

Electricity Production and the Environment

Canadians use about 2 000 000 000 000 000 000 J (2×10^{18} J) of electrical energy every year. Powering the generators that provide this electricity is an enormous task that has significant environmental effects.

Electric Energy from Burning Fuels

Fuel oil, natural gas, and coal, are burned in large **thermo-electric**—generating plants to produce about one quarter of our country's electricity. These fossil fuel resources are being consumed faster than they are produced in nature, so they are considered **non-renewable resources**.

Biomass, solid material from living things, can also be burned to power thermo-electric generators. Trees, agricultural crops and crop wastes, aquatic plants, wood, animal wastes, and municipal wastes: all these substances can be used as fuels, or turned into fuels and used to generate electricity. Biomass is considered a **renewable** energy source because it can be continually replenished.

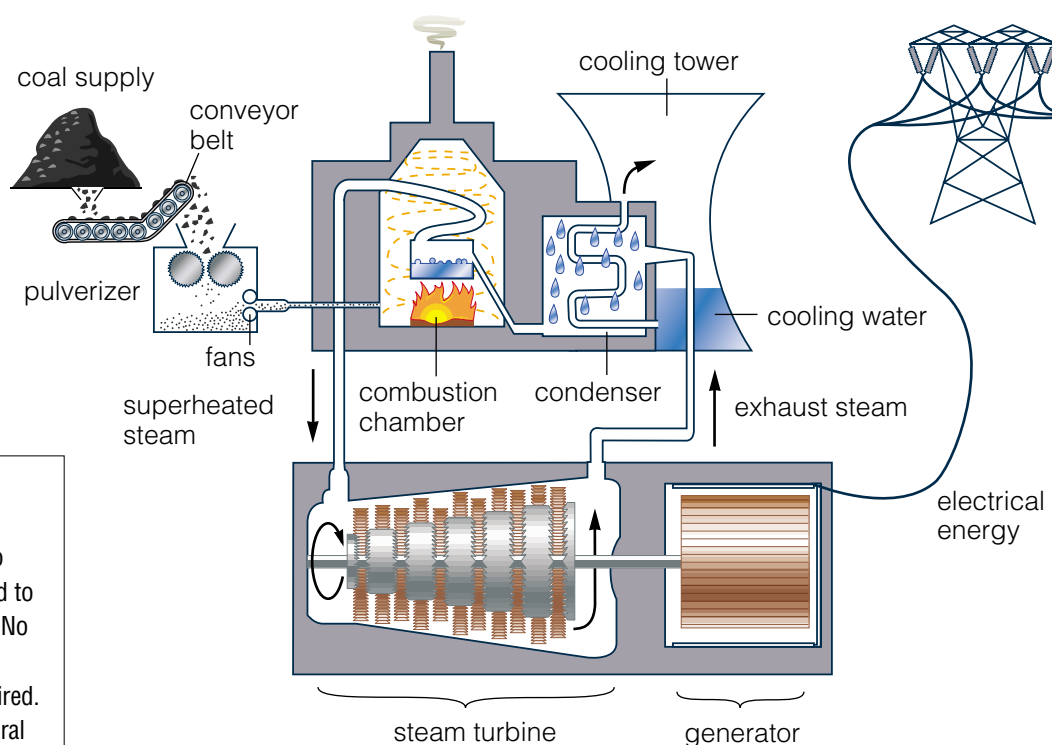


Figure 4.51 Heat from burning coal converts water into steam. The high-pressure steam flows through pipes into a turbine. The spinning turbine turns a generator that produces electric energy. Steam leaves the turbine cooled, condensed, and recycled through the turbine.



Turbogenerators use exhaust gases from burning fossil fuels to spin a turbine coupled to an electric generator. No steam, condenser, or cooling tower is required. In Alberta, some natural gas production facilities generate electricity with turbogenerators fueled by *flare gas*, a waste product from the facility.

Seek the Source

How does electrical production in Alberta compare to other parts of our country? In this activity, you will contrast the most common sources of electric energy in Canada.

Procedure

1. Use the map below and draw *one* bar graph that shows each of the following variables for regions with total production of more than 1000 GW•h. Shade or colour code the four graph bars for each region and include a legend (key) to the code.

- total electricity production
- electricity from *thermo-electric* sources
- electricity from *hydro-electric* sources
- electricity from *nuclear* sources

Computer **CONNECT**

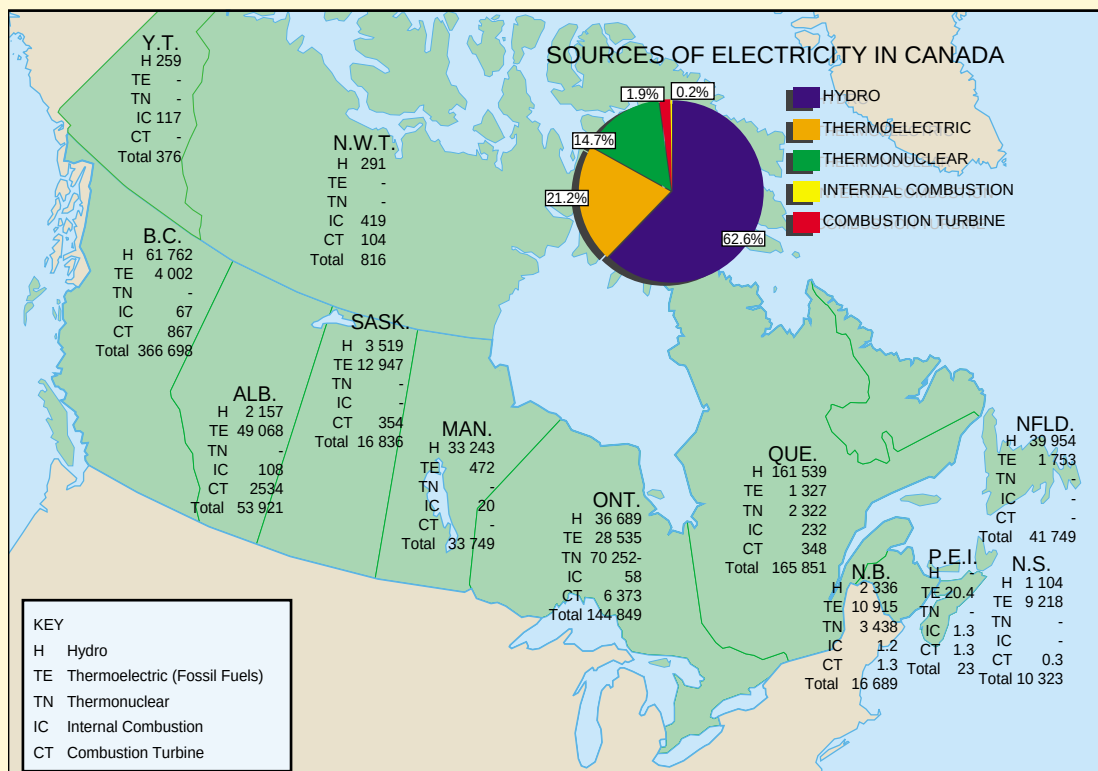
Use a computerized spreadsheet/graphing program to draw the bar graph.

What Did You Find Out? Analyzing and Interpreting

1. How does total electrical energy production in Alberta compare to that in other provinces? What percentage of Canada's electricity is produced in Alberta?
2. Which source of energy supplies most of Alberta's electricity? How does the electricity production in other provinces from this source compare to that of Alberta?
3. Rank the sources of electricity in Canada from highest to lowest.

Extension

4. Explain why Alberta, B.C., and Ontario produce most of their electricity in different ways.
5. Identify sources of electrical production other than the five mentioned on the map. Explain why each method is not more widespread.



Recent annual values for the amount of electric energy generated in each province are given in GW•h (gigawatt hours). A GW•h is a huge amount of energy: 3.6×10^{12} J. (source: Statistics Canada)

Efficiency of Electric Lighting from Coal

In every step in the process of mining coal, generating electricity, transmitting it to your home, and lighting a lamp, some energy is used or escapes in the form of thermal energy in the process. In this investigation you will examine the efficiency of operating electric lights with power produced by coal-burning generators.

Question

What percent of the energy originally stored in the coal is actually converted into the electricity used in a lightbulb?

Hypothesis

Examine the information about electricity production that is given below. With your classmates, discuss how to use the figures given to estimate an answer to the question. Calculate an estimate and explain how you arrived at it.



Summary of steps in converting energy stored in coal to electric energy, and to then light in a lamp.

1. *Mining the coal:* Mining coal uses relatively little energy compared with the energy stored in the coal that is produced. About 1% of a typical mine's coal production would supply enough energy to operate the mine. The remaining 99% of the mine's energy output is available for other uses.
2. *Transportation of coal:* Moving coal from the mine to the power plant uses some energy to power the train. The efficiency of transporting coal is about 97%.
3. *Generation of electricity:* Thermo-electric generating plants are not very efficient. Most of the energy from the coal escapes from the stacks or from coolant water as heat. Only about 33% of the energy from the coal that is burned is converted into electricity.
4. *Transmission of electricity:* When electric energy travels through power lines, some of the energy goes into heating the conductors. Electric power transmission is about 85% efficient.
5. *Conversion to light:* Incandescent light bulbs are very inefficient. Most of the electric energy is converted to heat. At best, an incandescent light bulb will be about 15% efficient.

In this investigation, you will start with an amount of coal that has 1 million joules (1 000 000 J or 1.0×10^6 J) of stored energy. You will determine the amount of useful energy that remains after each step in the process. Then you will determine the overall efficiency of the process.

Procedure

- 1 Make a table with the headings shown below. Allow enough rows for all the steps listed in the summary. Give your table a title.

Step	Energy at beginning of step (J)	Efficiency of step (%)	Energy at end of step (J)	Overall efficiency (%)
mining	1 000 000			

- 2 In the first column, write the names of the steps in the process of converting the energy stored in coal into electric energy.
- 3 In the second column, write the percent efficiency of each step.
- 4 Determine the amount of stored energy that remains after the process described in each step. You can determine this value by using the following formula.

Stored energy remaining =

$$\text{Energy remaining in previous step} \times \left(\frac{\text{efficiency}}{100\%} \right)$$

For example, the stored energy remaining after the first step is

$$\begin{aligned} \text{Stored energy remaining} &= 1\,000\,000 \text{ J} \times \left(\frac{99}{100} \right) \\ &= 990\,000 \text{ J} \end{aligned}$$

Write the answer in the third column. Then 990 000 J will be the “energy remaining” in the previous step when you do the calculations for the second step. Complete all the calculations for “Stored energy remaining.”

- 5 In the third column, compare the remaining energy to the original energy of the coal. You can calculate this value with the following formula.

Overall efficiency =

$$\frac{\text{Stored energy remaining} \times 100\%}{1\,000\,000 \text{ J}}$$

Write your results in the last column.

Analyze

1. Which step or steps in the conversion process is most efficient? Which step is least efficient?
2. What is the overall efficiency of converting the energy stored in coal to the energy of light from a light bulb?

Conclude and Apply

3. Carefully examine each step in the conversion process. Using your past studies as background, describe a way in which the efficiency of each step could be improved.



Figure 4.52 Open-pit mines affect land, water, and wildlife so much that projects such as the Cheviot Mine near Jasper have been abandoned after protests by environmentalists.

Fossil Fuels Affect Land and Air

Coal is the most common fuel for thermo-electric power plants in Alberta. Known reserves in this province are huge, enough to provide for as much as 800 years of domestic consumption. Production and use of coal, however, have serious environmental side effects. **Open pit mining** of surface deposits disturbs soil and vegetation (see Figure 4.52). Underground mines produce waste materials called “tailings,” which accumulate near the mine. Water used in the mining process or seeping through the tailings becomes acidified and contaminated.

When fossil fuels, including coal, are burned to generate electric energy, contaminants such as visible particles and invisible gases escape from the smokestacks. Electrostatic precipitators can remove most of the solid particles, but they cannot remove contaminating gases, such as sulfur dioxide (SO_2).

Sulfur dioxide is one of the causes of acid rain, which harms plant and animal life. Antipollution systems called **scrubbers** can remove sulfur dioxide. Scrubbers spray a water solution through the waste gases. Most, but not all, of the SO_2 and other pollutants react with chemicals in the water and are removed.

Even if there were no contaminants such as SO_2 , complete burning of pure coal or natural gas would still produce carbon dioxide gas (CO_2). Carbon dioxide is a natural part of the atmosphere. Every time you exhale, you breathe out some carbon dioxide. However, carbon dioxide is a **greenhouse gas**, which means that it helps delay the escape of heat from Earth’s atmosphere. If too much carbon dioxide, methane, and other greenhouse gases accumulate in the atmosphere, they absorb more heat from the surface of Earth. This could lead to a rise in the average temperatures on Earth — global warming.

The increased concern for the environment has led to more power-generating plants that burn natural gas rather than coal. Natural gas burns much cleaner than coal, producing less SO_2 . As electricity demand increases, this fuel, although somewhat more expensive, is an attractive alternative.

DidYouKnow?

Wastes decomposing in landfills produce “landfill gas,” which can be used as a fuel for thermo-electric plants. This process is used on a small scale in Edmonton’s Clover Bar landfill. Landfill gas is largely methane, the same chemical as natural gas.

Electric Energy from Flowing Rivers

Hydro-electric plants, use water pressure to generate electric energy. Large dams cause the water level to rise high above the power plant, which is often located inside the dam. In previous science courses, you learned that as the water depth increases, the pressure at the bottom becomes very large. Figure 4.53 shows how water flowing under great pressure is used to produce electricity.

A channel, called a penstock, directs the water from the bottom of the reservoir to a turbine. The high pressure of the rapidly flowing water turns enormous turbines, which then turn electric generators. The energy of the water stored in the reservoir is converted into electric energy. High voltage power lines carry the resulting electricity over many kilometres from the hydro-electric plant to cities, towns, and farms.

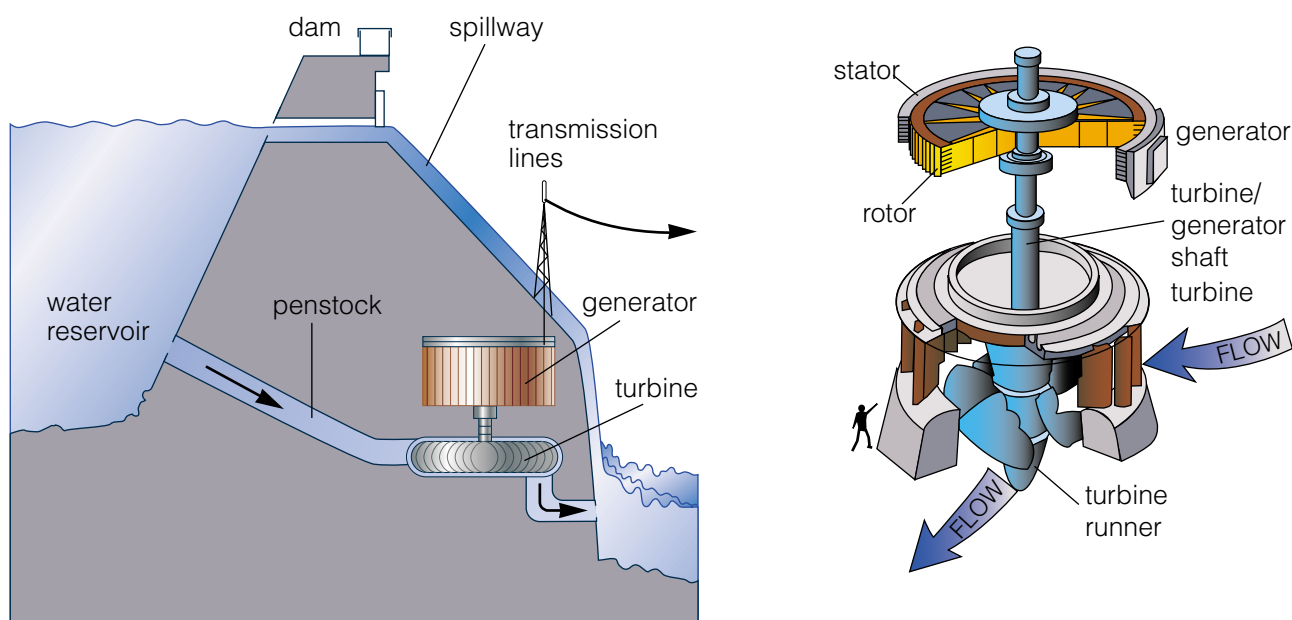


Figure 4.53 Energy is stored in the reservoir due to the tremendous mass of water and its height above the base of the dam. The turbine and generator convert this stored energy into electric energy.

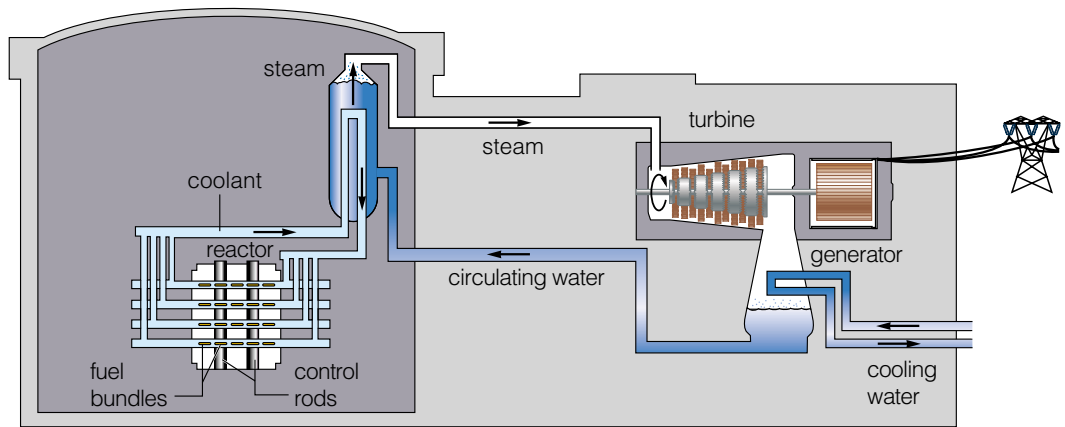
Hydro-electric power plants appear to be a very clean form of electric energy generation. They have no smokestacks and they use no radioactive materials. However, reservoirs, which store water behind the dams, flood many hectares of valuable land. Homes, small villages, and even entire towns may need to be moved, displacing people and industries. When land is flooded, submerged vegetation decays. Micro-organisms responsible for this process use up the oxygen supplies in the water and sometimes decaying matter produces methane gas. These conditions make it impossible for some species of fish to survive. Other forms of life, such as algae, take over and change the ecosystem. No matter where the dam is built, some form of life is threatened.

Energy from Atomic Reactions

Bombarding uranium atoms with tiny particles called neutrons causes the uranium to split into two smaller atoms. In this process, called **nuclear fission**, a tremendous amount of energy is released. Figure 4.54 shows the process of **thermonuclear** electric generation.

The fission reactions produce tremendous amounts of heat, which is carried away from the reactor core by a coolant. Pipes carry the coolant through a tank of water, producing steam. From this point, the process is very similar to a thermo-electric-generating station. The steam turns a turbine connected to a generator that produces electricity. Steam leaving the turbine is cooled, condensed, and recycled. The waste heat is released into the environment.

Figure 4.54 This simplified diagram shows how a CANDU (Canadian Deutrium Uranium) reactor produces electricity from nuclear energy. CANDU reactors are designed and built in Canada and have been sold around the world.



Fission reactors do not release soot or gases that cause acid rain, nor do they release greenhouse gases. However, used (spent) reactor fuel is highly radioactive for thousands of years. This means it emits high-energy particles and rays that can damage living tissues. Safe handling, transportation, and storage of these radioactive waste materials are unsolved environmental problems.

The reactors themselves also become slightly radioactive after years of use, so they are difficult and expensive to decommission.

Another type of nuclear reaction, however, does not produce large quantities of radioactive waste. In the Sun and other stars, **nuclear fusion** joins very small atoms to form a larger atom. Huge amounts of energy are released in this process. Scientists have produced controlled fusion reactions experimentally, but only for seconds. Developing technology to create and use continuous controlled fusion as a power source is an extremely difficult and expensive project that will take many decades.

DidYouKnow?

There are no nuclear power stations in western Canada. Many European countries are phasing out their nuclear power stations in favor of more environmentally friendly energy sources.

Heating the Environment

All thermonuclear and thermo-electric-generating plants release thermal energy into the environment. Seventy percent of the thermal energy from nuclear fuel and 43% from coal, oil, and gas leave the plant in the cooling water. **Thermal pollution** occurs when this warm water is returned directly to the lake or river from which it is taken, increasing the water temperature. Even a change of a few degrees can affect the plant and animal life in the water. Organisms adapted to one temperature will not thrive at another, even similar, temperature. Organisms not usually found in the lake or river may begin to replace the original species. To reduce thermal pollution, large generating plants have cooling ponds or towers where waste water can return to the temperature of the surroundings before it is released.

Cogeneration

It makes environmental sense to design electricity-generating stations as **cogeneration systems** that produce electricity and also supply thermal energy, such as hot water or steam, for industrial or commercial heating. Cogeneration power plants are often built near industrial complexes. The plant provides electricity and heat or steam to the industry and may sell excess electricity to the provincial power grid. One example of this type of facility is the Poplar Creek power plant located near Fort McMurray. The power plant provides electricity and heat needed to extract oil from the tar sands and then adds any surplus electricity to the Alberta power grid. Not only do these types of plants reduce the amount of energy wasted, they also reduce the dependence of large industrial power users on the Alberta electricity grid. This reduced demand makes it easier to meet the electricity needs of the rest of the province's consumers.

DidYouKnow?

Distribution of electric power can also cause environmental problems. Power grid transformers built before 1977, for example, often contained insulating chemicals called "polychlorinated biphenyls" or PCBs. PCBs persist, bioconcentrate, and can cause health problems if they are released when aging transformers are replaced. Some people are concerned that high-voltage transmission lines themselves, which produce radiation similar to radio waves, may be linked to health problems in people living nearby.

INTERNET CONNECT

www.mcgrawhill.ca/links/sciencefocus9

Three of the largest thermo-electric plants in Alberta are located on Lake Wabamun, which is about 70 km west of Edmonton. Keephills, Sundance, and Wabamun plants produce enough electricity to supply the equivalent of 3.3 million Alberta households. More than 15 million t of coal are burned in these three plants each year, all of which are obtained from surface mines in the area. To learn more about the effects they produce on local ecosystems, go to the web site above, and click on **Web Links** to find out where to go next.



Figure 4.55 Wind turbines similar to these generate electricity which powers C-train public transit equipment in Calgary.

Alternative Energy Sources

In 1998, less than 1% of Canada's electricity was generated from renewable energy sources. As supplies of coal, oil, and natural gas are depleted, however, these fuels are becoming more costly. Energy from the Sun, wind, and tides, which until now has been too expensive or too difficult to harness, is rapidly becoming competitive with conventional energy sources.

Windmills, for example, were used to pump water or generate electricity in rural Alberta for many years. Now, gigantic wind turbines are being used to supply "Green Energy" — electricity generated in an environmentally friendly manner—to the power grid. Large-scale "wind farms" are feasible in regions where the average windspeed exceeds 11 km/h, which is common in southwestern Alberta.

What happens on a windless day? Wind-driven electricity generation must be used together with other electric energy sources or storage devices. For example, wind-generated electricity could charge storage batteries, pump water into a reservoir for generating hydro-electric energy, or split water molecules into hydrogen and oxygen gas for use after as fuel for fuel cells.



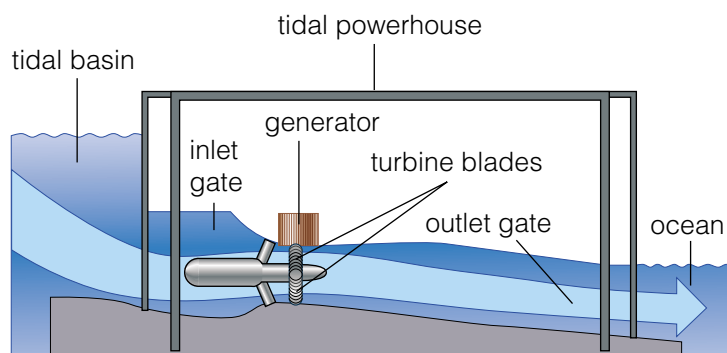
Figure 4.56 Reflective mirrors in the California solar farm are precisely curved to concentrate solar energy on oil-carrying pipes.

Sunlight can also be used to produce electricity on a large scale. "Solar farms" seldom use solar cells because they are expensive, fragile, and convert only about 15% of incoming light energy into electricity. Figure 4.56 shows an alternative method of harnessing solar energy by using it to heat a liquid. The hot liquid flows back to a generating station where it boils water into steam and drives a steam turbine and electric- generator. Solar-energy devices work only when sunlight is reaching the collectors. As a result, solar-powered-generating systems often include storage batteries to supply electricity at night or in cloudy conditions. In sunny conditions, the batteries can be recharged.

Ocean tides are another source of energy that can be used to generate electricity. Twice a day, tides change the water level between 1 m and 17 m, but the enormous energy of this slowly moving water is difficult to utilize. Only a few shorelines around the world have sufficiently high tides and an appropriate shape for trapping tidal waters. Several designs for tidal electricity-generating stations have been tested. As shown in Figure 4.57, the generating station at the Bay of Fundy traps tidal waters that have come in at high tide and uses the energy of the water as it flows out of the bay. Another design allows the station to use the energy of the water continuously, first as it flows into the basin and then again when it flows out of the basin.



Figure 4.57 The tidal powerhouse is quite similar to a hydro-electric generating station in a dam. As the water that has been trapped in the basin flows out, the water pressure turns turbine blades that turn an electric generator.



The hot inner parts of Earth contain a great deal of thermal energy, called **geothermal energy**. In some places, Earth's crust has cracks or thin spots in it. Ground water flows down from the surface, absorbs thermal energy, and rises again as hot springs and geysers. Steam produced by geothermal activity can be used to rotate turbines and turn electric generators. Because heated groundwater may contain dissolved sulfur compounds, condensed steam from the turbines is often pumped back underground to reduce pollution.

Only certain places on Earth have the proper geological characteristics to use geothermal energy. Iceland is one country that is ideally suited for the operation of geothermal power plants. You may remember that Iceland is located on the boundary of two tectonic plates and is known for its volcanic activity. In Canada, other forms of energy are more available and easily accessible, so use of geothermal energy sources has been limited.



Figure 4.58 Geothermal energy may be used in areas such as Iceland. Why isn't this form of energy the answer for other areas on Earth?



Alternative Methods of Generating Electricity

How can we balance our increasing need for electric energy and our concern about environmental problems caused by its production? Which method of generating electricity might help to solve our future energy problems in a practical and environmentally friendly way?

Procedure

1. Choose an alternative form of electrical production or a refinement of a common form of production that interests you.
2. Using the Internet, reference books, or other resource material, collect information about your chosen method of electricity production.
3. Display or present your findings in a format that has been approved by your teacher.

What Did You Find Out? Analyzing and Interpreting

1. As part of your research, find answers to the following questions.
 - (a) What equipment, facility, special conditions, or technology does your method of electricity production require?
 - (b) Is this method of electricity production currently being used? If so, where and by whom? If not, why?
 - (c) What impacts, positive or negative, would your method have on the environment?
 - (d) What challenges does the development of this method present? (Hint: challenges could be related to such areas as pollution control, energy conversion efficiency, energy transmission, environmental impact, cost/completion, and consumer demand.)

TOPIC 3 Review

1. Describe one environmental concern that can arise for each of the electric power generation methods listed below.
 - (a) hydro-electric
 - (b) nuclear
2. Of the steps involved in producing electric light from coal, which could result in damage to the environment? Explain your choices.
3. For each environment-damaging step mentioned in question 2, describe steps that could be taken to reduce the impact on the environment.
4. Which of the alternative ways of producing electricity would be the easiest and most productive to implement in Alberta? Explain your answer.

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

electric generator	dynamo	thermonuclear	neutral wire	thermal pollution
magnetism	power	flare gas	hot wire	cogeneration
electromagnet	watt	rotor	ground wire	geothermal energy
domains	hydro-electric plants	stator	short circuit	
alternating current (AC)	non-renewable resources	transformers	open pit mining	
alternators	fission products	circuit breakers	scrubbers	
direct current (DC)	nuclear fission	fuse	greenhouse gases	

Reviewing Key Terms

1. In your notebook, match the description in column A with the correct term in column B

A	B
• a device that converts mechanical energy into electric energy	• power (6)
• a generator that produces direct current	• dynamo (6)
• a metallic conductor with a lower melting point than that of the conducting wires	• electric generator (6)
• antipollution systems that remove sulfur dioxide from factory smokestacks	• stator (6)
• energy per unit time	• service panel (7)
• a two-pole electromagnet in an electric motor	• fuse (7)
• technology used to “step up” the voltage of an alternating current travelling over long distances	• transformers (7)
• technology that channels the power entering a home to different circuits	• circuit breaker (7)
• unwanted heat that is released into the environment	• ground wire (7)
• uninsulated copper wire	• scrubbers (8)
	• thermal pollution (8)
	• geothermal energy (8)

Understanding Key Concepts

2. Describe the difference between AC and DC. Describe the way(s) in which each form of current electricity is produced. (6)
3. How do hydro-electric plants produce electricity? (6)
4. Describe the function of each of the following electric motor parts. (6)
 - (a) split ring commutator
 - (b) armature
 - (c) brushes
5. Which type of light bulb is more efficient, an incandescent light bulb or a fluorescent light bulb? Explain your answer. (7)
6. In your home, what part of an electricity panel acts as a safety switch that cuts off power if necessary? How does the appropriate component achieve this? (7)
7. What is the process that involves two small atoms coming together to form a larger atom? How could this process be used to produce electricity?(8)
8. What is a kilowatt hour? Provide the formula that would be used to calculate this value. (7)
9. What happens when a “short circuit” occurs? Describe what might cause a short-circuit. (7)
10. Explain what thermal pollution is, how electricity generation might cause it, and why it is a problem. (8)



an

Expert



For the past six years, Su Ling Chong has been involved in a research project at the University of Alberta. Along with a neurophysiologist, mechanical engineer, and system developer, Su Ling works as the medical clinician in a fascinating project that allows people in wheelchairs to use electronic stimulation to propel themselves. This invention means that people who cannot use their leg muscles will have the opportunity to exercise them and stay active.

Q Have you always been interested in science?

A Yes. I had great science teachers in schools, and in grade eleven I participated in the Science Olympics and in the Women in Scholarship engineering Science and Technology program (WISEST). As a result, I got the opportunity to participate in an actual research project for six weeks in the summer.

Q How did you become involved in the wheelchair project at the U of A?

A As a clinician working with the elderly, I was always very interested in wheelchairs. The community rehabilitation program in which I was working in 1997 was being cut back and I noticed the job posting for a part-time physiotherapist working with electrical stimulation. I got the job. My role in this project is to provide clinical expertise on the wheelchair, determine a subject's suitability to participate, co-ordinate monthly testing and other required appointments, and help analyze the results.

Q How long has this design been in development?

A About five or six years. We took all the feedback from our subjects for each of our wheelchair prototypes and continued to improve on it. Biomotion, a medical

device manufacturing company, bought the intellectual property from the University of Alberta and has been providing all the prototypes for our research.

Q Why is this wheelchair unusual?

A A standard wheelchair allows people to use only their feet on the ground to move along. Paralyzed people are not able to do this at all. They have to use their arms to propel the wheelchair, which may cause overuse injuries in the shoulders. As well, people who have weak leg muscles may not be able to propel effectively with their feet on the floor. This new wheelchair allows people with poor standing balance, weak leg muscles, or an injured spinal cord to drive the wheelchair easily.

Q How does the wheelchair work?

A The wheelchair is a standard manual wheelchair with a modified footrest. The footrest is linked to a gear system under the wheelchair, which drives the wheelchair. Users' feet are strapped to the footrest and they propel the wheelchair by bending and straightening their knees. There is a rod on the left side of the wheelchair in the shape of a seven that they can steer with. They can use their hands to help propel the wheelchair when going up ramps. For users

who are paralyzed, electrical stimulation is used on their legs to stimulate the muscles that bend and straighten the knees to propel the wheelchair.

Q How does the electronic stimulator on the wheelchair work?

A The brain activates muscles in the body by sending electrical impulses to the spinal cord down to the nerve that stimulates the muscles. With spinal cord injuries, the electrical impulses from the brain do not get through, so a person is unable to move his or her legs voluntarily. The custom-made stimulator provides these electrical impulses to the muscles through electrodes placed over the motor points — that's where the nerves are the most superficial in the muscle.

Q How does this stimulation propel the wheelchair?

A It can stimulate up to eight muscle groups at the same time or alternately. Once we find all the motor points of the desired muscles for stimulation, we make a cuff to keep the electrodes in place. The user then has only to put on the cuff and the electrodes will be in the right positions. We use three rectangular electrodes on the top of the thigh for the quadriceps muscles and two or three electrodes on the bottom of each thigh for the hamstring muscles. In the “functional” mode, the stimulator is connected to the wheelchair.

Q How do the muscles know when to react?

A When the knees are bent in the resting position, the signal of the knee angle is sent to the Bio8 unit from the wheelchair to stimulate the top thigh muscles to straighten the legs. When the quadricep muscles are stimulated, the legs straighten. Once the knees have straightened or reached a threshold level that we have set, the signal is sent to stop the quadricep stimulation and to start the hamstring stimulation to bend the knees. These leg movements drive the wheelchair. The cycle is repeated until the muscles fatigue or the user stops the stimulation.

Q What does this design mean for people confined to wheelchairs?

A The implications of this method of propelling are wide. It prevents chronic wear and tear of the shoulder muscles, and it can prevent osteoporosis in the leg bones or increase bone density in the legs. The design helps users maintain muscle tone and muscle bulk and prevent atrophy in the legs while providing good circulation in the legs. It also requires less effort to propel the wheelchair than using the arm-propelled model, and it is easier for users to navigate slopes because they can use both their legs and their hands to propel the wheelchair. Lastly, it's a good cardiovascular workout if the wheelchair is used for long distances.

EXPLORING Further

You have been reading about an electronic wheelchair that enables paraplegics to move their legs. You may also have heard of devices such as electronic pacemakers that help to regulate irregular heartbeats. How do such devices work? What is the connection between electricity inside and outside the body?

How are electrical charges produced and transmitted in the human body? How do they help to keep the human body functioning? Conduct some research into the human nervous system and prepare a report, including diagrams, based on your findings. See if you can find out how positive and negative charges occur in the nervous system.

My Amazing Electrical Invention

Over the past century, countless electric devices have been invented to meet a wide variety of human needs. As needs change and new technologies are developed, we will have the opportunity to experience many new electric inventions in the future. What would it feel like to be the inventor of a new electric device? How would you go about its development and construction?



Challenge

You will be part of a team that sets out to design and then construct your own amazing electric invention. Your team's invention must be constructed using only the materials approved by your teacher and must meet the Design Specifications listed below.

Materials

Supplied by student teams:

- assorted chemical cells
- electric components from used or discarded toys, electronics equipment, and small appliances (bulbs, LEDs, motors, wire, buzzers, rheostats, etc.)
- materials for invention construction (wood, plastic, cardboard, hinges, pulleys, nails, tacks, screws, glue, etc.)
- tools for construction (hammers, glue guns, pliers, wire cutters, screwdrivers, etc.)

Supplied by the school:

- ammeter
- voltmeter

Depending on supplies at hand, the school may supply:

- D-cells and holders
- Nichrome™ wire
- cell holders
- wire cutters
- copper wire
- bulbs and receptacles

Safety Precautions

- Wear proper eye protection at all times
- Have your list of materials and your plan approved by your teacher before proceeding.

Design Specifications

Your invention must:

- have a “useful” function that can be easily communicated by your team
- be self-contained and portable; no size restrictions (within reason) exist
- be constructed of materials deemed “safe” by your teacher (commercial “electronics kits” may not be used)
- have electric components installed in one circuit
- be powered by a DC power source that does not exceed 9V
- incorporate a minimum of three different types of loads (two bulbs count as one type of load)
- have at least two separate switches, one of which controls all components while the other(s) control an individual component
- have a component capable of varying resistance within the circuit
- function properly in at least two out of three tests

Plan and Construct

- Brainstorm with your team members to identify a possible function, or functions, for your invention.
- Draw a prototype blueprint or design diagram that includes proper circuitry symbols for the electrical components. Each team member must contribute a drawing.

3. As a team, choose the design or combination of designs that will best meet your requirements.
4. Present a single labelled diagram of the chosen design to your teacher for approval.
5. Construct your invention.
6. Test, troubleshoot, and evaluate the functionality of your design throughout the construction process.
7. Measure and record the electric current and voltage of your entire circuit, with your “variable resistor” at different settings.
8. Each team member must draw a labelled scientific diagram of the team’s invention and a correctly labelled circuit diagram of the electrical components of the device. Note: Be sure to include the symbols for an ammeter and voltmeter at the positions in your circuit where they were connected.

Evaluate

Part A

Invention Evaluation (Shared by All Team Members)

Demonstrate your inventions operation for your teacher, explaining how each design criteria has been met. Based on the construction process your group followed and the performance of your invention, copy and then fill in the following scoring chart.

Category	Criteria	Score	
		Student Self-Evaluation	Teacher Evaluation
Planning Process	Initial Individual Diagram	/5	/5
	Final Group Plan	/5	/5
Construction Process	General Preparedness of group/individual	/5	/5
	Efficient Use of Time by group/individual	/5	/5
Specifications	Inclusion of Required Components	/10	/10
	Successful Operation	/10	/10
Aesthetics/Appearance	General Appearance	/5	/5
	Ease of operation (convenience)	/5	/5
	Total Score	/50	/50

Part B

Individual Analysis/Understanding of the Circuit Constructed (Individual Mark)

1. Record your team’s measured values for current and voltage next to your circuit diagram. Using this data, calculate the resistance within your circuit (show all work and include units).
2. What type of circuit did you construct (series or parallel)? Explain how you know it is this type. Why did your group choose this type of circuit?
3. Describe where your group placed the switches for your device. Explain why they were positioned this way.
4. Which types of energy were produced and used by the various components in your invention? (State energy conversions, e.g., electrical to mechanical.)
5. What type of component did your group use to vary resistance? Why did you install the variable resistor where you did, and how did it affect the operation of your invention?
6. State whether your invention passed the testing procedure. Describe what aspects of the design and/or construction process were least difficult and which were most difficult.

4 Review

Unit at a Glance

- Excess electrons on an object create a negative charge. A shortage of electrons creates a positive charge.
- The Laws of Charge state that
 - (a) unlike charges attract
 - (b) like charges repel
 - (c) charged objects attract uncharged (neutral) objects
- Conductors allow electric charge to move freely. Insulators prevent charge from moving freely.
- The basic parts of all electric circuits are a source of electric energy, conductors, a load, and a control device.
- Quantity of charge is measured in coulombs.
- Current is measured in amperes.
- Voltage (potential difference) is a measure of the energy of a standard unit of charge, and is measured in volts.
- Resistance is the property of substances that hinders charge motion and converts electric energy into heat. Resistance is defined as the ratio of voltage to current (Ohm's Law).
- A series circuit has one current path. A parallel circuit has more than one path along which current can flow.
- Thermocouples convert thermal energy to electric energy.
- Piezoelectric materials generate a small voltage when the pressure on them changes.
- Photovoltaic (solar) cells convert light energy to electric energy.
- Alessandro Volta observed that two different metals in a solution could generate a voltage. These observations led to the development of electrochemical cells and batteries, which consist of several cells connected together.
- Electric generators convert mechanical energy to electric energy. Their operation is based on the relationship between magnetism and electricity.
- Direct current (DC) flows in only one direction. Alternating current (AC) reverses direction periodically.
- The power grid generates and distributes AC electricity using transformers to change voltage for efficient power transmission.
- In homes, electric current travels through an electric meter and a service panel to branch circuits. Circuit breakers or fuses in the service panel cut off excessive current before wiring can overheat.
- Electric power is the product of voltage and current. Power measures the quantity of energy transfer each second.
- All electric devices convert some input energy into waste heat, so they are not perfectly efficient.
- Most of Canada's electric energy is generated using dams, thermo-electric plants that burn fossil fuels, and nuclear reactions.
- All methods of producing electricity affect the environment. Renewable sources of electric energy include biomass fuels and solar, wind, tidal, and geothermal energy.

Understanding Key Concepts

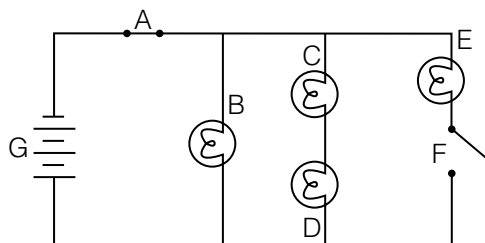
-  1. What does it mean to say a conductor is “grounded”?
-  2. Describe how positive and negative unbalanced charges are produced.
-  3. Why must electrostatic buildup in machinery be prevented? Give at least two examples to support your answer.
4. How does resistance within a series circuit change when more bulbs are added. Explain your answer.
5. Explain how piezoelectricity produces electric current.
6. Describe at least three factors that would affect the electrical production of a photo-voltaic cell.
7. Which “batteries” used in daily life are actually not batteries? Explain your answer.
8. Describe one advantage and one disadvantage of a hydrogen fuel cell.
9. Draw a labelled diagram of the main parts of a thermo-electric generating station.
10. What is the main function of the stations and sub-stations located along the power grid? Why is this function necessary?
11. Describe the appearance and function of each of the three wires found within a cable commonly used for home wiring.
12. Draw a circuit drawing of a bedroom that contains two lights controlled by a switch, four plug-ins that constantly have power, and a closet with a light and its own switch that runs independently of the rest of the room. (You will need to invent a symbol for the plug-ins.)

13. What is the electrical efficiency of a 100 W light bulb that produces 5.7 kJ (57 000 J) of heat when it is on for 10 min? (Hint: remember that the bulb is supposed to produce light.) Show your work.
14. Why do we need to find alternative methods of producing electricity?

Developing Key Skills

-  15. Bob charged objects A and B by rubbing them together. Once charged, Bob moved object B close to a third object, object C, and made the following observations. For each observation below, answer the accompanying question.
 - (a) Object **B** was attracted to object **C**. If object **B** is known to be negatively charged what is the charge of object **C**?
 - (b) Object **C** was also attracted to object **A**. What is the charge of object **C**?
 - (c) Based on the observations above, what is the charge of object **A**?
16. In your notebook, draw a circuit diagram for a circuit containing, two cells, one bulb and one switch.
17. Describe at least three conditions that must be met in order for the bulb in the circuit in question 2 to light.
18. (a) If the voltage in the circuit drawn for question 2 was 3.0 V and the bulb had a resistance of $24\ \Omega$, how much current would be flowing through the circuit?
(b) If the number of cells was increased to four, what would the current be?
19. Describe three different ways in which chemical energy could be converted to electricity.

20. Examine the circuit diagram below and then answer the questions that follow.



- How many batteries are shown in the circuit above?
- Which of the bulbs would presently be on the way the circuit is pictured?
- If bulb C were to burn out and switch F was closed, which bulbs would be lit?
- In what direction are the electrons flowing in the above diagram? (clockwise or counterclockwise) Explain your answer.

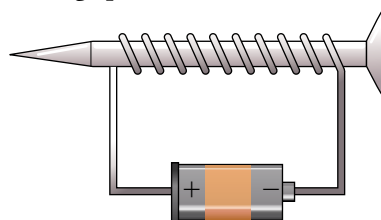
Problem Solving/Applying

- How many 100 W bulbs would a family have to remove in order to save \$25.00 in a 30-day month? The bulbs are on for an average of 6 h per day and electricity costs \$0.11 per kWh. (Please show your work.).
- Glenda wishes to run several metres of speaker wire from the upstairs stereo to her downstairs bedroom. Describe at least three measures Glenda should take to ensure that her bedroom speakers receive the strongest signal possible. Explain each of your suggestions.
- Shavez works in a factory that constructs highly sensitive computer components. Damage to their product due to electrostatic discharge (ESD) is of great concern to the owners of the company. Describe three different measures that Shavez or the owners could take that would decrease the chances of product damaging ESD.
- Describe three positive ways in which people make use of electrostatic phenomenon.

- Why do most power plants produce alternating current rather than direct current?
- Describe how you could determine whether a string of holiday lights was wired in parallel or series.
- Describe two advantages of wiring a circuit in parallel and two advantages of wiring a circuit in series.
- Draw a circuit diagram of a circuit that would allow you to vary the brightness of two bulbs wired in parallel. The circuit should include a two-cell battery and one switch that controls the entire circuit.
- In a voltaic cell, what is the function of the following components?
 - negative electrode (anode)
 - positive electrode (cathode)
 - electrolyte

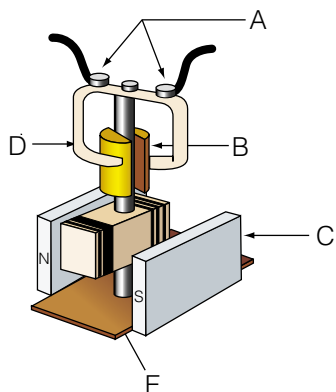
Critical Thinking

- Use the diagram below to answer the following questions.



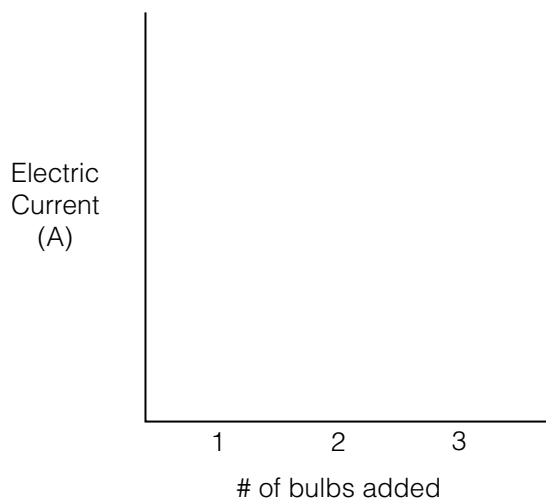
- Why does the iron nail become a magnet when the battery is connected?
- Describe the energy conversions that take place in a:
 - hydro-electric power plant
 - thermo-electric (fossil fuel) power plant
 - nuclear power plant

32. Examine the diagram of the St. Louis motor shown below. In your notebook, identify the parts indicated by letters on the diagram. Describe the function of each labelled part.



33. Howard wishes to reduce his electric bill by installing solar cells on the roof of his house. Describe some factors Howard must consider before undertaking this project.
34. Describe three alternative ways of producing electricity that have minimal impact on the environment. Explain the reasons for your choices.
35. Explain why each of the alternative methods for producing electricity that you mentioned in question 35 are not as commonly used as the traditional sources of electricity.
36. What would the power rating (in watts) be for a vacuum cleaner that requires 12 A of current from a 120 V circuit? How many joules of energy would the vacuum use in 10 min of use? (Show your work.)
37. What is the electrical efficiency of an electric water heater (with a power rating of 6300 W) that can raise the temperature of 151 L of water 10°C in 15 min (Hint: it takes 4180 J to raise the temp of 1 L of water 1°C)?

38. What happens to the electric current flowing within a parallel circuit compared to the electric current flowing within a series circuit when more bulbs are added? Illustrate your answer by copying the axis illustrated below into your notebook. Plot a line that represents the series circuit electric current and another that represents the parallel current.



Hint: Include a legend and use a different coloured line to indicate each circuit type.

39. What is the main source of electricity for the province of Alberta? Give reasons why this method is so popular, and identify some of its advantages.

Pause & Reflect

Go back to page 264 at the beginning of this Unit, and check your original answers to the Focussing Questions. How has your thinking changed? How would you answer those questions now that you have investigated the Topics in this Unit?