turbine.
2. Push a pin in the ends of the cork to act as axles.
3. Make a U-shaped cardboard holder for it.
4. Use the craft knife to cut slits into the cork.
5. Cut pieces of card to act as fins for the turbine.
6. Place the card the slits made in the cork.
7. Color one of the fins with the marker pen.
8. Place the cork into the holder.
9. Tape the holder to a table or similar surface.
10. Use the fan on the slowest speed setting to create wind to blow at your turbine.

Student Resource page (Continued)

Explore: Hands On Activity – Build a turbine

11. Use the timer to count how many times the colored fin makes a complete turn in one minute. (This is the revolutions per minute, or RPM of your turbine.) Record your data in the worksheet.
12. Repeat steps 9 and 10 using the two additional speeds of the fan.
13. Using a new cork, repeat steps 4 through 11. This time use a different design for the fins. (Hint: You can change the angle of the fins, or their shape, or both.)

Analysis:

1. How fast in RPMs did your turbine spin with the first design on the slowest fan speed?
2. How fast in RPMs did your turbine spin with the first design on the fastest fan speed?
3. What is the difference in your turbine RPMs between the slowest and fastest fan speeds with the first design?
4. How fast in RPMs did your turbine spin with the second design on the slowest fan speed?
5. How fast in RPMs did your turbine spin with the second design on the fastest fan speed?
6. What is the difference in your turbine RPMs between the slowest and fastest fan speeds with the second design?
7. Was your second design an improvement on the first? Explain.
8. In what ways could you improve further on your design?
9. You used wind to turn the turbine. What other ways could you use to turn the turbine?
10. How would you generate electricity with your turbine?

Data Collection
Student Worksheet

RPMs of turbine designs at different fan speeds

	Fan Speed		
	Slowest	Medium	Fastest
Design 1			
Design 2			

Draw and label a picture of each fan design. Include a title and scale for each drawing. Label all the parts and materials.

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