8.2 Greenhouse Gases and Human Activities

Key Terms
concentration
parts per million (ppm)
greenhouse gas
sink
ozone
chlorofluorocarbon (CFC)
anthropogenic greenhouse effect
global warming potential (GWP)

The greenhouse effect is an important part of Earth's energy budget. Without the greenhouse effect, Earth would be too cold to support life as we know it. But just as the absence of greenhouse gases in the atmosphere would result in a much colder Earth, so an increase in greenhouse gases will produce a warmer Earth. In this section, you will explore the roles of various greenhouse gases in climate change and discover why human production of greenhouse gases is a cause for concern.

Concentrations of Gases in the Atmosphere

The measure of the amount of one substance within a mixture is called **concentration**. **Figure 8.11** shows an example of concentration in liquids. In 1958, researchers began to make frequent, regular measurements of concentrations of carbon dioxide (CO_2) in the atmosphere. These systematic measurements were the first direct indication that levels of greenhouse gases have been steadily increasing in recent decades.

The concentration of carbon dioxide in Earth's atmosphere increased from an average of about 315 parts per million in 1960 to about 370 parts per million in 2000. **Parts per million (ppm)** is a measure of the number of parts of one substance relative to one million parts of another substance. For example, 300 ppm of carbon dioxide in the atmosphere means that one million units of atmosphere contain 300 units of carbon dioxide plus 999 700 units of other atmospheric gases. **Table 8.3** describes units that are commonly used when measuring concentrations.

concentration the amount of a particular substance in a specific amount of another substance

parts per million (ppm) a unit of measurement that indicates the number of parts of a substance per million parts of another substance; for example, for salt water, 1000 ppm of salt means 1000 parts salt in 1 000 000 parts of pure water

Table 8.3 Measurements of Concentration

Measurement	Example
Parts per million (ppm)	1 mg per kg = 1 ppm
Parts per billion (ppb)	1 mg per tonne = 1 ppb
Parts per trillion (ppt)	1 mg per kilotonne = 1 ppt

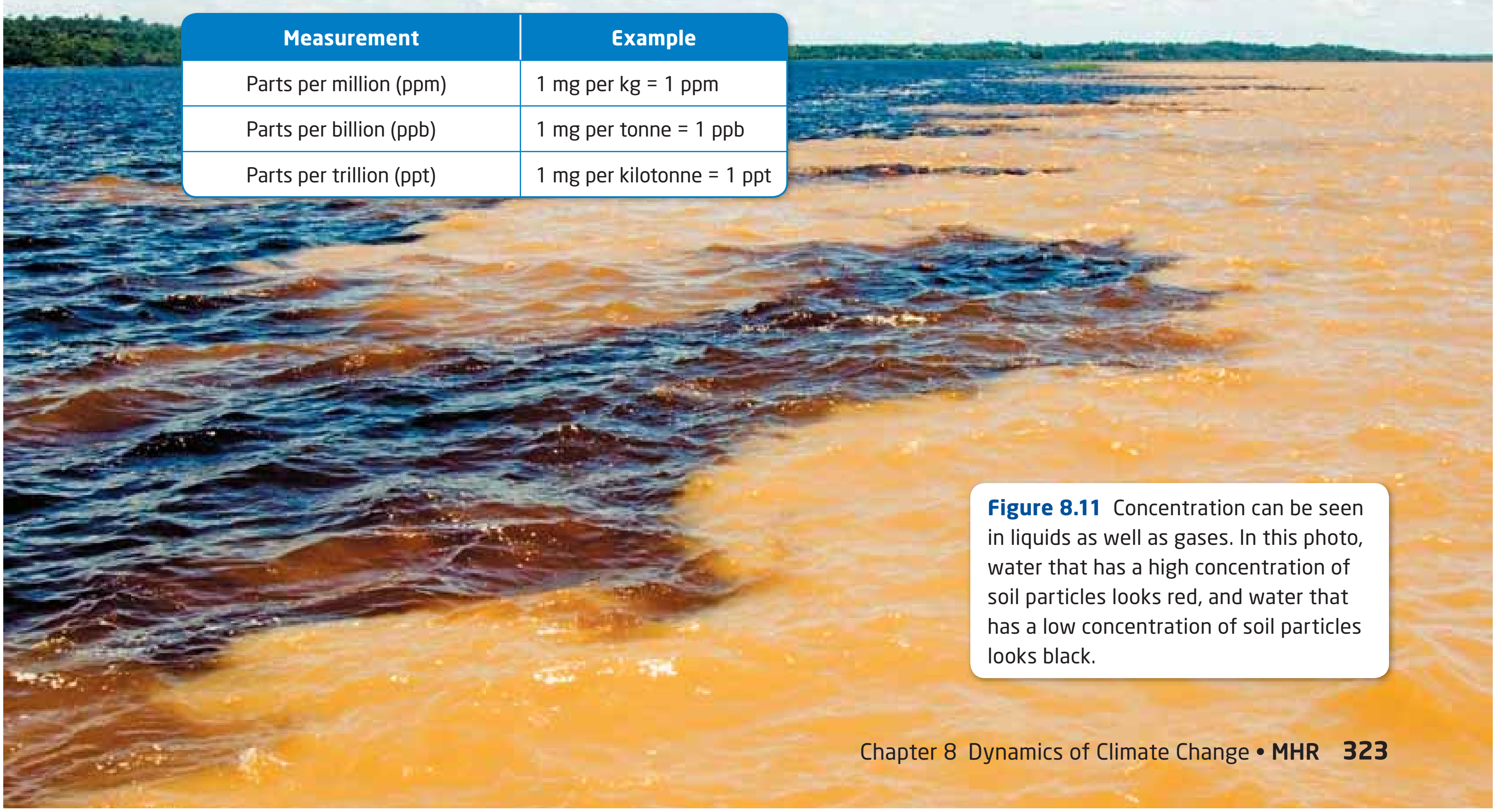

Figure 8.11 Concentration can be seen in liquids as well as gases. In this photo, water that has a high concentration of soil particles looks red, and water that has a low concentration of soil particles looks black.

greenhouse gas a gas in Earth's atmosphere that absorbs and prevents the escape of radiation as thermal energy; examples include carbon dioxide and methane

sink a process that removes greenhouse gases from the atmosphere

Greenhouse Gases and Global Warming

Ninety-nine percent of the atmosphere is made up of only two gases: nitrogen (N_2) and oxygen (O_2). However, neither of these two gases absorbs infrared radiation, and neither gas contributes to the greenhouse effect. Gases that absorb and re-emit infrared radiation are known as **greenhouse gases**. Molecules of the greenhouse gases all have three or more atoms each. Their molecular structure allows them to interact with radiation of different wavelengths. They produce a warming effect by absorbing and emitting energy. In **Figure 8.12** the gases highlighted in green show that carbon dioxide and water are the most abundant greenhouse gases in Earth's atmosphere.

The concentrations of many greenhouse gases have fluctuated throughout Earth's history. Processes that add greenhouse gases to the atmosphere are called *sources* of greenhouse gases. Processes that absorb greenhouse gases from the atmosphere are called **sinks**. Both sources and sinks can be natural or can be caused by human activities.

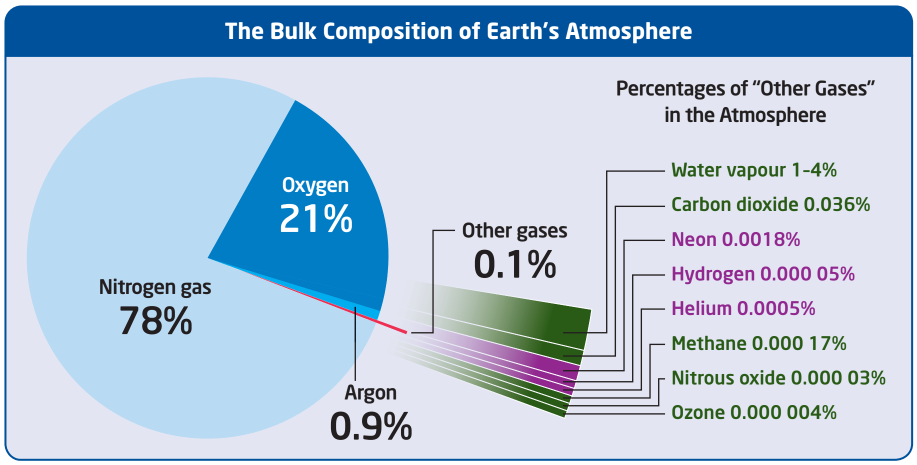

Figure 8.12 This pie graph illustrates the percentages of different gases in the atmosphere. The greenhouse gases are highlighted in green.

Suggested Investigation

Problem-Solving Investigation 8-C, Modelling the Greenhouse Effect, on page 344

Water Vapour as a Greenhouse Gas

Figure 8.12 shows that water vapour is the most abundant greenhouse gas in Earth's atmosphere. Scientists estimate that water vapour is responsible for between 65 and 85 percent of the greenhouse effect. However, water vapour is not added to or removed from the atmosphere in significant amounts by human activities. The concentration of water vapour in the atmosphere at any particular time is directly related to one factor—temperature.

Water vapour enters the atmosphere by evaporation. The rate of evaporation depends on the temperature of the air and oceans. The higher the temperature is, the higher the rate of evaporation is. This relationship creates a positive feedback loop. A warmer atmosphere leads to an increase in the rate of evaporation; increased evaporation leads to more water vapour in the atmosphere; and more water vapour absorbs more thermal energy and produces a warmer atmosphere.

Sense of scale

On average, only one in every 2000 molecules in the atmosphere is a greenhouse gas and contributes to the greenhouse effect. Therefore, even a small increase in greenhouse gases can have a large effect on climate.

Carbon Dioxide Sources and Sinks

The main natural source of atmospheric carbon dioxide (CO_2) is animal respiration. The main human source is combustion of fossil fuels. Carbon dioxide is removed from the atmosphere by plants when they convert it into stored carbon during photosynthesis. Because of this role, plants, such as those shown in **Figure 8.13**, are carbon sinks. Deforestation increases the amount of carbon dioxide in the atmosphere by clearing large areas of trees, which are important carbon sinks.

As you learned in Section 8.1, phytoplankton in the oceans also play a major role in the absorption and storage of carbon dioxide. Scientists estimate that the oceans currently absorb between 30 and 50 percent of the carbon dioxide produced by the burning of fossil fuels.

Figure 8.13 Canada's forests, such as this one in northern Alberta, form an important carbon sink. They help to remove carbon dioxide from the atmosphere.

Interaction of Water Vapour and Carbon Dioxide

Because carbon dioxide and water vapour are both greenhouse gases, the effect of one is added to the effect of the other to form a positive feedback loop. For example, some scientists estimate that a doubling of carbon dioxide in the atmosphere would, by itself, warm Earth by about 1°C. However, this amount of warming would increase the rate of evaporation, and thus increase the amount of water vapour in the atmosphere. The additional warming effect of the water vapour would double the temperature increase to about 2°C. When other feedbacks are also added, such as a lowered albedo due to melting ice, the total warming from a doubling of carbon dioxide is raised to about 3°C.

The amplifying effect of water vapour also applies to atmospheric cooling. For example, in 1991 a massive eruption of Mount Pinatubo in the Philippines sent huge amounts of ash and greenhouse gases into the atmosphere, as shown in **Figure 8.14**. The particles suspended high in the atmosphere increased Earth's albedo, reflecting sunlight and cooling the planet for a period of several years. The cooling led to atmospheric drying, which caused the global temperature to drop even further.

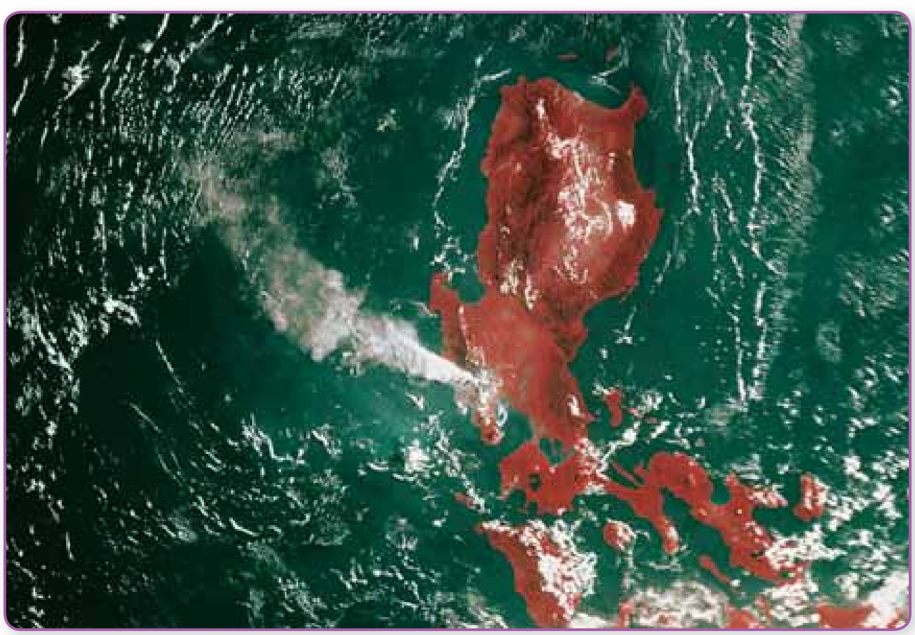

Figure 8.14 The white and grey plume in this satellite image is the column of ash and dust thrown into the air during the 1991 eruption of Mount Pinatubo in the Philippines. The brown area is the island of Luzon, which is about 225 km wide. This eruption cooled Earth's global average temperature by as much as 0.2°C for five years.

Sources of Methane

Methane (CH_4) is produced by bacteria that break down waste matter in oxygen-free environments. A major natural source of methane is wetlands (bogs and swamps), where large amounts of organic material decompose under water. Like wetlands, rice paddies also produce methane. Termites and cattle both produce methane during their normal digestive processes. Additional human sources include decomposing garbage in landfills, processing of coal and natural gas, and tanks of liquid manure from livestock production.

Scientists have suggested some unique ways to capture, or sequester, carbon from methane. One suggestion involves having cattle wear backpacks to capture the methane released from their digestive tract, as you saw at the beginning of this chapter. This methane could be collected for use as a fuel. Other scientists suggest that simply feeding cattle clover and alfalfa rather than corn and grain will reduce methane emissions by those animals by 25 percent. Some environmental activists have proposed a simple switch in human diets. These groups have started a campaign to convince people to stop eating beef and start eating camels and kangaroos, such as those shown in **Figure 8.15**. The digestive tracts of these animals do not produce the same greenhouse gases that the stomachs of cattle and sheep do.

Learning Check

1. Why do scientists need to measure greenhouse gases in parts per million?
2. What does the word *sink* mean when used in the phrase *carbon sink*?
3. Create a flowchart that illustrates how water vapour and carbon dioxide interact to form a positive feedback loop.
4. What two human activities might cause methane to accumulate in the atmosphere?

Figure 8.15 Kangaroo meat is produced in Australia and New Zealand and shipped to markets around the world. The digestive systems of these animals produce almost no methane.

Natural and Anthropogenic Sources of Nitrous Oxide

Most natural production of nitrous oxide (N_2O) comes from damp tropical soils and the oceans. Nitrous oxide also forms when nitrogen-rich compounds are broken down by bacteria. Human sources include chemical fertilizers, manure and sewage treatment, and vehicle exhausts.

Stratospheric Ozone: Earth's "Sunscreen"

Another greenhouse gas, called **ozone** (O_3), is composed of three atoms of oxygen. Ozone occurs naturally in the upper atmosphere at altitudes between 10 and 50 km. The ozone layer blocks harmful ultraviolet radiation from the Sun, preventing it from reaching Earth's surface. Ultraviolet radiation can cause skin cancers in humans and genetic damage in other organisms.

ozone a greenhouse gas that is composed of three atoms of oxygen; it is commonly found in a concentrated layer in the stratosphere

Ozone Depletion and the Ozone "Hole"

Since the 1970s, there has been a slow, steady decline in the total volume of ozone in the stratosphere. Beginning during the same period, an ozone "hole" has appeared over the Antarctic each year from September to December. The Antarctic ozone hole is shown in **Figure 8.16**. The ozone hole is not actually a hole; it is a large region in which ozone concentration is declining, which creates a thinning area in the stratospheric ozone layer. In this region, ozone levels have fallen to as little as one third of the concentration before 1970.

The main cause of ozone depletion is the addition to the atmosphere of human-made gases that contain chlorine. The depletion of the ozone layer results in an increase in the amount of ultraviolet light that reaches Earth's surface. However, scientists are also concerned by a positive feedback loop that results from the breakdown of stratospheric ozone. Because ozone acts as a greenhouse gas, reduced ozone levels will cause the stratosphere to cool. This cooling could lead to the formation of polar stratospheric clouds (PSCs). Within these clouds, chemical reactions result in the formation of free chlorine. The chlorine reacts with ozone and breaks apart the ozone, further reducing the amount of ozone in the stratosphere.

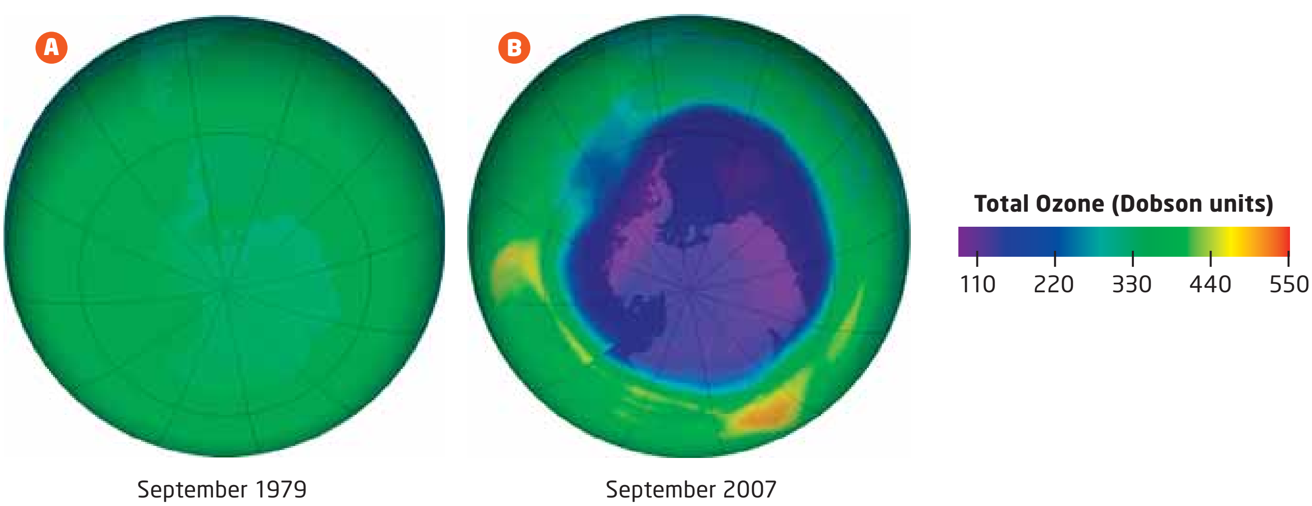

Figure 8.16 As the legend on the right shows, the concentration of ozone over Antarctica decreased between **A** 1979 and **B** 2007. The largest measurement recorded for the size of the ozone hole is 29.5 million km^2–larger than the size of North America.

Ground-Level Ozone

Figure 8.17 Vehicle exhaust is a direct source of greenhouse gases. It is also an indirect source of ground-level ozone.

Ozone also occurs in the atmosphere near ground level as a smog-forming pollutant. This ozone is produced by a chemical reaction between sunlight and chemicals in vehicle exhaust—mainly hydrocarbons and nitrogen oxides—as shown in **Figure 8.17**. The greatest concentrations of polluting ozone are found over cities, but ozone can also be blown many kilometres from its source by winds. Ground-level ozone can cause damage to the lungs and heart, and produces cracks in rubber and plastic products. In addition, this greenhouse gas can trap thermal energy close to Earth's surface, which could contribute to global warming.

Halocarbons

The other greenhouse gases you have learned about have natural sources as well as being produced by humans. However, halocarbons are formed only by industrial processes—no natural source of these powerful greenhouse gases exists. *Halocarbons* are a large group of chemicals formed from carbon and one or more halogens, such as chlorine, fluorine, or iodine. Halocarbon molecules are more efficient than carbon dioxide at absorbing infrared radiation. Some of them are very stable and can remain in the atmosphere for thousands of years before they are broken down.

The best-known halocarbons are **chlorofluorocarbons (CFCs)**. Their main use is as solvents, cleaners, and coolants in refrigerators and air conditioners. As well as absorbing infrared radiation, CFCs break apart ozone molecules in the upper atmosphere. This reaction has led to depletion of the ozone layer and the formation of the ozone hole over the Antarctic. The use of CFCs has been banned in most developed nations since 1987. Because CFCs remain in the atmosphere for so long, however, they continue to damage the ozone layer.

chlorofluorocarbon (CFC) a human-made chemical compound that contains chlorine, fluorine, and carbon; when released into the atmosphere may cause depletion of the ozone layer

Making a Difference

P.J. Partington thinks people interested in working for the environment should just "jump right into it." That's what he did. He started volunteering with the Canadian Youth Climate Coalition after a friend invited him to the coalition's first meeting. By the end of the meeting, P.J. was co-ordinator of the coalition's policy group. A month later he was helping to organize the youth delegation to the 2006 United Nations climate negotiations in Nairobi, Kenya. Soon after, P.J. began working for TakingITGlobal, an international, youth-led organization based in Toronto. In 2008, he was responsible for the Canadian Youth Delegation to the UN climate negotiations in Poznan, Poland.

P.J. studied environmental policy at the London School of Economics and Political Science in the United Kingdom. He is now a climate change policy analyst at The Pembina Institute.

What local environmental group(s) could you volunteer to assist? What value do you see in "just jumping in"?

The Anthropogenic Greenhouse Effect

Levels of carbon dioxide in the atmosphere have varied widely over the past 800 000 years. However, human activities have significantly increased the quantities of carbon dioxide and other greenhouse gases since about 1750, as shown in **Table 8.4**. Most of the increase in CO_2 has come from the burning of fossil fuels. Deforestation and agriculture have added carbon dioxide, methane, and nitrous oxide. Industrial activities have produced ground-level ozone, CFCs, and other pollutants that affect the climate system. The increase in global average temperature since the 1960s is likely due mainly to the increase in greenhouse gases produced by human activities. This result is known as the **anthropogenic greenhouse effect**.

anthropogenic greenhouse effect the increased capacity of the atmosphere to absorb and prevent the escape of thermal energy because of an increase in greenhouse gases introduced by human activities

Table 8.4 Greenhouse Gas Concentration Before and After the Industrial Revolution

Greenhouse Gas	Level Before 1750	Current Level	Increase Since 1750
carbon dioxide	280 ppm	384 ppm	104 ppm
methane	700 ppb	1745 ppb	1045 ppb
nitrous oxide	270 ppb	314 ppb	44 ppb
CFCs	0 ppt	533 ppt	553 ppt

Activity 8-3

Graphing Changes in Carbon Dioxide

What effect has the burning of fossil fuels had on global temperature? In this activity, you will track the amount of carbon dioxide in the atmosphere and the global temperature increase over time.

Materials

- graph paper
- coloured pencils or pens

Procedure

1. Use the data from the table to make the following three line graphs: year versus industrial carbon dioxide emissions, year versus carbon dioxide concentration in the atmosphere, year versus temperature increase since 1861.
2. Using a different colour, extend each of the line graphs to 2020. For help in creating your graph, refer to Math Skills Toolkit 3 on pages 555-558.

Questions

1. Describe the shape of each graph.
2. Describe the trends since 1861 for industrial carbon dioxide emissions, carbon dioxide concentration, and average global temperature increase.
3. "Human combustion of fossil fuels has resulted in rising global temperatures." How do the results of this activity affect your opinion about this statement?

Changes in Carbon Dioxide and Average Global Temperature

Year	Industrial CO_2 Emissions (gigatonnes)*	CO_2 Concentration (ppm per volume)	Temperature Increase Since 1861 (°C)
1861	0.67	285	0.00
1880	1.15	292	0.00
1900	2.63	298	0.05
1920	3.42	303	0.29
1940	4.95	307	0.46
1960	9.98	318	0.35
1980	20.72	340	0.41
2000	23.42	365	0.63

Source: Carbon Dioxide Information Analysis Center (CDIAC)
* 1 gigatonne = 1 billion tonnes

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Learning Check

5. Identify five sources of nitrous oxide.
6. Use the data in **Table 8.4** to calculate the percentage increase in greenhouse gases since the Industrial Revolution. How is this increase related to climate change?
7. How do halocarbons and ozone interact to change the upper atmosphere?
8. Summarize the sources of the greenhouse gases that contribute to the anthropogenic greenhouse effect.

Comparing the Global Warming Potential of Greenhouse Gases

Which greenhouse gases should we be most concerned about? The contribution of a particular greenhouse gas to global warming depends on three things:

- the concentration of the gas in the atmosphere
- the ability of the gas to absorb heat
- the length of time the gas remains in the atmosphere

global warming potential (GWP) the ability of a substance to warm the atmosphere by absorbing thermal energy

To help compare the relative impact of one greenhouse gas with that of another, scientists use a measure called **global warming potential (GWP)**. Carbon dioxide is assigned a GWP of 1. The warming effect of every other greenhouse gas is compared with the warming effect of the same mass of carbon dioxide over a specified period of time. **Table 8.5** compares the GWP of four major greenhouse gases. The table shows that methane is broken down in the atmosphere after about 12 years. However, since methane is able to absorb and emit more heat than carbon dioxide does, methane has a higher GWP.

Halocarbons account for less than 2 percent of all greenhouse gas emissions produced by human activities. But because they remain in the atmosphere almost indefinitely, concentrations of these gases will increase as long as emissions continue. Their ability to trap heat in the atmosphere over time can be thousands of times greater than that of carbon dioxide. Therefore, these gases are considered high GWP gases. Fortunately, many nations have banned the production and use of CFCs.

Table 8.5 Global Warming Potential of Major Greenhouse Gases

Greenhouse Gas	Chemical Formula	Atmospheric Lifetime (years)	Global Warming Potential (GWP) over 100 Years
carbon dioxide	CO_2	variable	1
methane	CH_4	12	25
nitrous oxide	N_2O	115	298
chlorofluorocarbons (CFCs)	various	indefinite	4750-5310

Ways to Reduce Greenhouse Gas Production

Canada ranks among the top 10 nations in the world for the amount of greenhouse gases produced per person. You play a part in adding greenhouse gases to the atmosphere, even if you do not drive a vehicle. Almost one fifth of Canada's total greenhouse emissions come from people's homes. Here are some ways that you can help to reduce greenhouse gas production at home.

Figure 8.18 Simply replacing incandescent light bulbs with fluorescent bulbs can prevent thousands of kilograms of carbon dioxide from ever being emitted.

Conserve electricity Where do the electricity supplies to your home and school come from? Power plants that burn coal and other fossil fuels to generate electricity are a source of greenhouse gases. You can reduce emissions from power plants by reducing your use of electricity. For example, you can reduce emissions by using more energy-efficient light bulbs and appliances. **Figure 8.18** shows an energy-efficient compact fluorescent light bulb. You can also reduce your impact by the simple act of conserving energy. For example, turn off lights, televisions, computers, and other appliances when you are not using them.

Improve home-heating efficiency Most home furnaces and boilers burn oil or natural gas. Greenhouse gas production can be reduced by lowering the thermostat setting and improving insulation. Modern furnaces have improved energy efficiency compared with older furnaces, and they release lower amounts of greenhouse gases. Many building standards and codes are related to the energy efficiency of new structures. Some local and national programs also exist to help retrofit older buildings to make them more energy efficient.

Reduce, re-use, and recycle How does the garbage you throw out each week add to greenhouse gas emissions? First, producing all of the products you buy and use took energy. If you re-use and recycle items instead of throwing them out, as shown in **Figure 8.19**, you reduce the demand for energy to make more products. Second, garbage buried in a landfill produces methane, and garbage burned in an incinerator produces carbon dioxide. The less garbage you produce, the fewer greenhouse gases you produce.

Figure 8.19 Recycling programs help to reduce the amount of trash in landfills and the amount of greenhouse gases produced by companies that manufacture product packaging.

Section 8.2 Review

Section Summary

- Earth emits thermal energy. Greenhouse gases in the atmosphere absorb this energy and radiate it in all directions. The thermal energy that returns to Earth gives rise to the greenhouse effect.
- Less than one gas molecule in a hundred is a greenhouse gas.
- The most common greenhouse gas is water vapour. Other major greenhouse gases include carbon dioxide, methane, ozone, nitrous oxides, and halocarbons.
- Human activities, such as agriculture and the burning of fossil fuels, are increasing the amounts of some of the greenhouse gases in the atmosphere.
- An increase in greenhouse gases has resulted in the anthropogenic greenhouse effect, which may be responsible for recent climate change.
- You can reduce your contribution of greenhouse gases by conserving electricity, improving home-heating efficiency, and minimizing waste as much as possible.

Review Questions

K/U **1.** Why do scientists measure the concentration of gases in the atmosphere?

C **2.** A friend says, "The greenhouse effect is a terrible thing because it is causing the world to heat up." Explain why this statement is inaccurate.

T/I **3.** Water vapour is the most abundant greenhouse gas, but scientists are not attempting to limit the amount of water vapour created by humans. Why do you think this is so?

K/U **4.** Identify three major anthropogenic sources of methane, and describe what is being done to minimize their impact.

K/U **5.** What are chlorofluorocarbons, and what effect do they have on climate?

T/I **6.** Sort the greenhouse gases into three categories: those made entirely by human activity, those that human activity has some effect on, and those that human activity has no significant effect on.

K/U **7.** What three factors determine the global warming potential of different greenhouse gases?

A **8.** The graph on the right shows the sources of greenhouse gases produced by Canadians. Assuming that the energy sector releases mainly carbon dioxide and the agriculture sector releases mainly methane, which source has the greatest global warming potential? Explain your answer.

Greenhouse Gases by Sources in Canada, 1990–2004