Key Terms
cellular respiration
fermentation
greenhouse gases
greenhouse effect
acid precipitation

1.3 Extracting Energy from Biomass

Photosynthesis produces glucose, removes carbon dioxide from the atmosphere, and supplies the atmosphere with oxygen. Although not all organisms undergo photosynthesis, all organisms, from single-celled bacteria to complex many-celled life forms such as humans, get energy from glucose. For organisms to release and use the energy, however, the glucose has to be broken down. Once this has happened, cells can extract the energy to complete the processes that are essential to life, such as nursing offspring, as shown in **Figure 1.18**. There are two main processes through which organisms extract the energy from glucose: cellular respiration and fermentation. **Cellular respiration** occurs when oxygen is present, or under aerobic conditions. **Fermentation** occurs when oxygen is absent, or under anaerobic conditions. Organisms such as bacteria and some fungi use fermentation to release the energy in glucose.

cellular respiration a process that releases energy from organic molecules, especially carbohydrates, in the presence of oxygen

fermentation a process that releases energy from organic molecules, especially carbohydrates, in the absence of oxygen

Cellular Respiration

The most common and efficient method for extracting the energy from glucose is cellular respiration. Plants, animals, fungi, and other organisms use cellular respiration to do this.

In cellular respiration, as in fermentation, the glucose that was originally assembled by photosynthesis is broken down to make the energy available to body cells. The energy you use when you blink your eyes as you read comes from cellular respiration. In contrast to photosynthesis, cellular respiration *consumes* oxygen and *produces* carbon dioxide. The chemical equation for cellular respiration is shown below.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy}$$

Figure 1.18 By eating grass, the cow obtains the glucose produced by photosynthesis. The cow's digestive system breaks down the glucose to release the energy. The energy is used to complete life processes, such as reproducing and nursing young.

Extracting Energy from Food

In cellular respiration, organisms take in oxygen, which reacts with the glucose in cells to produce carbon dioxide, water, and energy. All organisms undergo some type of process to extract energy from biomass, whether in the presence of oxygen or not. Most organisms, including animals and plants, extract energy through the process of cellular respiration. So, even though plants produce their own food through photosynthesis, they still have to break down the glucose to get energy from it. Plants break down the glucose through cellular respiration. **Figure 1.19** shows how a plant uses both carbon dioxide and oxygen to carry out life processes.

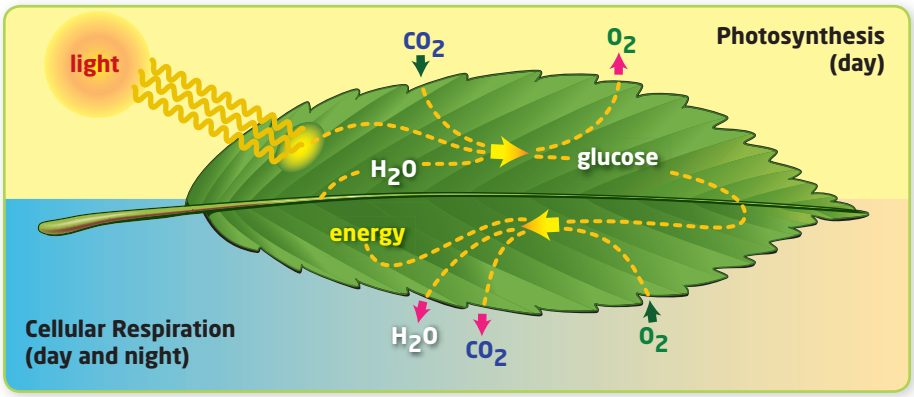


Figure 1.19 Plants and algae undergo both photosynthesis and cellular respiration. Cellular respiration makes energy available to cells by consuming oxygen and producing water and carbon dioxide.

Carbon Dioxide and Other Greenhouse Gases

Greenhouse gases are atmospheric gases that prevent heat from leaving the atmosphere, thus increasing the temperature of the atmosphere. Examples of greenhouse gases include water vapour, carbon dioxide, and methane. Without greenhouse gases, Earth's temperatures would average less than 0°C. This natural insulating capacity of greenhouse gases, shown in **Figure 1.20**, is known as the **greenhouse effect**.

greenhouse gases atmospheric gases that prevent heat from leaving the atmosphere, thus increasing the temperature of the atmosphere

greenhouse effect the warming of Earth as a result of greenhouse gases, which trap some of the energy that would otherwise leave Earth

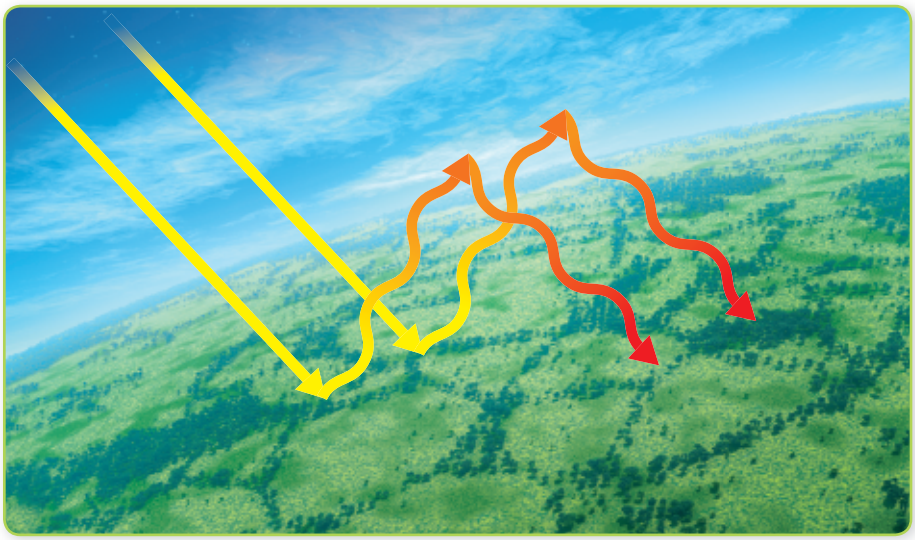


Figure 1.20 Greenhouse gases trap heat within Earth's atmosphere, similar to the way that glass traps heat within a greenhouse.

Biomass and Fossil Fuels

Based on fossil evidence, scientists have concluded that single-celled organisms used photosynthesis to generate biomass more than 3 billion years ago. Most of the matter in this biomass has been cycled through the biosphere countless times. Small amounts, however, escaped the biosphere's cycling system when the remains of organisms settled in places where there was not enough oxygen to decompose them. Over time, with pressure and heat, the biomass changed into fossil fuels such as coal, petroleum, and natural gas. Because fossil fuels come from biomass that was produced by photosynthesis millions of years ago, it is not surprising that burning them has an effect that is very similar to cellular respiration. Both processes are chemical reactions that consume oxygen, release energy, and produce carbon dioxide.

Sense of Value

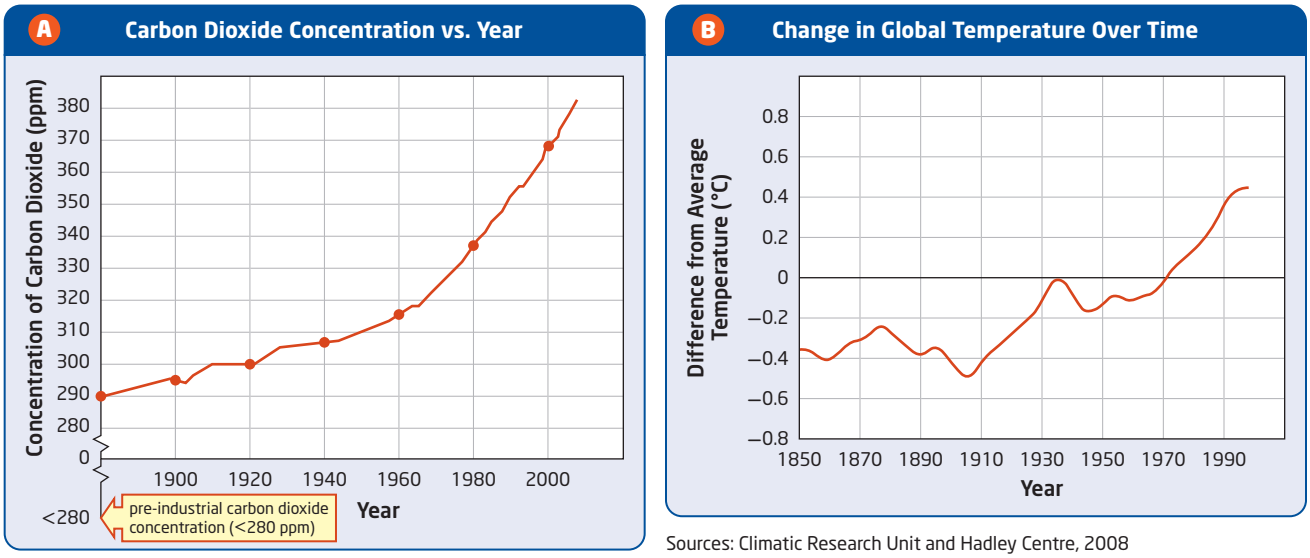
The estimated 200 billion tonnes of biomass produced every year by plants is the base of 99 percent of terrestrial ecosystems.

Enhanced Greenhouse Effect

Fossil fuels have been accumulating for many millions of years. However, significant portions of Earth's reserves have been burned by humans in the span of only a few centuries. Because humans have "suddenly" released much of the carbon dioxide that was converted to biomass by ancient plants, the net result for the atmosphere is added carbon dioxide.

Figure 1.21A shows that since the Industrial Revolution, which began in the late 1700s, the concentration of carbon dioxide in the atmosphere has increased. The Industrial Revolution marked the start of increased and widespread burning of fossil fuels as a source of energy for many countries around the world. Many scientists hypothesize that the increased concentration of carbon dioxide in the atmosphere, along with an increase in other greenhouse gases, such as methane, is the cause of global warming.

Global warming is the increase in Earth's average surface temperature. **Figure 1.21B** shows that as the amount of carbon dioxide in the atmosphere has increased, so has Earth's average surface temperature.



Sources: Climatic Research Unit and Hadley Centre, 2008

Figure 1.21 **A** Since the Industrial Revolution, carbon dioxide levels have risen steadily. **B** Earth's average surface temperature has also increased by about 0.74°C.

Reducing Carbon Dioxide in the Atmosphere

There are many ways to reduce the amount of carbon dioxide being released into the atmosphere. These include international initiatives by governments from around the world, initiatives by the federal, provincial, and local governments of Canada, and efforts by individuals. **Table 1.3** presents three examples of efforts to reduce carbon dioxide.

Table 1.3 Reducing Carbon Dioxide in the Atmosphere

Action	Description	
Kyoto Protocol	The Kyoto Protocol is an international agreement to reduce greenhouse gas emissions, which was signed by over 180 countries. To meet the terms of the Protocol, countries can reduce emissions or get credits for removing carbon dioxide from the atmosphere by planting trees in non-forested areas. Since plants remove carbon dioxide from the atmosphere, large areas of trees and other plants, such as forests, are known as carbon sinks.	
Protecting existing forests	In July 2008, Ontario announced that roughly half of its boreal forests will be protected. The protected forests will only be used for tourism and traditional Aboriginal purposes. About 225 000 km^2 of forests will be protected from logging, mining, and oil and natural gas exploration. Like other forests, the boreal forest in Ontario is a carbon sink, absorbing about 12 million tonnes of carbon dioxide per year.	
Recycling programs	Recycling helps to reduce carbon dioxide emissions because, in most cases, less energy is needed to make something from recycled materials than from new materials. For example, energy input is reduced by 95 percent when an aluminum product is made from recycled aluminum, rather than a raw material. In 1978, the Recycling Council of Ontario was established in Toronto, Ontario. Through its programs, more than 2.3 million tonnes of waste are recycled or composted each year.	

Learning Check

1. Explain the process of cellular respiration.
2. Describe the greenhouse effect.
3. Make a list of actions you could take to reduce the amount of carbon dioxide being released by the burning of fossil fuels.
4. As you write your answers to questions, using either a pen or a keyboard, you are using energy. Draw a flowchart that traces this energy back to the Sun.

Activity 1-3

Recycling in Ontario

Recycling helps to reduce the amount of carbon dioxide released into the atmosphere and the amount of waste placed in landfills. The table below contains data from Statistics Canada. Electronic waste consists of materials such as computers, printers, and cellphones.

Amounts of Materials Recycled in Ontario in 2002, 2004, and 2006 (t)

Material Recycled	2002	2004	2006
Newspapers	479 473	410 496	380 281
Cardboard	357 881	467 476	474 211
Glass	152 484	189 804	179 341
Aluminum and copper	17 265	21 327	21 290
Plastic	37 396	52 935	60 195
Tires	no data	6 441	4 948
Electronic waste	no data	5 259	4 251

Materials

- graph paper
- ruler
- coloured pencils

Procedure

1. Construct a bar graph with "Year" on the *x*-axis and "Tonnes of Recycled Materials" on the *y*-axis. Plot the data for newspapers, cardboard, and glass for each year. Use a different-coloured pencil to represent each material.
2. Construct a second bar graph to plot the data for the remaining materials listed in the table.

Questions

1. Describe the trend in recycling for each material in your graphs.
2. What factors may be affecting the amounts of materials that are being recycled in Ontario?
3. Some people, such as those who live in rural areas or apartment buildings, may not be included in curb-side recycling programs. Describe an action that could be taken by the Government of Ontario or by an environmental group to ensure that recycling programs reach these people.

Fermentation, Methane, and Landfills

Landfill sites are not as attractive as tropical rainforests, but the gulls, raccoons, and other animals that visit them confirm they are ecosystems. The presence of these animals is usually obvious. Either the animals themselves or the evidence of their visits can be seen. There are, however, other organisms in a landfill ecosystem—organisms that are not as easily seen. Within the landfill are organic wastes, such as food scraps and yard waste, which contain countless energy-storing molecules, especially glucose from photosynthesis. Here, many trillions of bacteria are at work.

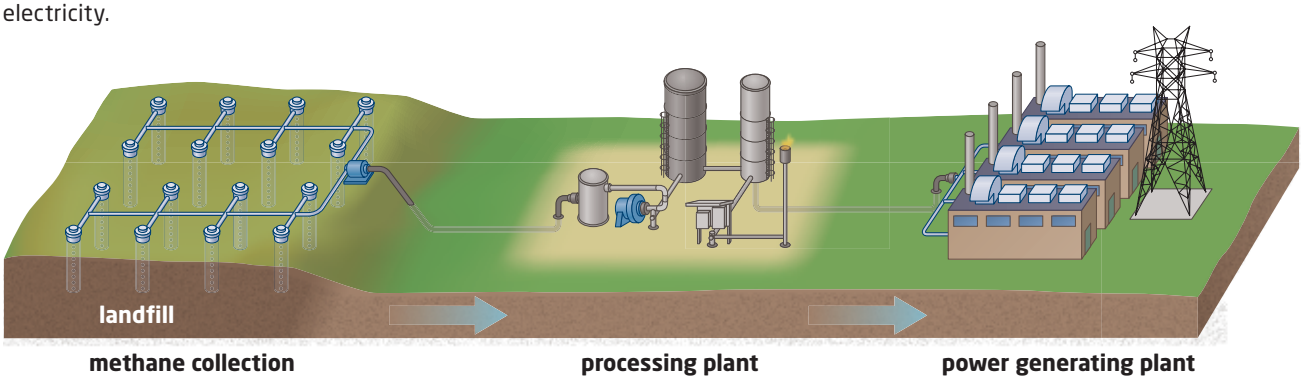


Figure 1.22 Methane from a landfill site can be processed, and then transported to a nearby power generating plant, where it can be burned to produce electricity.

Fuel from Waste

Since there is almost no oxygen in a landfill ecosystem, the bacteria break down the glucose in the waste using fermentation. This process allows them to use some of the energy that is stored in the glucose molecules. But they cannot extract all the energy. The energy they cannot extract gets re-assembled into a gas called methane (CH_4). The bacteria then release this gas, which moves through the landfill.

Methane gas is a fuel. Recognizing that fermentation in landfills produces large quantities of methane, Ontario has introduced a law requiring all large landfill sites to install pipes to collect the gas. **Figure 1.22** shows how methane gas is collected from a landfill and burned to produce electricity. Many homes in Canada run on electricity that is at least partly generated from bacteria at a local landfill site! In Sudbury, Ontario, methane gas from a landfill site is used to produce about 1.6 MW (megawatts) of electricity per year. This is enough energy to power about 1200 homes.

Go to **scienceontario** to find out more

Acid Precipitation

Since fossil fuels come from ancient organisms, they contain the same nutrients that are found in living things. Although these nutrients are vital for the health of living things, they can be released in undesirable forms when fossil fuels are burned. **Figure 1.23** shows how nitrogen oxides and sulfur dioxide are produced when fossil fuels are burned. When these gases combine with water in the atmosphere, nitric acid and sulfuric acid are produced. These acids can travel great distances in the wind, eventually descending to Earth's surface in rain, sleet, or snow. As a result, the precipitation becomes acidic. This phenomenon is called **acid precipitation**.

acid precipitation rain, snow, or fog that is unnaturally acidic due to gases in the atmosphere that react with water to form acids

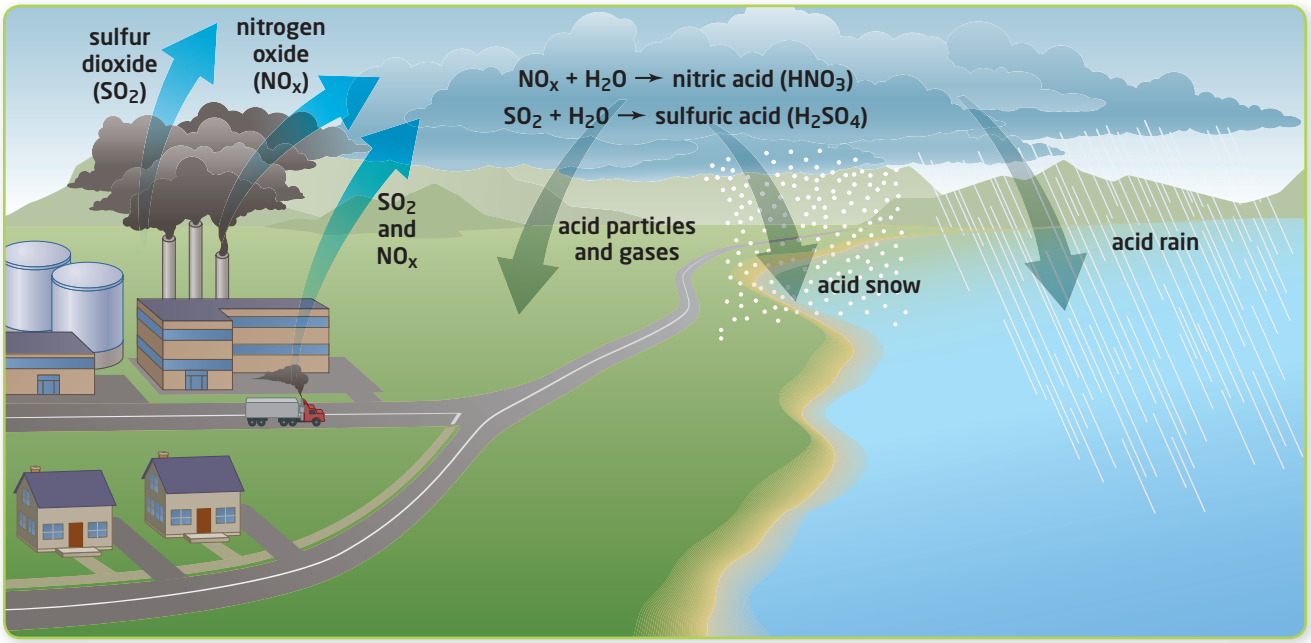


Figure 1.23 Acids from burning fossil fuels combine with water in the atmosphere to form acid precipitation. Acid precipitation may fall locally or hundreds of kilometres downwind, far from the source.

Suggested Investigation

Inquiry Investigation 1-C, Soil-water Acidity and Plant Growth, on pages 40–41

Measuring pH

Like the pH of other substances, the pH of precipitation can be measured. A pH scale is shown in **Figure 1.24**. A substance that has a pH of 7, such as pure water, is considered neutral. A substance that has a pH higher than 7 is considered basic. A substance that has a pH below 7 is considered acidic. The closer the pH is to 0, the stronger the acid is. The pH of rainwater that has not been affected by pollution is about 5.6. The pH of acid precipitation can be as low as 4.2.

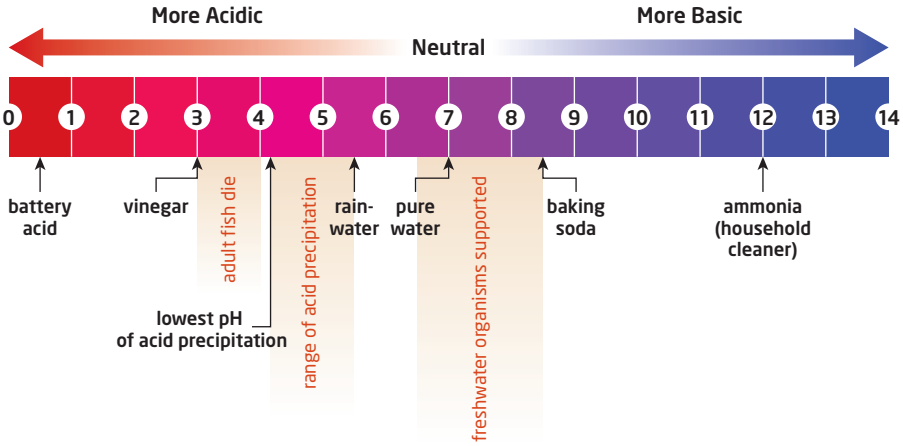


Figure 1.24 The pH scale identifies a substance as acidic, neutral, or basic.

Effects of Acid Precipitation

Figure 1.25 Trees in this forest could not survive changes to the environment as a result of acid rain.

Continued exposure to acid precipitation causes forest soils to lose valuable nutrients, such as calcium. Although calcium does not dissolve in water, it does dissolve in acids, so it can be washed away. On the other hand, acid precipitation increases the amount of aluminum in soil, which interferes with the uptake of nutrients by trees. Some trees, such as those shown in **Figure 1.25**, cannot survive the changes to their ecosystem caused by acid precipitation.

Acid precipitation can be even more devastating to aquatic ecosystems, because it can lower the pH of the water, causing problems for fish, amphibians, and other organisms that live in the water. Many aquatic organisms cannot survive if the pH of the water begins to drop. **Figure 1.26** shows the tolerance level of certain aquatic organisms to pH changes in the water. Some organisms, such as clams and snails, are very sensitive to a drop in pH. Other organisms, such as frogs, have a higher tolerance for changes. However, if the food that the organisms consume, such as the mayflies that frogs consume, cannot survive, then the organisms will face a reduced food supply.

Ecologists at the Experimental Lakes Area demonstrated many negative effects of acidification when they modelled acid precipitation by adding acids to the experimental lakes. Because the ecologists were required to return the lakes to a natural state following their experiments, they also studied how lakes can recover from acid damage.

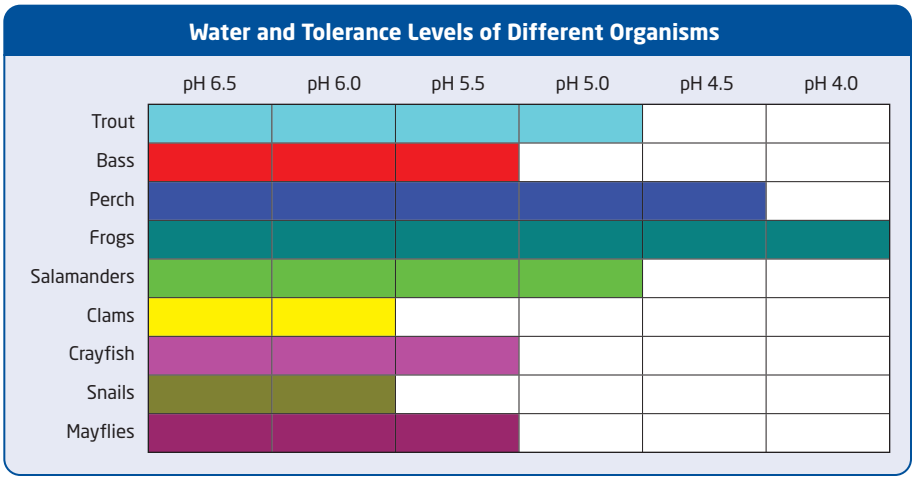


Figure 1.26 The bars in this chart extend out to the pH that an organism can no longer tolerate. For example, trout cannot survive if the pH of the water drops below 5.

Reducing Acid Precipitation

In the 1980s, by studying wind patterns, precipitation, and sources of pollution, scientists discovered that more than half of the acid precipitation in eastern Canada came from pollution sources in the United States, including states that border the Great Lakes. Negotiations between the two countries led to agreements and laws that reduced emissions in both countries. The graph in **Figure 1.27** shows the extent to which Canada has reduced its emissions of sulfur dioxide and nitrogen oxides since 1990.

Like eutrophication, however, acid precipitation has not disappeared. But improved technologies, such as scrubbers to remove undesirable gases from industrial emissions, as well as higher standards for motor-vehicle emissions, have reduced the acidity of precipitation since the 1980s.

Study Toolkit

Previewing Text Features
How do the headings on these two pages help you understand the main ideas being presented?

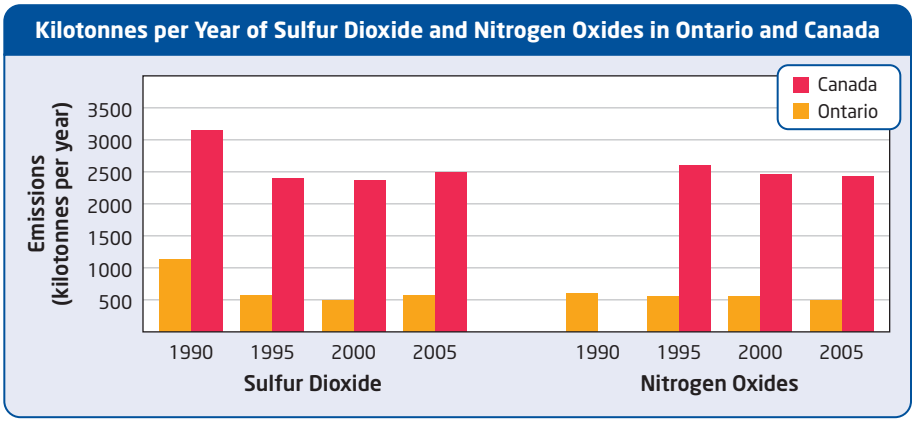


Figure 1.27 Canada has made progress in reducing its emissions of sulfur dioxide and nitrogen oxides.

Section 1.3 Review

Section Summary

- Organisms use cellular respiration and fermentation to extract the energy stored in the glucose produced by photosynthesis.
- Burning fossil fuels has dramatically increased the concentration of carbon dioxide, a greenhouse gas, in the atmosphere.
- Acid precipitation is caused by burning fossil fuels. It can have negative effects on terrestrial and aquatic ecosystems.
- Increased awareness and improved technology have led to a decrease in acid precipitation since the 1980s.

Review Questions

K/U **1.** Identify two processes that organisms use to extract the energy stored in the glucose produced by photosynthesis.

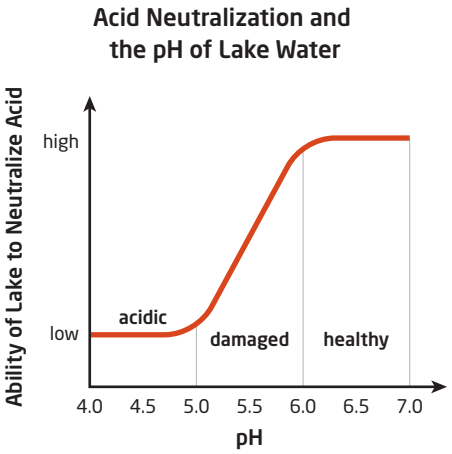
K/U **2.** What gas must be present for the aerobic breakdown of glucose to occur?

C **3.** Draw a flowchart to show how methane gas can be collected from a landfill site and used to produce electricity.

K/U **4.** Write two or three sentences to explain the following statement: "In the last 200 years, humans have 'suddenly' released previously stored carbon dioxide."

K/U **5.** What substances that are responsible for acid precipitation are released into the atmosphere from burning fossil fuels?

T/I **6.** Certain types of aquatic organisms, such as clams and crayfish, are negatively affected when the pH of the water drops below 5.5. Some fish, such as trout, cannot survive when the pH of the water drops below 5.0. Use the graph on the right to determine whether any of these organisms can survive if a lake becomes acidic.



T/I **7.** Suppose that you have a choice between two products of equal quality. You look at the labels of the two products to see where they were made. You have a list of countries that are committed, under an international agreement, to requiring industries to become more efficient by reducing greenhouse gas emissions. You see that the more expensive product is from a country on your list, but the less expensive product is not. Which product would you buy? Explain your choice.

A **8.** Many Ontario residents commute thousands of kilometres each year by car between home and work. How may their commuting be connected to the death of trees?