3 Greenhouse Gases

OVERVIEW

Climate change is undoubtedly one of the biggest challenges humankind has ever faced. The bad news is that a large share of it is our own doing. The good news is that there is still a window of opportunity left to fix it if we act now. That is right. This is a significant, global problem, but with a transition of habits and some dedicated work, there is still a window of hope. But the clock is ticking and we are quickly running out of time.

This chapter discusses the greenhouse gases—the chief contributor and reason for the rise in temperature and trigger for the negative global impacts the earth is now experiencing and will experience for thousands of years to come. The chapter begins by presenting the basics of solar radiation and the processes the Sun's energy takes to get to the earth. Once it reaches the planet, it explains the various pathways it takes and the complications that then occur because of the greenhouse gases that humans have overloaded the atmosphere with. This introduces the important concept of radiative forcing and how that has now permanently impacted the earth's energy balance.

Next, the various greenhouse gases are introduced, their properties, and why their collection and buildup in the atmosphere is so detrimental. The concept of climate change potential of each of the greenhouse gases is presented as an illustration of why this whole process has such long and far-reaching effects—why some of the greenhouse gases can remain in the atmosphere and cause damage for thousands of years. The chapter then presents the concept of carbon sequestration and why this process is so important, as well as various carbon sinks and sources and why these must be managed in order to help mitigate the rate of greenhouse gas influx into the atmosphere. Next, it examines the impacts of deforestation, the burning of fossil fuels, and coal emissions, and lays the foundation as to why these activities are so environmentally detrimental. In conclusion, it discusses various health concerns and the key impacts to the earth's ecosystems as a result of the increasing concentration of greenhouse gases in the atmosphere and why it is imperative that the world's nations come together now in order to effectively mitigate the problem before it is too late.

INTRODUCTION

According to Dr. James E. Hansen of the National Aeronautics and Space Administration (NASA), one of the world's foremost climate experts, there is still a small window of time left where actions can be taken to slow down the climate change processes that have been put in motion in order to keep temperatures from climbing over the 2°C mark. But everyone has to play a part and make a commitment—large or small. As Canadian philosopher Marshall McLuhan said, "There are no passengers on Spaceship Earth. We are all crew."

One of the areas where humans can have the biggest impact in mitigating the rise in atmospheric temperature is through the control of greenhouse gas emissions. The emission of greenhouse gases is the most significant factor in climate change and the area where attention is most needed. Most greenhouse gases are emitted through the burning of fossil fuels—coal, oil, and gas. Fossil fuels are burned not only for public and private transportation, but also in the manufacture of most commodities, the generation of most electricity, most manufacturing and industrial processes, and commerce and commercial transportation. Developed countries are pumping greenhouse gases into the atmosphere at alarming rates. In order to halt the destruction being caused by greenhouse gases, action needs to be taken immediately. In order to make this happen, however, public education is critical. This chapter lays the foundation as to why greenhouse gases are so detrimental and why their mitigation is critical.

DEVELOPMENT

As we saw in Chapter 2, the earth needs the natural greenhouse effect in order for life to survive. It is the process in which the emission of infrared radiation by the atmosphere warms the planet's surface. The atmosphere naturally acts as an insulating blanket, which is able to trap enough solar energy to keep the global average temperature in a comfortable range in which to support life. This insulating blanket is actually a collection of several atmospheric gases, some of them in such small amounts that they are referred to as trace gases.

The framework in which this system works is often referred to as the greenhouse effect because this global system of insulation is similar to that which occurs in a greenhouse nursery for plants. The gases are relatively transparent to incoming visible light from the Sun, yet opaque to the energy radiated from the earth.

These gases are the reason why the earth's atmosphere does not scorch during the day and freeze at night. Instead, the atmosphere contains molecules that absorb the heat and reradiates the heat in all directions, which reduces the heat lost back to space. It is the greenhouse gas molecules that keep the earth's temperature ranges within comfortable limits. Without the natural greenhouse effect, life would not be possible on earth. In fact, without the greenhouse effect to regulate the atmospheric temperature, the Sun's heat would escape and the average temperature would drop from 14°C to −18°C, a temperature much too cold to support the diversity of life that exists today on the planet.

Radiation Transmission

Understanding radiation transmission is important to understanding how and why specific gases in the atmosphere are affected during the greenhouse gas process. The earth reflects 30 percent of the incoming solar radiation back out into space. The remaining 70 percent is absorbed and warms the atmosphere, land, and oceans. In order to maintain an energy balance, keeping the earth from getting too hot or cold, the amount of incoming energy must roughly equal the amount of outgoing energy (see Figure 3.1).

The majority of insolation is in the short and medium wavelength regions of the spectrum. The highest energy, short wavelengths, such as the gamma rays, X-rays, and ultraviolet (UV) light is absorbed by the mid to high levels of the atmosphere. This is desirable because if these wavelengths traveled to the surface, they could cause harm to life on earth. For example, exposure to UV light can lead to cancer. The medium wavelengths—referred to as visible light—travel to the earth's surface. These waves can be absorbed or reflected at the earth's surface as well as by the CO_2 and water vapor in the atmosphere.

When wavelengths from the electromagnetic spectrum reach the earth, several things can happen. They can get reflected; the earth's surface, the ocean, the clouds, or the atmosphere can absorb them; and they can be scattered. Of that which does enter the earth's atmosphere, nearly one-quarter of that is reflected by clouds and particulates (tiny suspended particles) in the atmosphere. Of the remaining visible light that does reach the earth's surface, approximately one-tenth is reflected upward by snow and ice, due to their extremely high albedo (high reflectivity). As the infrared radiation (heat) is emitted upward, it does not simply escape to space. Water vapor and other gases in the atmosphere absorb it and trap it in the atmosphere. This trapped heat then radiates in all directions: upward, down toward the earth's surface again, and sideways. This trapped heat energy is what constitutes the greenhouse effect.

The Natural and Enhanced Greenhouse Effect

In this "greenhouse environment," it is the combination of water vapor and trace gases that are responsible for trapping the heat radiated from the Sun. As stated, this natural amount keeps the earth habitable instead of at −18°C, in which case the earth would look much different—there would most likely be very little, if any, liquid water available. The entire earth would have an ecosystem similar to that of the harshest areas in Antarctica.

The earth's natural greenhouse effect is critical for the survival and diversity of life. Since the Industrial Revolution (over the past 250 years or so), the natural greenhouse effect has been augmented by human interference. Carbon dioxide (CO_2), one of the atmosphere's principal greenhouse gases, has been altered to such an extent by human activity that the natural greenhouse effect is no longer in balance. The earth's energy balance now must contend with what is referred to as the enhanced greenhouse effect or anthropogenic greenhouse warming. CO_2 is being added in voluminous amounts as a result of human activity, deforestation, agricultural practices, the burning of fossil fuels for transportation, urban development, the heating and cooling of homes, and industrial processes. In fact, CO_2 in the atmosphere has increased 31 percent since 1895. Concentration of other greenhouse gases, such as methane and nitrous oxides (also related to human activity), have increased 151 percent and 17 percent, respectively.

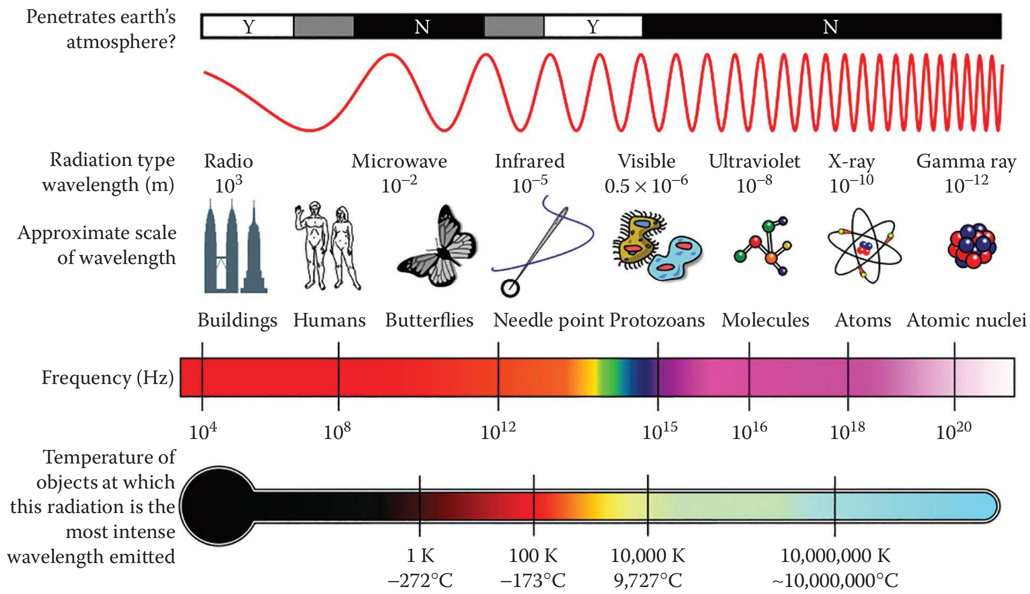


FIGURE 3.1 The sun's electromagnetic spectrum ranges from short wavelengths, such as X-rays, to long wavelengths, such as radio waves. The majority of the sun's energy is concentrated in the visible and nearly visible portions of the spectrum—the wavelengths located between 400 and 700 nm. (From Gines, J. K., *Climate Management Issues: Economics, Sociology, and Politics*, CRC Press, New York, 2012.)

At the beginning of the Industrial Revolution, the CO_2 content in the atmosphere was 280 parts per million (ppm). By 1958, it had increased to 315 ppm; by 2004, 378 ppm; and by 2011, 392.4 ppm. By February 2016, it had climbed to a record of 404.16 ppm. According to Dr. James E. Hansen, a world-renowned expert on climate change at NASA's Goddard Institute for Space Studies (GISS) in New York, "Climate is nearing dangerous tipping points. We have already gone too far. We must draw down atmospheric CO_2 to preserve the planet we know. A level of no more than 350 ppm is still feasible, with the help of reforestation and improved agricultural practices, but just barely—time is running out" (Hansen, 2008).

Although not the only greenhouse gas, CO_2 does seem to be the one most focused on because it is one of the most important and prevalent. It makes up about 25 percent of the natural greenhouse effect because there are several natural processes that put it in the atmosphere, such as the following:

- *Forest fires*: When trees are burned, the CO_2 stored within them is released into the atmosphere.
- *Volcanic eruptions*: CO_2 is one of the gases released in abundance by volcanoes.
- *Ocean equilibrium*: Oceans both absorb and release enormous amounts of CO_2. Historically they have served as a major storage facility of CO_2 put into the atmosphere from human sources. Recently, however, scientists at NASA and National Oceanic and Atmospheric Administration (NOAA) have determined that the oceans have become nearly saturated and are approaching their limits as a carbon store.
- *Vegetation storage*: Trees, plants, grasses, and other vegetation serve as significant stores of carbon. When they die and decompose, half of their stored carbon is released into the atmosphere in the form of CO_2.
- *Soil processes*: When vegetation dies, the other half of their stored carbon is absorbed by the soil. Over time, some of this carbon is released into the atmosphere as CO_2.
- *Biological factors*: Any life form that consumes plants that contain carbon also emits CO_2 into the atmosphere through breathing. This includes animals, insects, and even humans.

With this amount of CO_2 entering the atmosphere, fortunately there are some processes that help keep it in check. Plants and trees remove CO_2 from the atmosphere through photosynthesis, the oceans absorb large amounts of CO_2, and phytoplankton take in CO_2 through photosynthesis. Ideally, keeping CO_2 in balance is desirable, but throughout the earth's history, this has not always been possible. When CO_2 levels have dropped, the earth has consistently experienced an ice age. Since the last ice age, CO_2 levels remained fairly constant, however, until the Industrial Revolution, when billions of tons of extra CO_2 began to be added to the earth's atmosphere.

The turning point was the use of fossil fuels—coal, oil, and gas—made from the carbon of plants and animals that decomposed millions of years ago and were buried deep under the earth's surface, subjected to enormous amounts of heat and pressure. When this carbon is converted into usable energy forms and is burned as fuel, the carbon combines with oxygen and releases enormous amounts of CO_2 into the atmosphere.

According to NASA/GISS, CO_2 levels have not been as high as they are today over the past 400,000 years (Hansen, 2007). As James Hansen of NASA explained, "The total energy imbalance now is about six-tenths of a watt per square meter. That may not sound like much, but when added up over the whole world, it's enormous. It's about 20 times greater than the rate of energy use by all of humanity. It is equivalent to exploding 400,000 Hiroshima atomic bombs per day 365 days per year. That's how much extra energy Earth is gaining each day. This imbalance, if we want to stabilize climate, means that we must reduce CO_2 from 391 ppm, parts per million, back to 350 ppm. That is the change needed to restore energy balance and prevent further warming" (Hansen, 2012).

CO_2 FAST FACTS

- Global carbon (C) emissions from fossil fuel use were 9.795 gigatons (Gt) in 2014.
- Fossil fuel emissions were 0.6 percent above emissions in 2013 and 60 percent above emissions in 1990 (the reference year in the Kyoto Protocol).
- Fossil fuel emissions accounted for about 91 percent of total CO_2 emissions from human sources in 2014. This portion of emissions originates from coal (42%), oil (33%), gas (19%), cement (6%), and gas flaring (1%).
- Changes in land use are responsible for about 9 percent of all global CO_2 emissions.
- In 2013, the largest national contributions to the net growth in total global emissions were China (58%), the United States (20%), India (17%), and European Union-28 (EU28) (a *decrease* of 11%).
- The 2014 level of CO_2 in the atmosphere was 43 percent above the level when the Industrial Revolution started in 1750.
- February 2016 was the warmest February in the past 137 years. The temperature deviated from the twentieth-century average by 1.21°C. This is the tenth consecutive month that the monthly temperature record has been broken.
- NOAA's global analysis for 2015 lists 2015 as the warmest year on record since 1880 at 0.90°C above the twentieth-century average. The year 2014 is the second warmest at 0.74°C above the average. The year 2013 was the fourth warmest at 0.66°C above the average.

Source: NOAA Global Analysis.

The enhanced greenhouse effect has not come as a surprise to climate scientists, other experts, and decision makers, however. Climate scientist, Charles David Keeling of the Scripps Institution of Oceanography, made enormous strides in establishing the rising levels of CO_2 in the earth's atmosphere and the subsequent issue of the enhanced greenhouse effect and climate change. Keeling set up a CO_2 monitoring station at Mauna Loa, Hawaii, in 1957. Beginning in 1958, Keeling made continuous measurements of CO_2, which still continue today. He chose the remote Mauna Loa site so that the proximity of large cities and industrial areas would not compromise the atmospheric readings he was collecting. Air samples at Mauna Loa are collected continuously from air intakes at the top of four 7-meter towers and one 27-meter tower. Four air samples are collected each hour to determine the CO_2 level.

The measurements he gathered show a steady increase in mean atmospheric concentration from 315 ppm by volume (ppmv) in 1958 to more than 392 ppmv by 2011. The increase is considered to be largely due to the enhanced greenhouse effect and the burning of fossil fuels and deforestation. This same upward trend also matches the paleoclimatic data shown in ice cores obtained from Antarctica and Greenland. The ice cores also show that the CO_2 concentration remained at approximately 280 ppmv for several thousand years, but began to rise sharply at the beginning of the 1800s (Figure 3.2).

The Keeling Curve also shows a cyclic variation of about 5 ppmv each year. This is what gives it the sawtooth appearance. It represents the seasonal uptake of CO_2 by the earth's vegetation (principally in the Northern Hemisphere because that is where most of the earth's vegetation is located). The CO_2 lowers in the spring because new plant growth takes CO_2 out of the atmosphere through photosynthesis, and it rises in autumn as plants and leaves die off and decay, releasing CO_2 gas back into the atmosphere.

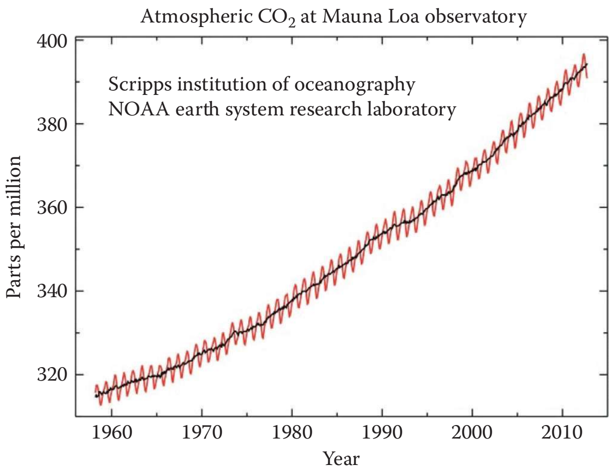


FIGURE 3.2 Collected since 1958, the data in the Keeling Curve have been instrumental in providing convincing evidence that CO_2 levels are rising worldwide. The jagged line depicts the readings collected from the Mauna Loa observation station, and the smoother line depicts the data collected from the south pole. Without these continuous data, it would be much more difficult to determine the existence of climate change. (Courtesy of NOAA.)

Mauna Loa is considered the premier long-term atmospheric monitoring facility on earth. It is also one of the world's most favorable locations for measuring undisturbed air because vegetation and human influences are minimal, and any influence from volcanic vents has been calculated and excluded from the measurement. The methods and equipment used to create the continuous monitoring record have been the same for the past 58 years, rendering the monitoring program highly controlled and consistent.

Keeling was a true pioneer in establishing the existence of climate change. His work was instrumental in showing scientists worldwide that the CO_2 level in the atmosphere was indeed continually rising. This was the first strongly compelling evidence that climate change not only existed but was accelerating. Because of the worthwhile merits and significance of his work, NOAA began monitoring CO_2 levels worldwide in the 1970s. There are currently about 100 sites continuously monitored today because of what was started on Mauna Loa.

Ralph Keeling, Charles David Keeling's son, says, "The Keeling Curve has become an icon of the human imprint on the planet and a continuing resource for the study of the changing global carbon cycle. Mauna Loa provides a valuable lesson on the importance of continuous earth observations in a time of accelerating global change" (Keeling, 2008).

The Intergovernmental Panel on Climate Change (IPCC) has projected that with continued climate change, temperatures will rise an average of 1.4°C–5.8°C in the next 100 years (IPCC, 2001). The polar regions, however, are expected to rise more than the average. Currently, with much of the polar areas being covered by snow and ice, they have a high albedo, so much of the insolation is reflected back to space. As temperatures warm, however, the snow and ice will melt, exposing darker surfaces (land and water), which will naturally absorb more heat, melt more ice, and uncover more dark surface area. This could continue in a cycle until all the snow and ice are melted, greatly changing the heat balance in the polar regions, resulting in a rapid warming (Riebeek, 2010).

Radiative Forcing

When discussing the enhanced greenhouse effect and climate change, climate scientists often refer to a concept called "radiative forcing." This is a measure of the influence that an independent factor (ice albedo, aerosols, land use, carbon dioxide) has in altering the balance of incoming and outgoing energy in the earth–atmosphere system. It is also used as an index of the influence a factor has as a potential climate change mechanism. Radiative forcings can be positive or negative. A positive forcing (corresponding to more incoming energy) warms the climate system. A negative forcing (corresponding to more outgoing energy) cools the climate system.

As shown in the illustration, examples of positive forcings (those which warm the climate) include greenhouse gases,

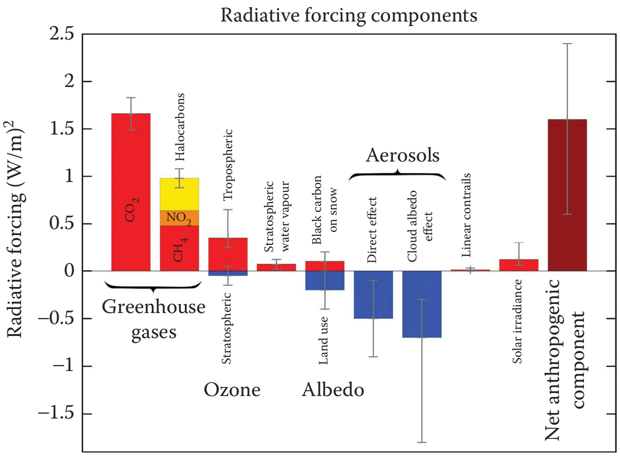


FIGURE 3.3 Graph illustrating the concept of radiative forcing. In order to understand the climate change, it is necessary to understand the components in the atmosphere that control the overall warming and cooling on short- and long-term bases. (From NASA/GISS, Forcings in GISS climate model, http://data.giss.nasa.gov/modelforce/.)

tropospheric ozone, water vapor, solar irradiance, and anthropogenic effects (see Figure 3.3). Those that have a negative rating (they cool the climate) include stratospheric ozone and certain types of land use. Climatologists often use radiative forcing data to compare various cause-and-effect scenarios in climate systems where some type of change (warmer or cooler) has taken place. Radiative forcings and their effects on climate are also built into climate models in order to enable climatologists to determine the effects from multiple input factors on climate change. The greenhouse gases that remain in the atmosphere the longest will have the greatest impact on climate change, making it imperative that climatologists not only be able to identify them but also understand them and how they react with the atmosphere.

The Earth's Energy Balance

Even if greenhouse gas emissions were stabilized at today's rates, climate change would not stop. According to scientists at NASA, CO_2 levels are rising because there is more CO_2 being emitted into the atmosphere than natural processes such as photosynthesis and absorption into the oceans can presently remove. There is no longer a carbon balance, and there is a net gain that continues to increase each year. As the CO_2 levels increase, the temperatures continue to rise.

Because the earth's carbon system is already so out of balance, in order to stop climate change, emissions must actually be reduced over the coming years, not just stabilized. Even with the best of intentions, the earth's temperature would not react immediately—there is a delayed reaction. This occurs because there is already an abundance of excess energy stored in the world's oceans. This "lag" time responding to the reaction is referred to as thermal inertia. Because of thermal inertia, scientists at NASA have determined that the 0.6°C–0.9°C of climate change that has already occurred this past century is not the full amount of warming the environment will eventually reach from the greenhouse gases that have already been emitted into the atmosphere. Even in the extreme case that all greenhouse emissions stopped immediately, the earth's average surface temperature would continue to climb another 0.6°C or more over the next several decades before temperatures leveled off.

The half-life of CO_2 is about 100 years. Therefore, most of the CO_2 being released today will still be in the atmosphere in 2116. Although there are natural factors that control the CO_2 levels and climate, NASA supports the notion that human influence is changing the climate on earth—many agree today's documented climate change trend is at least partly anthropogenic in origin. The IPCC (2013) says, "The balance of evidence suggests that there is a discernible human influence on global climate."

According to Dr. James E. Hansen, this "lag time" is a key reason why it is risky to hold off any longer trying to control greenhouse gas emissions (Climate Policy Watcher, 2012). The longer the society waits to take positive action to stop climate change, the more severe and long-lasting the consequences will become. He stresses that the time to act is now, not some time in the future.

If climate change is allowed to continue, there will be many negative effects, such as the disappearance of ecosystems, leading to the extinction of many species; there will be a greater number of heat-related deaths; there will be a greater spread of infectious diseases, such as encephalitis, malaria, and dengue fever through the proliferation of disease-carrying mosquitoes; malnutrition and starvation as a result of droughts; loss of coastal areas due to sea-level rise from melting ice caps and thermal expansion of the oceans; unpredictable agricultural production; and threatened food supply and contaminated water. Impacts will be health related, social, political, ecological, environmental, and economic.

Greenhouse Gases

It is the existence of trace gases in the atmosphere that act like the glass in a greenhouse. The trace gases serve to trap the heat energy from the Sun close to the earth. Most greenhouse gases occur naturally and are cycled through the global biogeochemical system. It is the greenhouse gases added by human activity that are trapping too much heat today and causing the atmosphere to overheat. There are several different types of greenhouse gases; some exist in greater quantities than others. They include water vapor, CO, methane, nitrous oxide, and halocarbons. They capture 70–85 percent of the energy in upgoing thermal radiation emitted from the earth's surface.

Water vapor—the most common greenhouse gas—accounts for roughly 65 percent of the natural greenhouse effect. When water heats up, it evaporates into vapor and rises from the earth's surface into the atmosphere, where it forms clouds and acts as an insulating blanket to help keep the earth warm or it can reflect and scatter incoming sunlight. This is why cloudy nights are warmer than clear nights. As water vapor condenses and cools, it then comes back to the earth as snow or rain and continues on its way through the water cycle.

The second most prevalent greenhouse gas, CO_2 comprises one-fourth of the natural greenhouse effect. Humans and animals exhale CO_2, vegetation releases CO_2 when it dies and decomposes, burning trees in a forest fire or burning during deforestation releases it, and burning fossil fuels (such as exhaust from cars and industrial processes) are all common sources of CO_2.

Methane is a colorless, odorless, flammable gas, formed when plants decay in an environment of restricted air. It is the third most common greenhouse gas and is created when organic matter decomposes without the presence of oxygen—a process called anaerobic decomposition. One of the most common sources is from "ruminants"—grazing animals that have multiple stomachs in which to digest their food. These include cattle, sheep, goats, camels, bison, and musk ox. In their digestive system, their large fore-stomach hosts tiny microbes that break down their food. This process creates methane gas, which is released as flatulence. Livestock also emit methane when they belch. In fact, in one day a single cow can emit one-half pound of methane into the air. Each day 1.3 billion cattle burp methane several times per minute.

Methane is also a by-product of natural gas and decomposing organic matter, such as food and vegetation. Also present in wetlands, it is commonly referred to as "swamp gas." Since 1750, methane has doubled its concentration in the atmosphere, and it is projected to double again by 2050. According to Nick Hopwood and Jordan Cohen at the University of Michigan, every year 350–500 million tons of methane is added to the atmosphere through various activities, such as the raising of livestock, coal mining, drilling for oil and natural gas, garbage sitting in landfills, and rice cultivation (Hopwood and Cohen, 2008). Because rice is grown in waterlogged soils, such as swamps, they release methane as a by-product.

Nitrous oxide (N_2O), another greenhouse gas, is released from manure and chemical fertilizers that are nitrogen based. As the fertilizer breaks down, N_2O is released into the atmosphere. Nitrous oxide is also contained in soil by bacteria. When farmers plow the soil and disturb the surface layer, N_2O is released into the atmosphere. It is also released from catalytic converters in cars and also from the ocean. According to Hopwood and Cohen, nitrous oxide has risen more than 15 percent since 1750. Each year 6–12 million metric tons is added to the atmosphere principally through the use of nitrogen-based fertilizers, the disposal of human and animal waste in sewage treatment plants, automobile exhaust, and other sources that have not yet been identified.

Halocarbons include the fluorocarbons, methyl halides, carbon tetrachloride (CCl_4), carbon tetrafluoride (CF_4), and halons. They are all considered to be powerful greenhouse gases because they strongly absorb terrestrial infrared radiation and stay in the atmosphere for many decades.

Fluorocarbons are a group of synthetic organic compounds that contain fluorine and carbon. A common compound is chlorofluorocarbon (CFC). This class contains chlorine atoms and has been used in industry as refrigerants, cleaning solvents, and propellants in spray cans. These fluorocarbons are harmful to the atmosphere, however, because they deplete the ozone layer, and their use has been banned in most areas of the world, including the United States.

Hydrofluorocarbons (HFCs) contain fluorine and do not damage the ozone layer. Fluorocarbon polymers are chemically inert and electrically insulating. They are used in place of CFCs because they do not harm or break down ozone molecules, but they do trap heat in the atmosphere. HFCs are used in air conditioning and refrigerators. The best way to keep them out of the atmosphere is to recycle the coolant from the equipment they are used in.

Fluorocarbons have several practical uses. They are used in anesthetics in surgery, as coolants in refrigerators, as industrial solvents, as lubricants, as water repellants, as stain repellants, and as chemical reagents. They are used to manufacture fishing line and are contained in products such as Gore-Tex and Teflon.

Climate Change Potential

Although there are several types of greenhouse gases, they are not the same—they all have different properties associated with them and the differences are critical, especially their half-life's—the duration of time they remain active in the atmosphere. They also differ significantly in the amount of heat they can trap.

It is important to note that these gases and their effects will continue to increase in the atmosphere as long as they continue to be emitted and remain there. Even though these gases represent a very small proportion of the atmosphere—less than 2 percent of the total—because of their enormous heat holding potential, they are a significant component to the atmosphere and represent a serious problem for climate change.

The U.S. Environmental Protection Agency (EPA) has identified three major groups of high global warming potential (GWP) gases: (1) HFCs, (2) perfluorocarbons (PFCs), and (3) sulfur hexafluoride (SF_6). These represent the most potent greenhouse gases; PFCs and SF_6 also have extremely long atmospheric lifetimes—up to 23,900 years. Because their lifetime is so incredibly long, for practical management purposes, once they are emitted into the atmosphere, they are considered to be there permanently. According to the EPA (2011), once present in the atmosphere, it results in "an essentially irreversible accumulation."

HFCs are man-made chemicals; most of them developed as replacements for the prior used ozone-depleting substances that were common in industrial, commercial, and consumer products. The GWP index for HFCs ranges from 140 to 11,700, depending on which one is used. Their lifetime in the atmosphere ranges from 1 to 260 years. Most of the commercially used HFCs have a lifetime of less than 15 years, such as HFC-134a, which is used in automobile air conditioning and refrigeration.

PFCs generally originate from the production of aluminum and semiconductors. They have very stable molecular structures and usually do not get broken down in the lower atmosphere. When they reach the mesosphere 60 kilometers above the earth's surface, high-energy UV electromagnetic energy destroys them, but it is a very slow process, which enables them to accumulate in the atmosphere for up to 50,000 years.

Sulfur hexafluoride has a GWP of 23,900, making it the most potent greenhouse gas. It is used in insulation, electric power transmission equipment, magnesium industry, and semiconductor manufacturing to create circuitry patterns on silicon wafers, and also as a tracer gas for leak detection. Its accumulation in the atmosphere shows the global average concentration has increased by 7 percent per year during the 1980s and the 1990s—according to the IPCC from less than 1 part per trillion (ppt) in 1980 to almost 4 ppt in the late 1990s (IPCC, 2007).

In order to understand the potential impact from specific greenhouse gases, they are rated as to their GWP. The GWP of a greenhouse gas is the ratio of climate change—or radiative forcing—from one unit mass of a greenhouse gas to that of one unit mass of CO_2 over a period of time, making the GWP a measure of the *potential for climate change per unit mass relative to* CO_2. In other words, greenhouse gases are rated on how potent they are compared to CO_2.

GWPs take into account the absorption strength of a molecule and its atmospheric lifetime. Therefore, if methane has a GWP of 23 and carbon has a GWP of 1 (the standard), this means that methane is 23 times more powerful than CO_2 as a greenhouse gas. The IPCC has published reference values for GWPs of several greenhouse gases. Reference standards are also issued and supported by the United Nations Framework Convention on Climate Change, as shown in Table 3.1. The higher the GWP value, the larger the infrared absorption and the longer the atmospheric lifetime. Based on this table, even small amounts of SF_6 and HFC-23 can contribute a significant amount to climate change.

TABLE 3.1
Climate Change Potential of Greenhouse Gases

Greenhouse Gas	Lifetime in the Atmosphere (years)	GWP over 100 years (Compared to CO_2)
Carbon dioxide	50–200	**1**
Methane	12	**23**
Nitrous oxide	120	**296**
CFC 115	550	**7,000**
HFC-23	264	**11,700**
HFC-32	5.6	**650**
HFC-41	3.7	**150**
HFC-43-10mee	17.1	**1,300**
HFC-125	32.6	**2,800**
HFC-134	10.6	**1,000**
HFC-134a	14.6	**1,300**
HFC-152a	1.5	**140**
HFC-143	3.8	**300**
HFC-143a	48.3	**3,800**
HFC-227ea	36.5	**2,900**
HFC-236fa	209	**6,300**
HFC-245ca	6.6	**560**
Sulfur hexafluoride	3,200	**23,900**
Perfluoromethane	50,000	**6,500**
Perfluoroethane	10,000	**9,200**
Perfluoropropane	2,600	**7,000**
Perfluorobutane	2,600	**7,000**
Perfluorocyclobutane	3,200	**8,700**
Perfluoropentane	4,100	**7,500**
Perfluorohexane	**3,200**	**7,400**

Source: United Nations Framework Convention on Climate Change.

In response to climate change, the U.S. EPA is working to reduce the emission of high GWP gases because of their extreme potency and long atmospheric lifetimes. High GWP gases are emitted from several different sources. Major emission sources of these today are from industries such as electric power generation, magnesium production, semiconductor manufacturing, and aluminum production.

In electric power generation, SF_6 is used in circuit breakers, gas-insulated substations, and switchgear. During magnesium metal production and casting, SF_6 serves as a protective cover gas during the processing. It improves safety and metal quality by preventing the oxidation and potential burning of molten magnesium in the presence of air. It replaced sulfur dioxide (SO_2), which was more environmentally toxic. The semiconductor industry uses many high GWP gases in plasma etching and in cleaning chemical vapor deposition tool chambers. They are used to create circuitry patterns. During primary aluminum production, GWP gases are emitted as by-products of the smelting process.

The best solution found to date to solve the negative impact to the environment and combat climate change is by the EPA working with private industry in business partnerships that involve developing and implementing new processes that are environmentally friendly. In addition, EPA is also working to limit high GWP gases through mandatory recycling programs and restrictions. If a greenhouse gas can remain in the atmosphere for several hundred years, even though it may be in small amounts, it can do a substantial amount of damage. Some of the greenhouse effect today is due to greenhouse gases put in the atmosphere decades ago. Even trace amounts can add up significantly.

Carbon Sequestration

Because CO_2 is the most prevalent greenhouse gas in the atmosphere, it is important to understand carbon: what it is used for, where it comes from, where it goes, and how it interacts with other elements. As it relates to climate change, the concept of carbon sequestration—or carbon storage—is especially important. If carbon can be stored, it is removed from the environment, and therefore removed from being a potential source of greenhouse gas. It becomes a sink—a storage place for carbon. In effective management issues, it is important to understand which places store carbon (carbon sink) and which places release carbon (carbon source). Carbon sinks play a direct role in climate change—the more that can be sequestered, the less available to contribute to climate change.

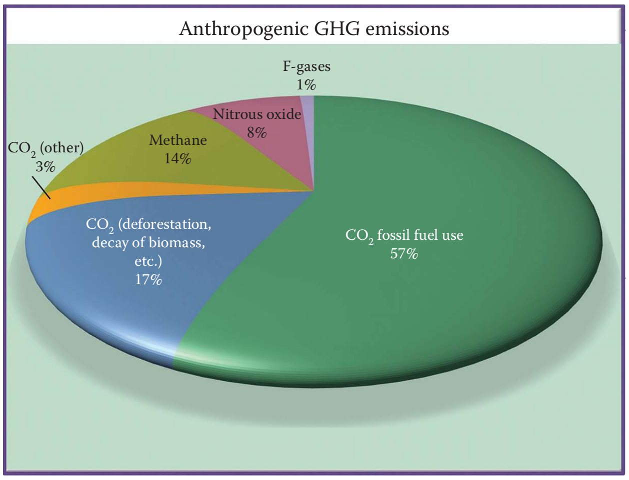
Sinks and Sources

In terms of climate change, storing CO_2 in reservoirs—or sinks—is desirable in order to keep the CO_2 out of the atmosphere so that it does not contribute to ever-increasing atmospheric temperatures. There are several mechanisms whereby carbon can be put into storage.

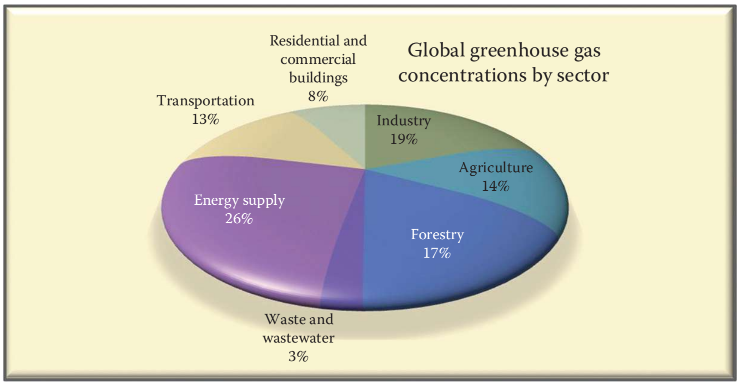
During the process of photosynthesis, plants convert CO_2 from the atmosphere into carbohydrates and release oxygen during the process. Trees in forests over a period of years are able to store large amounts of carbon, which is why promoting the regrowth of old forests and encouraging the growth of new forests are positive methods of combating climate change. Vegetation sequesters 544 billion metric tons of carbon each year. In fact, the regrowth of forests in the Northern Hemisphere is the most significant anthropogenic sink of atmospheric CO_2. When forests are destroyed during the process of deforestation and the land is cleared for other uses such as grazing, it removes a valuable carbon sink from the ecosystem. In areas where the forests are cleared through burning, this process serves to release the CO_2 back into the atmosphere.

In the oceans, as living organisms with shells die, pieces of the shells break apart and fall toward the bottom of the ocean, slowly accumulating as a sediment layer on the bottom. Small amounts of plankton settle through the deepwater and come to rest of the floors of the ocean basins. Even though this source does not represent huge sources of carbon, over thousands or millions of years it does add up, becoming another useful long-term carbon store. The world's oceans are currently holding huge amounts of CO_2, helping to minimize the effects of climate change. As the oceans become saturated, however, they will not be able to store as much CO_2 as they have previously. Currently, about half of all the anthropogenic carbon emissions are absorbed by the ocean and the land.

A sink can also become a source if the situation changes. Carbon can enter the cycle from several different sources. One of the most common is through the respiration process of plants and animals. Once a plant or animal dies, carbon enters the system. Through the decaying process, the bacteria and fungi break down the carbon compounds. If oxygen is present, the carbon is converted into CO_2. If oxygen is not present, then methane is produced instead. Either way, both are greenhouse gases. A major source into the carbon cycle is through the combustion of biomass. This oxidizes the carbon, which produces CO_2. The most prevalent source of this is through the use of fossil fuels—coal, petroleum products, and natural gas (Figure 3.4). Fossil fuels are large



(a)



(b)

FIGURE 3.4 (a) Anthropogenic greenhouse gas emissions by type and (b) global greenhouse gas concentrations by sector. (Courtesy of IPCC, Geneva, Switzerland.)

deposits of biomass that have commonly been preserved inside geologic rock formations in the earth's crust for millions of years. Although they are preserved in rock formations, there is no release of carbon to the atmosphere; but as soon as they are processed into fuel products and used for transportation and industrial processes, millions of tons are released into the atmosphere. According to the EPA, the burning of fossil fuels and deforestation releases nearly eight billion metric tons of carbon into the atmosphere each year (FAO, 2014).

Another major source of CO_2 to the atmosphere is from forest fires. When trees burn, the stored carbon is released into the atmosphere (see Figure 3.5). Other gases, such as carbon monoxide and methane, are also released. After a fire has occurred and deadfall is left behind, it will further decompose and release additional carbon into the atmosphere. One of the predictions with climate change is that as temperatures rise, certain areas will experience increased drought conditions. When this occurs, vegetated areas will become extremely dry; then, when lightning strikes, wildfires can easily start, destroying vegetation, increasing the concentration of CO_2 gases in the atmosphere, and warming it further.

FIGURE 3.5 Increasing temperatures will cause mountain environments to become drier, increasing the highly flammable tinder in forest areas. Both natural lightning strikes and human carelessness will increase the risk of forest fires. The drier conditions will make the fires spread more quickly and be harder to extinguish, putting both the natural environment and bordering urban areas at extreme risk and causing millions of dollars in damage. (Courtesy of Kelly Rigby, Bureau of Land Management, Salt Lake City, Utah.)

Another source of carbon occurs near urban settings. When cement is produced, one of its principal components—lime (produced from the heating of limestone)—produces CO_2 as a by-product. Therefore, in urban areas, this is another factor to consider; areas of increasing urbanization are areas of increasing CO_2 concentrations.

Volcanic eruptions can be a significant source of CO_2 during a major event. Enormous amounts of gases can be released into the atmosphere, including greenhouse gases such as water vapor, CO_2, and sulfur dioxide. It can also be released from the ocean's surface into the atmosphere from bursting bubbles. Phytoplankton, little organisms floating in the world's oceans, also use some of the CO_2 to make their food through photosynthesis.

The earth's zones of permafrost are another potential source of CO_2. According to the Oak Ridge National Laboratory in Tennessee, if climate temperatures continue to rise and cause the permafrost soils in the boreal (northern) forests to thaw, the carbon released from them could dramatically increase atmospheric CO_2 levels and ultimately affect the global carbon balance.

According to Mike Goulden, a scientists working on a NASA project to determine the net exchange of carbon in a Canadian forest, "The soils of boreal forests store an enormous amount of carbon" (McDermott, 2009).

He says the amount of carbon stored in the soil is greater than both the carbon stored in the moss layer and the wood of the boreal forests. Boreal forests cover about 10 percent of the earth's land surface and contain 15–30 percent of the carbon stored in the terrestrial biosphere. Most of the carbon is located in deep layers 40–80 centimeters below the surface, where it remains frozen—the zone called permafrost.

The reason that the permafrost layer is so high in carbon is that the decomposing plant material accumulates on the forest floor and becomes buried before it decomposes. With the steady increase in atmospheric temperatures over recent years, some of the permafrost has been experiencing deep-soil warming and been melting in mid-summer. This process releases CO_2 through increased respiration.

According to Goulden, "Assessing the carbon balance of forest soil is tricky, but if you've got several pieces of evidence all showing the same thing, then you can really start to believe that the site is losing soil carbon. Our findings on the importance of soil thaw and the general importance of the soil carbon balance is already influencing the development of models for carbon exchange." What Goulden is hoping to accomplish in the future is to find a way to use satellite data to improve carbon exchange models (McDermott, 2009).

There are several human-related sources of CO_2. By far, the largest human source is from the combustion of fossil fuels, such as coal, oil, and gas. This occurs in electricity generation, in industrial facilities, from automobiles in the transportation sector, and in heating homes and commercial buildings. According to the Energy Information Administration (EIA), in 2014, petroleum supplied the largest share of domestic energy demands in the United States. This equates to 43 percent of the total fossil fuel-based energy consumption during that year. Coal and natural gas followed, at 22 and 35 percent, respectively, all heavy producers of CO_2. Electricity generation is the single largest source of CO_2 emissions in the United States, according to the EPA. This is one reason why the EPA began their Energy Star® program in 1992, geared toward the production and use of energy efficient appliances.

Industrial processes that add significant amounts of CO_2 to the atmosphere include manufacturing, construction, and mining activities. The EPA has identified six industries in particular that use the majority of energy sources, thereby contributing the largest share of CO_2: (1) chemical production, (2) petroleum refining, (3) primary metal production, (4) mineral production, (5) paper production, and (6) the food processing industry.

In the residential and commercial sectors, the main source of direct CO_2 emissions is due to the burning of natural gas and oil for the heating and cooling of buildings. The transportation sector is the second largest source of CO_2 emissions, primarily due to the use of petroleum products such as gasoline, diesel, and jet fuel. Of this, 65 percent of the CO_2 emissions are from personal automobiles and light-duty trucks.

Specific commodities in the industrial sector that produce CO_2 emissions include cement and other raw materials that contain calcium carbonate that is chemically transformed during the industrial process, which produces CO_2 as a by-product. Industrial processes that use petroleum products also contribute CO_2 emissions to the atmosphere. This includes the production of solvents, plastics, and lubricants that have a tendency to evaporate or dissolve over a period of time. The EPA has identified four principal industrial processes that produce significant CO_2 emissions. They are as follows:

- Production of metals, such as aluminum, zinc, lead, iron, and steel
- Production of chemicals, such as petrochemicals, ammonia, and titanium dioxide
- Consumption of petroleum products in feedstocks and other end uses
- Production and consumption of mineral products, such as cement, lime, and soda ash

Also important are industrial processes that produce other harmful greenhouse gases as by-products, such as methane, nitrous oxide, and fluorinated gases. These gases have a far greater GWP than CO_2. The GWP of methane is 23, that of nitrous oxide is 296, and that of fluorinated gases ranges from 6500 to 8700, posing an even more critical negative effect.

Types of Carbon Sequestration

Carbon sequestration is the process through which CO_2 from the atmosphere is absorbed by various carbon sinks. Principal carbon sinks include agricultural sinks, forests, geologic formations, and oceanic sinks. Carbon sequestration, or storage, occurs when CO_2 is absorbed by trees, plants, and crops through photosynthesis and stored as carbon in biomass, such as tree trunks, branches, foliage, and roots, as well as in the soil. In terms of climate change and impacts to the environment, sequestration is very important because it has a large influence on the atmospheric levels of CO_2. According to the IPCC, carbon sequestration by forestry and agriculture alone significantly helps offset CO_2 emissions that contribute to climate change. The amount of carbon that can be sequestered varies geographically and is determined by tree species, soil type, regional climate, type of topography, and even the type of land management practice used in the area. For example, in agricultural areas, if conservation tillage practices are used instead of conventional tillage, this limits the introduction of CO_2 into the atmosphere by sequestering larger amounts of CO_2 in the soil. According to the EPA, switching from conventional to conservation tillage can sequester 0.1–0.3 metric tons of carbon per acre per year.

Carbon sequestration does reach a limit, however. The amount of carbon that accumulates in forests and soils will eventually reach a saturation point where no additional carbon will be able to be stored. This typically occurs when trees reach full maturity or when the organic matter contained in soils builds up. According to the EPA, the U.S. landscape currently functions as an efficient carbon sink, sequestering more than it emits. They do warn, however, that the overall sequestration amounts are currently declining because of increased harvests, land use changes, and maturing forests. As far as global sequestration, the IPCC has estimated that 100 billion metric tons of carbon over the next 50 years could be sequestered through forest preservation, tree planting, and improved conservation-oriented agricultural management. In the United States, Bruce McCarl (professor of Agricultural Economics at Texas A&M University) and Uwe Schneider (assistant professor of the Research Unit Sustainability and Global Change Department of Geosciences and Economics at Hamburg University in Germany) have determined that an additional 50–150 million metric tons of carbon could be sequestered through changes in both soil and forest management, new tree planting, and biofuel substitution (Schneider and McCarl, 2003).

Another positive aspect supporting carbon sequestration is that it also affects other greenhouse gases. In particular, methane (CH_4) and nitrous oxide (N_2O) can also be sequestered in agricultural activities such as grazing and growing of crops. Nitrous oxide can be introduced via fertilizers. Instead of using these fertilizers, which can have a negative environmental effect, other practices could be used instead, such as rotational grazing. In addition, if forage quality is improved, livestock methane emissions should be significantly reduced. Nitrous oxide emissions could be avoided by eliminating the need for fertilizer. The EPA stresses that finding the right sequestration practices will help lessen the negative effects of all the greenhouse gases.

Other environmental benefits of carbon sequestration include the enhancement of the quality of soil, water, air, and wildlife habitat. For instance, when trees are planted, they not only sequester carbon but also provide wildlife habitat. When the rain forests are preserved, it keeps both plant and animal species from becoming endangered and helps control soil erosion. When forests are maintained, it also cuts down on overland water flow, soil erosion, loss of nutrients, and improved water quality.

The continuation of climate change, however, can have an impact on carbon sequestration. According to the EPA (2011), “In terms of global warming impact, one unit of CO_2 released from a car’s tailpipe has the same effect as one unit of CO_2 released from a burning forest. Likewise, CO_2 removed from the atmosphere through tree planting can have the same benefit as avoiding an equivalent amount of CO_2 released from a power plant.”

The experts at the EPA also caution, however, that even though forests, agriculture, and other sinks can store carbon, the process can also become saturated and slow down or stop the storage process (such as traditional agricultural cultivation), or the sink can be destroyed and completely stop the process (such as complete deforestation). Carbon sequestration processes can naturally slow down and stop on their own as they age. In addition, carbon sequestration can be a natural or man-made process. Research is currently in progress to perfect the methodologies that enhance the natural terrestrial cycles of carbon storage that remove CO_2 from the atmosphere by vegetation and store CO_2 in biomass and soils. In order to accomplish this, research of biological and ecological processes is underway by the EPA. Specific technical areas that are currently being researched include the following:

- Increasing the net fixation of atmospheric CO_2 by terrestrial vegetation with an emphasis on physiology and rates of photosynthesis of vascular plants.
- Retaining carbon and enhancing the transformation of carbon to soil organic matter.
- Reducing the emission of CO_2 from soils caused by heterotrophic oxidation of soil organic carbon.
- Increasing the capacity of deserts and degraded lands to sequester carbon. Man-made processes include technologies such as geologic, mineral, and ocean sequestration.

In carbon sequestration, the main goal is to prevent CO_2 emissions from power plants and industrial facilities from entering the atmosphere by separating and capturing the emissions and then securing and storing the CO_2 on a long-term basis. Currently, EPA is involved in research in an attempt to separate and capture the CO_2 from fossil fuels and from flue gases—these are both pre- and postcombustion processes. Underground storage facilities have been also receiving large amounts of attention recently, and their potential is enormous. In 2012, the Department of Energy published a *Carbon Utilization and Storage Atlas*, outlining up to 5700 years of CO_2 storage potential in the United States and portions of Canada. Currently, more than 2.8 trillion liters of both hazardous and nonhazardous fluids are disposed of through a process called underground injection.

Impacts of Deforestation

Deforestation is occurring today at alarming rates, determined through the analysis of satellite imagery. It accounts for about 20 percent of the heat-trapping gas emissions worldwide. The Food and Agriculture Organization (FAO) estimates current tropical deforestation at 15,400,000 hectares per year. This equates to an area roughly the size of North Carolina being deforested annually (Figure 3.6). Tropical forests hold enormous amounts of carbon. In fact, the plants and soil of tropical forests hold 460–575 billion metric tons of carbon worldwide. This equates to each acre of tropical forest storing roughly 180 metric tons of carbon.

When a forest is cut and replaced by pastures or cropland, the carbon that was stored in the tree trunks joins with the oxygen and is released into the atmosphere as CO_2. Because the wood in a tree is about 50 percent carbon, deforestation has a significant effect on climate change and the global carbon cycle. In fact, according to the Tropical Rainforest Information Center, from the mid-1800s to 1990, worldwide deforestation released 122 billion metric tons of carbon into the atmosphere. Currently 1.5 billion metric tons is released into the atmosphere each year (Climate and Weather, 2012). In fact, deforestation in tropical rainforests adds more CO_2 to the atmosphere than the total amount of cars and trucks on the world’s roads. According to the World Carfree Network, cars and trucks account for

FIGURE 3.6 Deforestation, shown here in Madagascar, is a serious problem and has become so widespread that its connection to global warming cannot be overlooked. These huge resultant erosional features are called lavaka. The world’s rain forests must be managed properly to avoid this kind of environmental damage. (Courtesy of Rhett Butler, Mongabay.com.)

about 14 percent of global carbon emissions, whereas most analysts attribute upward of 15 percent to deforestation. The Environmental Defense Fund states that 32 million acres of tropical rainforest were cut down each year between 2000 and 2009—and the pace of deforestation continues to increase. They warn that unless we change the present system that rewards forest destruction, forest clearing will put another 200 billion tons of carbon into the atmosphere in the coming decades (Scientific American, 2012). Tropical deforestation is the largest source of emissions for many developing countries (Tropical Rainforest Information Centre, 2011).

According to Peter Frumhoff of the Union of Concerned Scientists (UCS), he and an international team of 11 research scientists found that if deforestation rates were cut in half by 2050, it would amount to 12 percent of the emissions reductions needed to keep the concentrations of heat-trapping gases in the atmosphere at relatively safe levels (Global Climate Notes, 2015).

There are multiple impacts of deforestation. Many of the most severe impacts will be to the tropical rain forests. Even though they cover only about 7 percent of the earth's land surface, they provide habitat for about 50 percent of all the known species on earth. Some of these endemic species have become so specialized in their respective habitat niches that if the climate changes, which then causes the ecosystem to also change, this will threaten the health and existence of multiple species, even to the point of forcing them to become extinct. In addition to the species that are destroyed, the ones that remain behind in the isolated forest fragments become vulnerable and sometimes are threatened with extinction themselves. The outer margins of the remaining forests become dried out and are also subjected to die off.

Two other major impacts in addition to the loss of biodiversity are the loss of natural resources, such as timber, fruit, nuts, medicine, oils, resins, latex, and spices, and the economic impact that causes along with the extreme reduction of genetic diversity. The loss of genetic diversity could mean a huge loss for the future health of humans. Hidden in the genes of plants, animals, fungi, and bacteria that may not have even been discovered yet could be the cures for diseases such as cancer, diabetes, muscular dystrophy, and Alzheimer's disease. The FAO of the United Nations says, "The keys to improving the yield and nutritional quality of foods may also be found inside the rain forest and it will be crucial for feeding the nearly ten billion people the earth will likely need to support in the coming decades" (Lindsey, 2009).

Two of the largest climate impacts will revolve around rainfall and temperature. One-third of the rain that falls in the tropical rain forest is rain that was generated in the water cycle by the rain forest itself. Water is recycled locally as it is evaporated from the soil and vegetation, condenses into clouds, and falls back to earth again as rain in a repetitive cycle. The evaporation of the water from the earth's surface also acts to cool the earth. As climatologists continue to learn about the earth's climate and the effects of climate change, they are able to build better models. When the tropical rain forests are replaced by agriculture or grazing, many climate models predict that these types of land-use changes will perpetuate a hotter, drier climate. Models also predict that tropical deforestation will disrupt the rainfall patterns outside the tropics, causing a decrease in precipitation—even to far-reaching destinations such as China, northern Mexico, and the South Central United States.

Predictions involving deforestation can get complicated in models, however. For instance, if deforestation is done in a "patchwork" pattern, then local isolated areas may actually experience an increase in rainfall by creating "heat islands," which increase the rising and convection of air that causes clouds and rainstorms. If rainstorms are concentrated over cleared areas, the ground can be vulnerable and susceptible to erosion.

The carbon cycle plays an important role in the rain forests. According to NASA, in the Amazon alone, the trees contain more carbon than 10 years worth of human-produced greenhouse gases. When the forests are cleared and burned, the carbon is returned to the atmosphere, enhancing the greenhouse effect. If the land is utilized for grazing, it can also be a continual source of additional carbon. It is not certain today whether or not the tropical rain forests are a net source or sink of carbon. Although the vegetation canopies hold enormous amounts of carbon, trees, plants, and microorganisms in the soil also respire and release CO_2 as they break down carbohydrates for energy. In the Amazon alone, enormous amounts of CO_2 escape from decaying organic matter in rivers and streams that flood huge areas. When tropical forests remain undisturbed, they remain essentially carbon neutral, but when deforestation occurs, it contributes significantly to the atmosphere.

Rainforest countries need to give serious consideration about what decisions need to be made for the future. Currently, Papua New Guinea, Costa Rica, and several other forest-rich developing countries are seeking financing from the global carbon market (such as the United States) to create attractive financial incentives for tropical rain forest conservation. Developed nations helping developing nations is one approach to help get a handle on the problem, but developed countries also need to cut back on their own emissions.

Anthropogenic Causes and Effects—Carbon Footprints

When looking for the causes of climate change, it is easy to point fingers and put the blame on industry, other nations, transportation, deforestation, and other sources and activities. But the truth of the matter is that every person on the earth plays a part and contributes to climate change. Even simple daily activities—such as using an electric appliance, heating or cooling a home, or taking a quick drive to the grocery store—contribute CO_2 to the atmosphere. Scientists refer to this input as a "carbon footprint." A carbon footprint is simply a measure of how much CO_2 people produce just by going about their daily lives. For every activity that involves the combustion of fossil fuels (coal, oil, and gas), such as the generation of electricity, the manufacture of products, or any type of transportation, the user of the intermediate or end product is leaving a carbon footprint. Of all the CO_2 found in the atmosphere, 98 percent originates from the burning of fossil fuels. Simply put, it is one measure of the impact people make individually on the earth by the lifestyle choices they make. In order to combat climate change, every person on the earth can play an active role by consciously reducing the impact of his/her personal carbon footprint. The two most common ways of achieving this is by increasing his/her home's energy efficiency and driving less. A carbon footprint is calculated (carbon footprint calculators are available on the Internet), and a monthly, or annual, output of total CO_2 in tons is derived based on the specific daily activities of that person. The goal then is to reduce or eliminate his/her carbon footprint. Some people attempt to achieve "carbon neutrality," which means they cut their emissions as much as possible and offset the rest. Carbon offsets allow one to "pay" to reduce the global greenhouse total instead of making personal reductions. An offset is bought, for example, by funding projects that reduce emissions through restoring forests, updating power plants and factories, reducing the energy consumption in buildings, or investing in more energy-efficient transportation. In order to educate and make people more environmentally conscious, some companies are even advertising today what their carbon footprint is, drawing in additional business support because of their positive environmental commitments. Some commercial products today contain "carbon labels" estimating the carbon emissions that were involved in the creation of the product's production, packaging, transportation, and future disposal.

Carbon footprints are helpful because they allow individuals to become more environmentally aware of the implication of their own choices and actions and enable them to adopt behaviors that are more environmentally friendly—what is referred to as "going green." For example, transportation in the United States accounts for 27 percent of CO_2 emissions. Ways to make a difference include driving less, using public transportation, carpooling, driving a fuel efficient car such as a hybrid, or bicycling. According to the EPA (2013), home energy use accounts for 12 percent of CO_2 emissions in the United States. Therefore, cutting down in these areas by increasing energy efficiency helps lessen the carbon footprint. There are several practical ways to do this, such as lowering the thermostat, installing double-paned windows, and installing good insulation, to name a few. Using compact fluorescent lamps and using energy efficient appliances (such as those listed on the Energy Star program) also increases efficiency and lowers the carbon footprint. Carbon footprints can be a helpful measurement for those who want to take personal initiative and do their part to fight climate change.

Timing is right for individuals to become aware of their personal behavior and how it impacts the environment. The atmospheric concentration of CO_2 has risen by more than 30 percent in the past 250 years. Based on a study conducted by Michael Raupach of the Commonwealth Scientific and Industrial Research Organisation in Australia, worldwide carbon emissions of anthropogenic CO_2 are rising faster than previously predicted. From 1990 to 1999, the increase in CO_2 levels averaged about 1.1 percent per year, but from 2000 to 2004, levels increased to 3 percent per year. For this research, the world was divided into nine separate regions for analysis of specific factors such as economic factors, population trends, and energy consumption. The result of the study showed that the developed countries, which only account for 20 percent of the world's population, accounted for 59 percent of the anthropogenic global emissions in 2004. The developing nations were responsible for 41 percent of the total emissions in 2004 but contributed 73 percent of the emissions growth that year. The developing countries, such as India, are expected to become the major CO_2 contributors in the future. Today, the largest CO_2 emitter is China.

This study is significant because even the IPCC's most extreme predictions underestimate the rapid increase in CO_2 levels seen since 2000. The scientists involved in the study believe this shows that no countries are decarbonizing their energy supply and that CO_2 emissions are accelerating worldwide.

Also from Australia's Commonwealth Scientific and Industrial Research Organisation, Josep G. Canadell calculated that CO_2 emissions were 35 percent higher in 2006 than in 1990, a faster growth rate than expected. Canadell attributed this to an increased industrial use of fossil fuels and a decline in the amount of CO_2 being absorbed by the oceans or sequestered on land.

According to Canadell, "In addition to the growth of global population and wealth, we now know that significant contributions to the growth of atmospheric CO_2 arise from the slowdown of nature's ability to take the chemical out of the air. The changes characterize a carbon cycle that is generating stronger-than-expected and sooner-than-expected climate forcing" (Schmid, 2007c).

In response to the study, Kevin Trenberth from the National Center for Atmospheric Research said, "The paper raises some very important issues that the public should be aware of: namely that concentrations of CO_2 are increasing at much higher rates than previously expected and this is in spite of the Kyoto Protocol that is designed to hold them down in western countries" (MSNBC, 2007c).

According to the Brookings Institution, a research organization in Washington, DC, the carbon footprint of the United States is expanding. As the population of the United States grows and cities expand, they are building more, driving more, and consuming more energy, which means they are emitting more CO_2 than ever before. The Brookings Institution believes that existing federal policies are currently limiting. They believe federal policy should play a more powerful role in helping metropolitan areas so that the country as a whole can collectively shrink their carbon footprint. They believe that besides economy-wide policies to motivate action, five targeted policies should be put in place that are extremely important within metro areas (Brown et al., 2008):

- Promote a wider variety of transportation choices.
- Design more energy-efficient freight operations.
- Require home energy cost disclosure when selling a home in order to encourage more energy efficient appliances in homes.

- Use federal housing policies to create incentives to build with both energy and location conservation in mind.
- Challenge/reward metropolitan areas to develop innovative solutions toward reducing carbon footprints.

Areas Most at Risk

About 634 million people—10 percent of the global population—live in coastal areas that are within just 10 meters above sea level, where they are most vulnerable to sea-level rise and severe storms associated with climate change. Three-quarters of these are in the low-elevation coastal zones in Asian nations on densely populated river deltas, such as India. The other areas most at risk are the small island nations. According to the Earth Institute at Columbia University, the 10 countries with the largest number of people living within 10 meters of the average sea level in descending order are as follows:

China
India
Bangladesh
Vietnam
Indonesia
Japan
Egypt
The United States
Thailand
The Philippines

The 10 countries with the largest share of their population living within 33 feet (10 m) of the average sea level are as follows:

The Bahamas (88%)
Suriname (76%)
The Netherlands (74%)
Vietnam (55%)
Guyana (55%)
Bangladesh (46%)
Djibouti (41%)
Belize (40%)
Egypt (38%)
Gambia (38%)

Fossil Fuels and Climate Change

The burning of fossil fuels (oil, gas, and coal) is one of the leading contributors to climate change, as they are comprised almost entirely of carbon and release CO_2 into the atmosphere when they are burned. In the case of oil, they also contain toxic materials that when burned, or when the fumes are inhaled, are known to cause cancer in humans.

In developed countries, such as the United States, fossil fuels are the principal sources of energy that are used to produce the majority of the fuel, electricity, heat, and air conditioning. In fact, more than 86 percent of the energy used worldwide originates from fossil fuel combustion. Although for years fossil fuels have been readily available and convenient, they have also played a major role in climate change over the past few decades. According to the Center for Biological Diversity, fossil fuel use in the United States causes more than 80 percent of the greenhouse gas emissions and 98 percent of just the CO_2 emissions. This adds approximately 4.1 billion metric tons of CO_2 to the atmosphere each year and would even be greater if some of the earth's natural carbon sequestration processes such as carbon storage in the world's oceans, vegetation, and soils did not occur (CBD, 2008).

Even though scientists warn that climate change is already under way and will likely continue for the next several centuries due to the long natural processes involved, such as the long lifetimes of many of the greenhouse gases, there are ways the potential effects can be reduced. Because everyone uses energy sources every day, the biggest way to reduce the negative effects of climate change is by using less energy. By cutting back on the amount of electricity used, the use of fossil fuels can be reduced because most power plants burn fossil fuels to generate power. The most effective way to half the emission of greenhouse gases into the atmosphere is through the adoption of nonfossil fuel energy sources, such as hydroelectric power, solar power, hydrogen engines, and fuel cells.

Former Vice President Al Gore, author of *An Inconvenient Truth*, and recipient of the 2007 Nobel Peace Prize (received jointly with the IPCC) said, "It is the most dangerous challenge we've ever faced, but it is also the greatest opportunity we have had to make changes" (MSNBC, 2007b).

Because the IPCC's last two reports were released identifying fuels as a principal cause of climate change with a virtual certainty (99% certainty) (IPCC, 2007, 2013), upgraded from its 2001 report of likely (66%), several achievements and advancements have been made. The levels of research have grown, public awareness has increased, the subject has been incorporated into many school curriculums worldwide, and legislation—local, national, and international—has been passed and is being currently introduced into governments around the world. In addition to the 2007 Nobel Peace Prize shared by Al Gore and the IPCC, the film *An Inconvenient Truth* received two Oscar nominations at the 2007 Academy Awards in Los Angeles, California. Climate change issues are finally receiving the media attention they deserve, making the public more aware of the real issues and the reasons why they need to be addressed now.

Growing public education and awareness has not solved all the problems, however. Even though the public is becoming more educated, the opposition and efforts of skeptics are also raising their voices in protest, continuing to cloud the issues, making it important for the public to pay attention to the facts. In light of this, however, many cities worldwide, foreign countries, and individual states in the United States are taking action to curb fossil fuel emissions. Arnold Schwarzenegger, former governor of California, for example, ordered the world's first low-carbon limits on passenger car fuels. The new standard reduces the carbon content of transportation fuels at least 10 percent by the year 2020.

Climatologists at Lawrence Livermore National Laboratory in California have created a climate and carbon cycle model to examine global climate and carbon cycle changes. What they concluded was that if humans continued with the same lifestyles and habits they are accustomed to today (commonly referred to as a business-as-usual approach), the earth's atmosphere would warm by 8°C if humans use all of the earth's available fossil fuels by the year 2300.

Their model predicted several alarming results: In the next few centuries the polar ice caps will have vanished, ocean levels will rise by 7 meters, and the polar temperatures will climb higher than the predicted 8°C–20°C, transforming the delicate ecosystems from polar and tundra to boreal forest.

Govindasamy Bala, the Laboratory's Energy and Environment Directorate and lead author of the project, said, "The temperature estimate was actually conservative because the model didn't take into consideration changing land use such as deforestation and build-out of cities into outlying wilderness areas" (Williams, 2015).

Their model projected that by 2300, the CO_2 level will have risen to 1423 ppm—roughly a 400 percent increase. The model identified the soil and biomass as significant carbon sinks. However, according to Bala, the land ecosystem would not take up as much carbon dioxide as the model assumes, because it did not take land-use change into account.

The results of the model showed that ocean uptake of CO_2 starts to decrease in the twenty-second and twenty-third centuries as the ocean surface warms. It takes longer for the ocean to absorb CO_2 than it does for the vegetation and soil. By 2300, the land will absorb 38 percent of the CO_2 released from the burning of fossil fuels, and 17 percent will be absorbed by the oceans. The remaining 45 percent will stay in the atmosphere. Over time, roughly 80 percent of all CO_2 will end up in the oceans via physical processes, increasing its acidity and harming aquatic life.

According to Bala, the most drastic changes during the 300-year period will occur during the twenty-second century—when precipitation patterns change, when an increase in the amount of atmospheric precipitable water and a decrease in the size of sea ice are the largest, and when emission rates are the highest. Based on the model's results, all sea ice in the Northern Hemisphere summer will have vanished by 2150.

When referring to climate change skeptics, Bala says, "Even if people don't believe in it today, the evidence will be there in 20 years. These are long-term problems. We definitely know we are going to warm over the next 300 years. In reality, we may be worse off than we predict" (Williams, 2015).

The New Carbon Balance—Summing It All Up

Carbon dioxide enters the air during the carbon cycle. Because it is so plentiful, it comes from several sources. Vast amounts of carbon are stored naturally in the earth's soils, oceans, and sediments at the bottom of oceans. Carbon is stored in the earth's rocks, which is released when the rocks are eroded. It exists in all living matter. Every time animals and plants breathe, they exhale carbon dioxide. The earth maintains a natural carbon balance. Throughout geologic time, when concentrations of CO_2 have been disturbed, the system had always gradually returned to its natural (balanced) state. This natural readjustment works very slowly.

Through a process called diffusion, various gasses that contain carbon move between the ocean's surface and the atmosphere. For this reason, plants in the ocean use CO_2 from the water for photosynthesis, which means that ocean plants store carbon, just as land plants do. When ocean animals eat these plants, they then store the carbon. Then when they die and decompose, they sink to the bottom and decompose, and their remains become incorporated in the sediments on the bottom of the ocean. Once in the ocean, the carbon can go through various processes: it can form rocks, then weather, and it can also be used in the formation of shells. Carbon can move to and from different depths of the ocean, and also exchange with the atmosphere.

As carbon moves through the system, different components can move at different speeds. Scientists break these reaction times down into two categories: (1) short-term cycles and (2) long-term cycles. In short-term cycles, carbon is exchanged quickly. Examples of this include the gas exchange between the oceans and the atmosphere (evaporation). Long-term cycles can take years to millions of years to occur. Examples of this would be carbon stored for years in trees or carbon weathered from a rock being carried to an ocean, being buried, being incorporated into plate tectonic systems, then later being released into the atmosphere through a volcanic eruption.

Throughout geologic time, the earth has been able to maintain a balanced carbon cycle. Unfortunately, this natural balance has been upset by recent human activity. Over the past 150–200 years, fossil fuel emissions, land-use change, and other human activities have increased atmospheric carbon dioxide by 30 percent (and methane, another greenhouse gas, by 150 percent) to concentrations not seen in the past 420,000 years.

Humans are adding CO_2 to the atmosphere much faster than the earth's natural system can remove it. Prior to the Industrial Revolution, atmospheric carbon levels remained constant at around 280 ppm. This meant that the natural carbon sinks were balanced between what was being emitted and what was being stored. After the Industrial Revolution began and carbon dioxide levels began to increase—315 ppm in 1958, to 383 ppm in 2007, to 414 ppm in 2016—the "balancing act" became unbalanced and the natural sinks could no longer store as much carbon as was being introduced into the atmosphere by human activities, such as driving and industry. In addition, according to Dr. Joseph Canadell of the National Academy of Sciences, 50 years ago for every ton of CO_2 emitted, 600 kilograms was removed by natural sinks (Center for Climate Change and Environmental Studies, 2011). In 2006, only 550 kilograms was removed per ton, and the amount continues to fall today, which indicates the natural sinks are losing their carbon storage efficiency. This means that, although the world's oceans and land plants are absorbing great amounts of carbon, they cannot keep up with what humans are adding. The natural processes work much slower than the human ones do. The earth's natural cycling usually takes millions of years to move large amounts from one system to another.

TABLE 3.2

U.S. Energy-Related Carbon Dioxide Emissions by Source and Sector, 2015 (million metric tons)

Sector	Residential	Commercial	Industrial	Transportation	Electric Power	Source Total
Coal	0	6	129	0	1364	1499
Natural gas	252	175	474	49	530	1480
Petroleum	67	40	338	1816	24	2285
Other					7	7
Electricity	723	702	495	4		
Sector total	1043	922	1437	1869	1925	5271

Source: Energy Information Administration, 2015.

TABLE 3.3

Sources of Energy-Related Carbon Dioxide Emissions by Type of Fuel for the United States and the World, 2012 (million metric tons)

	The United States		The World	
	Amount	Share of Total (%)	Amount	Share of Total (%)
Total from fossil fuels	5,270		32,723	
Coal	1,656	31	14,229	43
Natural gas	1,374	26	6,799	21
Petroleum	2,240	43	11,695	36

Source: Energy Information Administration, 2015.

The problem with human interference is that the impacts are happening in only centuries or decades—and the earth cannot keep up with the fast pace. The result is that each year the measured CO_2 concentration of the atmosphere gets higher, making the earth's atmosphere get warmer.

Levels of several greenhouse gases have increased by about 25 percent because large-scale industrialization began about 150 years ago. According to the EIA's National Energy Information Center, 75 percent of the anthropogenic CO_2 emissions added to the atmosphere over the past 20 years is due to the burning of fossil fuels (Casper, 2009 and Gines, 2012).

According to the EIA, natural earth processes can absorb approximately 3.2 billion metric tons of anthropogenic CO_2 emissions annually. An estimated 6.1 billion metric tons is added each year, however, creating a large imbalance, which is why there is a steady, continual growth of greenhouse gases in the atmosphere. In computer models, an increase in greenhouse gases results in an increase in average temperature on earth. The warming that has occurred over the past century is largely attributed to human activity. According to a study conducted by the National Research Council in May 2001, "Greenhouse gases are accumulating in earth's atmosphere as a result of human activities, causing surface air temperatures and sub-surface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities" (Energy Information Administration, 2004; Scientific American, 2009).

Table 3.2 shows the U.S. energy-related carbon dioxide emissions by source and sector, and Table 3.3 shows the sources of energy-related carbon dioxide emissions by type of fuel for the United States and the world. The EIA has determined that greenhouse gas emissions originate principally from energy use, driven mainly by economic growth, fuel used for electricity generation, and weather patterns affecting heating and cooling needs. Table 3.4 illustrates the world's top CO_2 emitters by country in 2015, and Figure 3.7 illustrates the annual and cumulative emissions by country (1751–2014).

Developing new technologies that create energy by using fossil fuels more efficiently alone is not enough to control the emissions of greenhouse gases being ejected into the

TABLE 3.4

The World's Top Carbon Dioxide Emitters, 2015

Country	Total Emission (%)
China (mainland)	28.03
The United States	15.9
India	5.81
Russian Federation	4.79
Japan	3.84
Germany	2.23
Korea	1.78
Canada	1.67
Iran	1.63
Brazil	1.41
Indonesia	1.32

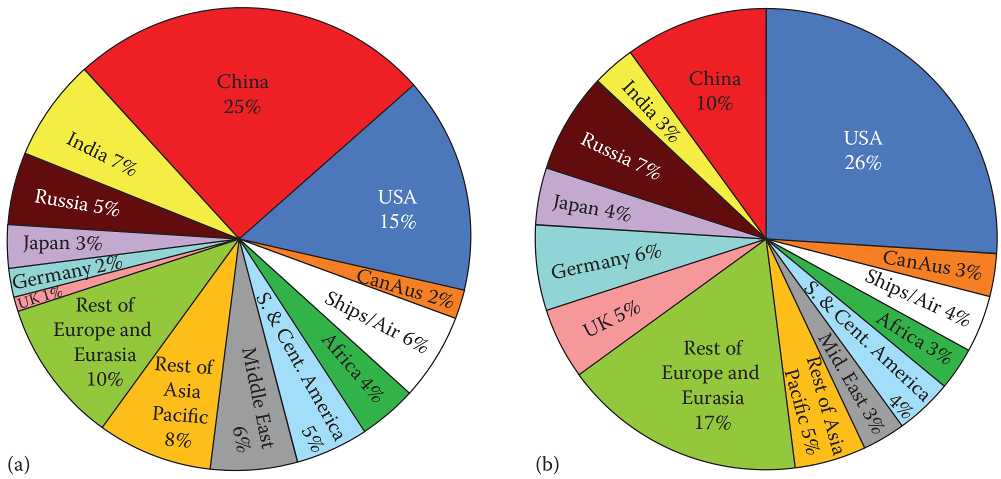


FIGURE 3.7 Annual and cumulative emissions by country, 1751–2014. Current and cumulative fossil fuel carbon dioxide emissions: (a) 2014 annual emissions (9.6 GtC/yr) and (b) 1751–2014 cumulative emissions (396 GtC). (Courtesy of Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.)

atmosphere. Without the increased use of renewable energy resources, and the weaning off of the dependence on fossil fuels, it will not be possible to bring climate change under control in time to prevent irreversible damage to the environment and life on the planet.

The Concern about Coal Emissions

According to an article in *The New York Times* back on December 4, 2007, titled “Stuck on Coal, Stuck for Words in a High-Tech World,” although the society of the twenty-first century has progressed technologically in many ways over the past century, it is still stuck in the old-fashioned, outdated mode of popular energy choices (Revkin, 2007). In particular, even with new technology such as the growing cadre of renewable forms of energy, societies worldwide are still heavily dependent on coal and plan to remain that way despite the repeated pleas and warnings from climatologists about the future, life-threatening consequences of climate change if changes are not made now. It still remains an energy source in demand in 2016.

Using coal-fired plants to generate electricity produces more greenhouse gases for each resulting watt than using oil or natural gas, but coal—often referred to as a “dirty fuel”—is attractive because it is relatively inexpensive. In countries where there are no emission controls (such as China and India), the coal industry is booming today. The International Energy Agency projects that the demand for coal will grow by 2.2 percent a year until 2030, which is a rate faster than the demand for oil or natural gas. Yet, even with warnings to cut back on coal use and greenhouse gas emissions, according to the UCS, the United States currently has plans to increase its emissions by building many more coal-fired plants, with the majority of them lacking the carbon capture and storage technology—equipment that allows a plant to capture a certain amount of CO_2 before it is released and then store it underground (UCS, 2008).

One of the most serious contenders of coal use now and in the future is China. New figures from the Chinese government reveal that coal use has been climbing faster in China than anywhere else in the world. According to a report in *The Economist*, China opens a new coal-fired plant each week (*The Economist*, 2007). Their rising energy consumption is making it more difficult to effectively slow the climate change process. The International Energy Agency in Paris predicts that the increase in greenhouse gas emissions from 2000 to 2030 in just China will be comparable to the increase from the entire industrialized world (Bradsher, 2003).

China is currently the world’s largest consumer of coal, and its power plants are burning it faster than the trains can deliver it from the mines in China. As a result, it is also importing coal from Australia to meet its rising demands. Concerning energy products, it has also become the world’s fastest growing importer of oil. The Chinese are using more energy in their homes than ever before, and with a population of one and a quarter billion people, energy usage is expected to skyrocket. And this increase in energy usage will affect other energy-related sectors. China, for example, is now the world’s largest market for television sets and one of the largest for other electrical appliances as well. It also has the world’s fastest growing automobile market. All of these commodities require the use of fossil fuels to manufacture and operate their industries, either directly or indirectly. Energy generated from coal and oil is expected to have a significant impact on climate change.

China is not the only country with a growing demand for energy, however. India, Brazil, and Indonesia are other countries and regions that are also showing a surging demand for energy. Power plants are burning increasing amounts of coal to meet the exploding new demands for electricity to serve both industry and private households. According to the New China News Agency, they have predicted that China’s capacity to generate electricity from coal will be almost 3 times as high in 2020 as it was in 2000. China currently uses more coal than the United States, the European Union, and Japan combined" (Bradsher et al., 2006).

In a recent report from the Global Warming Policy Foundation in 2015, China will present a favorable presence at the UN Climate Conference in Paris but will not make any binding commitments, which is summarized in their new report *The Truth About China*. According to economist Patricia Adams, the study's author, "China's Communist Party has as its highest priority its own self-preservation, and that self-preservation depends overwhelmingly on its ability to continue raising the standard of living of its citizens" (Global Warming Policy Foundation, 2015). The study also revealed that more than 2400 coal-fired power stations are under construction or being planned around the world. The new plants will emit 6.5 billion tons of carbon dioxide a year and undermine the efforts at the Paris climate conference to limit global warming to 2°C. China is building 368 plants and planning a further 803. India is building 297 plants and planning to build 149. Japan has planned to build 40 plants and 5 currently under construction (*The Times*, 2015) (Figure 3.8).

If China's carbon usage keeps up with its current economic growth, its CO_2 emissions are projected to reach 8 GT a year by 2030, an amount equal to the entire world's CO_2 production today. In 2000, steel production in China was reported at 127 million metric tons, and in 2006, they produced 380 million metric tons. According to the International Iron and Steel Institute, in 2008, China's production now heads the world at 444 million metric tons, which is twice as much as the production of the United States and Japan combined (Tang, 2010). In 2014, they produced 822 million metric tons. In addition to new construction, the steel is also being used for the manufacture of cars. In 1999, Chinese consumers bought 1.2 million cars. In 2006, 7.2 million cars were sold—an increase of 600 percent. In 2013, 20 million were bought, and in 2015, it was nearly 25 million.

In a report in *The New York Times*, pollution from China's coal-fired plants is already affecting the world. In April 2006, a thick cloud of pollutants originating from Northern China drifted airborne to Seoul, Korea, then across the Pacific Ocean to the West Coast of the United States. Scientists were able to track the progression and route of this "brown cloud" via real-time satellite imagery. According to researchers in California, Oregon, and Washington, DC, a coating of sulfur compounds, carbon, and other by-products of coal combustion were found on mountaintop detectors in the Pacific Northwest.

Steven S. Cliff, an atmospheric scientist at the University of California at Davis, said, "The filters near Lake Tahoe in the mountains of eastern California are the darkest we've ever seen outside smoggy urban areas" (Bradsher and Barboza, 2006).

The sulfur dioxide produced during coal combustion poses an immediate threat to China's population, contributing to roughly 400,000 premature deaths each year. In addition, it causes acid rain that poisons rivers, lakes, wetland ecosystems, agricultural areas, and forest ecosystems. The CO_2 coming from China will exist in the atmosphere for decades. According to the report, concerning China's newly growing economy, "Coal is China's double-edged sword—the new economy's black gold and the fragile environment's dark cloud" (Bradsher et al., 2006).

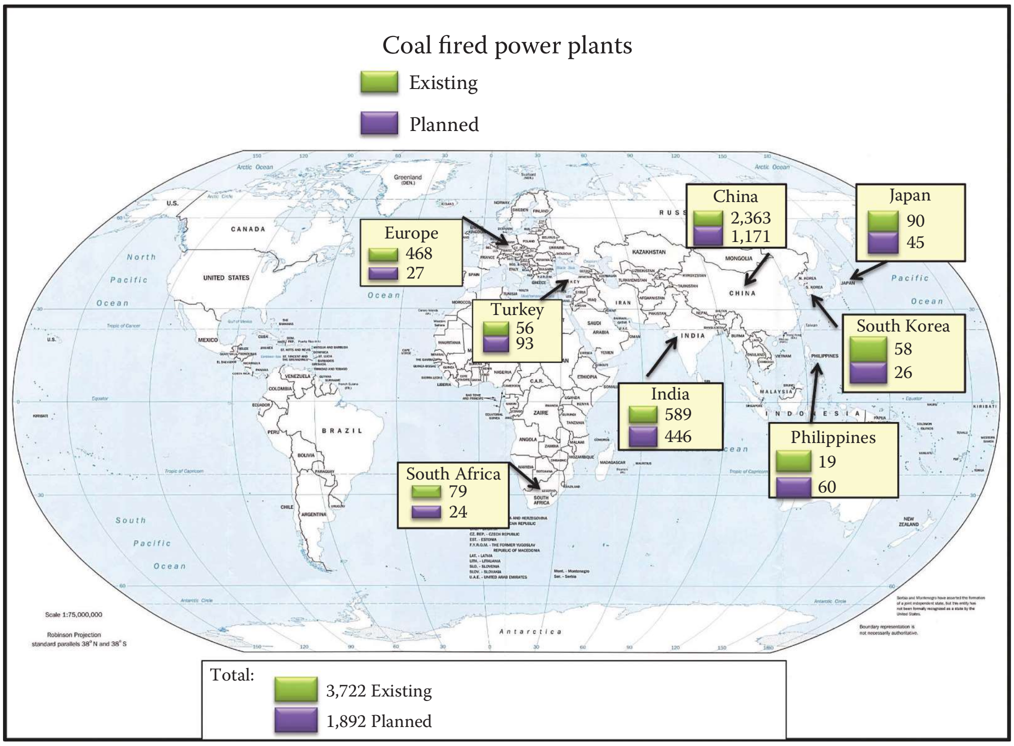


FIGURE 3.8 Coal-fired power stations planned worldwide.

Health Issues Associated with Climate Change

One component of preparing for climate change involves planning for new or increasing threats to human health. As ecosystems change through intense weather events, shifting habitats, wildfires, heat waves, and other effects, humans must be prepared for inevitable changes. There is an overwhelming amount of evidence that rising levels of CO_2 in the earth's atmosphere are having a serious impact on the climate with secondary effects on the earth's physical systems and ecosystems, such as an increase in severe weather events, rising sea levels, migration and extinction of both plant and animal species, shifts in climate patterns, and melting of glaciers and permafrost. Another serious impact that has been clearly identified related to climate change and rising amounts of CO_2 in the atmosphere are the negative health effects being experienced by populations worldwide.

The segments of the population that are at the greatest risk of health problems from the atmospheric changes associated with climate change, such as increased air particulates, greenhouse gases, and pollution, are young children and the elderly of 65 years of age or older. Because young children are still developing physically and breathe faster than adults, they are more at risk to the adverse effects of air quality and extreme temperatures. According to the Environmental Defense Fund, there are four key health-related factors associated with climate change: heat waves, smog and soot pollution, food- and water-borne diseases, and stress from post-traumatic stress disorder (PTSD).

Infants and children of 4 years old and younger are extremely sensitive to heat. When heat waves occur and when children are subjected to the urban heat island effect—the situation in which urban areas are warmer than rural areas because asphalt pavements, buildings, and other human-made structures absorb incoming solar radiation and reemit the energy as long-wave (heat) radiation—they face the risk of becoming rapidly dehydrated and can suffer the negative—sometimes fatal—effects of heat exhaustion or stroke. In addition, because young children's lungs are still developing, they can also suffer irreversible lung damage from being exposed to smog and soot pollution and breathing it into their lungs.

As climate change increases in intensity and food- and water-borne diseases spread into areas where they have never existed before, children are much more susceptible to becoming ill—especially those living in poverty. As extreme weather events occur—such as hurricanes and flooding—and families are left homeless, children are especially prone to complications of PTSD as they try to cope with the upheaval of their lives and often loss of their homes.

The elderly, aged 65 years and older, are also at greater risk than the general population. By the year 2030, one-fifth of the U.S. population is projected to be older than 65 years. Because the elderly often have more frail health and less mobility, they are at greater risk to the negative effects of heat waves. If the income of an elderly person is limited and they cannot afford air conditioning in their home, their health and safety can be in jeopardy because the elderly are more sensitive to changes in temperature and cannot physically adjust to extremes as younger people can.

Another sector of the population at risk is those with chronic health conditions. People, for example, with heart problems, respiratory illnesses, diabetes, or compromised immune systems are more likely to suffer serious health complications because of the effects of climate change than healthy people. Those that suffer from diabetes are at greater risk of death from heat waves. Stagnant hot air masses and areas with high ozone and soot concentrations pay a heavy toll on those with heat and respiratory illnesses. According to the American Lung Association (ALA), their offices in California recognize climate change as one of the greatest threats to public health we will face this century. As testament to it, Californians are already experiencing climate change effects, including increasing air pollution, more frequent and severe heat waves, longer wildfire seasons, severe drought conditions, and other threats to lung health.

In California's favor, they are leading in efforts to reduce climate pollution from cars, trucks, and energy sources in an attempt to reduce impacts to the air, while enhancing multiple public health benefits by reducing the reliance on fossil fuels. Their goal toward a zero carbon economy is a positive movement toward a clean air future. The ALA in California has determined in their report *Driving California Forward* that California's Low Carbon Fuel Standard and Cap and Trade fuels programs will result in cumulative benefits of $10.4 billion by 2020 and $23.1 billion by 2025 from avoided health costs, energy insecurity, and climate change impacts. In addition, the transition to cleaner fuels and more diverse vehicles will result in cleaner air and better health for Californians, increased energy security, as well as a healthier climate (ALA, 2016).

Smog forms when sunlight, heat, and relatively stagnant air meet up with nitrogen oxides and various volatile organize compounds. Exposure to smog can do serious damage to someone's lungs and respiratory systems. In the case of inflammation and irritation to the lungs, it can cause shortness of breath, throat irritation, chest pains, and coughing, and lead to asthma attacks, hospital admissions, and emergency room visits. These consequences are even more severe if people are exposed while being active. More hot days mean better conditions for creating smog that can trigger asthma and other breathing problems.

Those with preexisting conditions of weakened immune systems, such as those suffering from AIDS or cancer are also highly susceptible to catching diseases spread by mosquitoes or other vectors.

The Environmental Defense Fund has identified other groups as being potentially more vulnerable to the negative effects of pollution, illness, and climate change. They include the following:

1. *Pregnant women and their unborn children*: They may be unable to take specific medications or get to properly air conditioned locations.

2. *People living in poverty*: They may not have access to air conditioning or ready access to medical assistance.
3. *People living in areas of chronic pollution*: Consistent exposure to unhealthy air conditions may be compromising; they may have increased exposure to infectious diseases.
4. *Geographic areas prone to harmful climate change*: People in these areas may experience violent storms, coastal flooding and erosion, damage to buildings, and contamination of drinking water.

Table 3.5 shows the risks associated with potential climate change in different regions in the United States.

It is becoming more common today for individual cities to prepare emergency plans outlining actions that need to be taken if the negative effects of climate change and global warming affect their specific geographic area. According to the Environmental Defense Fund, several cities in the United States have already put together working Heat Health Watch/Warning System plans to make their populations prepared in order to deal with various climate issues when necessary. Cities already taking proactive action include Dallas/Fort Worth, Texas; Cincinnati/Dayton, Ohio; Chicago, Illinois; Jackson, Mississippi; Lake Charles, Louisiana; Little Rock, Arkansas; Memphis, Tennessee; New Orleans, Louisiana; Philadelphia, Pennsylvania; Phoenix, Arizona; Portland, Oregon; St. Louis, Missouri; Shreveport, Louisiana; Seattle, Washington; and Yuma, Arizona (Trust for Americas Health, 2009).

TABLE 3.5
Potential Regional Effects of Climate Change in the United States

Geographic Region	Potential Negative Effects
Southeast Atlantic and Gulf Coast	Violent storms, strong storm surges and flooding, coastal erosion, more damage to buildings and roads, contamination of drinking water
Southwest	Higher temperatures, less rainfall, hot, arid climate, increased wildfires, worsened air quality
Northwest	Heavy rainfall, flooding, sewage overflow, increased illness, and spread of disease
The Great Plains	Milder winters, scorching summers, decreased agricultural production, intense heat waves
Northeast	Higher temperatures, more allergies, spread of disease by insects and animals
Alaska	Melting permafrost, retreating sea ice, disturbed ecosystems, reduced subsistence hunting and fishing, milder temperatures, increase in insects and forest pests such as the spruce bark beetle

Source: Environmental Defense Fund.

Local topography also plays a role in the pollution that an area experiences. Cities located in close proximity to mountain ranges experience unique patterns of recurrent pollution. Large cities that commonly experience photochemical smog—the brown air that often results from car, bus, and truck exhaust (composed of nitrogen oxide, oxygen, hydrocarbons, and sunlight to produce ozone, which can be deadly at lower elevations), as well as sulfurous fog (created from coal-burning plants)—are often found with the negative consequences of air pollution and ill effects on health. Currently, there are some controls implemented on automobiles and coal-fired plants. Catalytic converters are used in some areas. They convert carbon monoxide, nitrous oxide, and hydrocarbons into CO_2, nitrogen, and water. Some cars recirculate exhaust gas along with a catalytic converter to reduce emissions.

In areas where the existence of mountain ranges is a factor, coal-fired plants may burn only low-sulfur content coal. They may also use a process that converts the coal directly to gas (gasification process) or use scrubbing technologies.

In areas where mountain ranges act as physical barriers and trap pollution over cities, air inversions are common, especially during the winter months. In valleys or on the lee side of mountains, if a warmer air mass moves above cooler air, it traps the cooler, denser air underneath and increases the severity of the air pollution. Los Angeles is an example of this, where the warm desert air from the east comes over the mountains to the east of Los Angeles and lies over the cooler Pacific Ocean air. The cooler air becomes trapped because it cannot rise through the less dense warm air above it, and the pollution in the cold air accumulates. In mountain valleys, a similar situation occurs where warm air overlies the colder air that accumulates in the valleys. In cities, heat island effects are common. Warm air filled with pollutants collects and then spreads out over the nearby suburbs. The greenhouse gases contributing the most to the anthropogenic greenhouse effect are listed in Table 3.6.

Based on the research conducted at the Scripps Institution of Oceanography in San Diego, California, an analysis of the pollution-filled "brown clouds" over southern Asia offers hope that the region may be able to slow or stop some of the

TABLE 3.6
Gases Contributing to the Anthropogenic Greenhouse Effect

Gas	Rate of Increase (% per year)	Relative Contribution (%)
CO_2 (carbon dioxide)	0.5	60
CH_4 (methane)	1	15
N_2O (nitrous oxide)	0.2	5
O_3 (ozone)	0.5	8
CFC-11 (trichlorofluoromethane)	4	4
CFC-12 (trichlorofluoromethane)	4	8

alarming retreat of glaciers in the region by reducing the existing air pollution.

Leading the research team, Dr. V. Ramanathan, a chemistry professor at Scripps, concluded from the research, “Concerning the rapid melting of these glaciers, the third-largest ice mass on the planet, if it becomes widespread and continues for several more decades, will have unprecedented downstream effects on southern and eastern Asia” (*Scripps News*, 2007, UNEP, 2008).

According to Achim Steiner, the United Nations under-secretary general and executive director of the UN Environment Programme, “The main cause of climate change is the buildup of greenhouse gases from the burning of fossil fuels. But brown clouds, whose environmental and economic impacts are beginning to be unraveled by scientists, are complicating, and in some cases aggravating, their effects. The new findings should spur the international community to even greater action. For it is likely that in curbing greenhouse gases we can tackle the twin challenges of climate change and brown clouds and in doing so, reap wider benefits from reduced air pollution to improved agricultural yields” (MSNBC, 2007a).

Jay Fein, program director in the National Science Foundation’s Division of Atmospheric Sciences, remarked, “In order to understand the processes that can throw the climate out of balance, Ramanathan and colleagues, for the first time ever, used small and inexpensive unmanned aircraft and their miniaturized instruments as a creative means of simultaneously sampling clouds, aerosols, and radiative fluxes in polluted environments, from within and from all sides of the clouds. These measurements, combined with routine environmental observations and a state-of-the-science model, led to these remarkable results” (NSF, 2006).

What the study was successfully able to reveal was that the effect of the brown cloud was necessary to explain temperature changes that have been observed in the region over the last 50 years. It also clarified that southern Asia’s warming trend is more pronounced at higher altitudes than closer to sea level.

Ramanathan concluded, “This study reveals that over southern and eastern Asia, the soot particles in the brown clouds are intensifying the atmospheric warming trend caused by greenhouse gases by as much as 50 percent.”

In a subsequent article published in *Science* in 2012, China and India are releasing two million metric tons of carbon soot and other dark pollutants into the air annually. As a result, it is affecting climate thousands of kilometers away, warming some areas and cooling others. For example, it is projected that under current rates, the United States will be up to 0.4°C warmer by 2024 just from the brown clouds alone. These dark aerosols are primarily soot from diesel engines and power plants, which absorb more sunlight than they scatter, warming the atmosphere around them. Concerns from this include the triggering of significant changes in long-term weather patterns, similar to a human-caused El Niño which could alter temperature and precipitation patterns (Perkins, 2012).

His current research includes Project Surya, a cook-stove project that is aimed at eliminating pollutants from traditional biomass cooking that are warming the atmosphere. He is also involved with the California Air Resources Board and R. K. Pachauri (chairman of the IPCC) to initiate a project called ICAMP—a World Bank-sponsored project designed to reduce soot emissions from the transportation sector in India, seen as a practical application in climate change mitigation (Ramanathan, 2015).

It was not until the late 1940s when air pollution disasters occurred on two separate continents that public awareness began to grow concerning outdoor air quality and its effects on human health. Both the 1948 “killer fog” in Denora, Pennsylvania, that killed 50 people and the London “fog” in 1952, where roughly 4000 people died, prompted an investigation into the cause, and it was determined that the widespread use of dirty fuels were to blame. This began the concerted effort for governments to begin taking the problem of urban air pollution seriously (Figure 3.9).

Since this time, many contaminants in the atmosphere have been identified as harmful, and serious efforts have been undertaken to clean up the atmosphere from harmful components. The most common and damaging pollutants include sulfur dioxide, suspended particulate matter (PM), ground-level ozone, nitrogen dioxide, carbon monoxide, and lead. All of these pollutants are tied either directly or indirectly to the combustion of fossil fuels. Even though major efforts are under way today to clean polluted air over cities, many

FIGURE 3.9 A man guiding a bus with a flaming torch through thick fog during the London smog of 1952. (Courtesy of http://www.nickelinthemachine.com.)

cities worldwide still lack a healthy air quality. An inventory completed by the European Environment Agency determined that 70–80 percent of 105 European cities surveyed exceeded World Health Organization (WHO) air quality standards for at least one pollutant. In the United States, an estimated 80 million people live in areas that do not meet U.S. air quality standards, which are comparable to WHO standards. Other areas that do not meet WHO standards include Beijing, Delhi, Jakarta, and Mexico City. In these cities, pollutant levels sometimes exceed WHO air quality standards by a factor of 3 or more. Some of the cities in China exceed WHO standards by a factor of 6. Worldwide, the WHO estimates that up to 1.4 billion urban residents breathe air exceeding the WHO air guidelines and that the health consequences are considerable, with a mortality rate of 200,000–570,000 annually. In addition, the World Bank has estimated that exposure to particulate levels exceeding the WHO health standard accounts for roughly 2–5 percent of all deaths in urban areas in the developing world.

Addressing the issue of public policies that can reduce the health impacts of ambient air pollution, the WHO strongly recommends tackling the issue of inefficient fossil fuel combustion from motor vehicles, power generation, and improving energy efficiency in buildings, homes, and manufacturing processes. In addition, reducing health impacts will require cooperation from authorities at all levels: local, regional, national, and even international. Individuals also have an important role to play. Each of us has the responsibility to choose more efficient and cleaner energy sources and solutions. The key is to get multilevel and cross-sector cooperation, such as the transport, housing, industrial, and energy sectors of various geographic levels all working toward like goals to reduce air pollution and improve health conditions (WRI, 2002, World Health Organization, 2014).

It is stressed, however, that these mortality estimates do not reflect the huge toll of illness and disability that exposure to air pollution brings on a global level. Health effects span a wide range of severity from coughing to bronchitis to heart disease and lung cancer. In developing cities alone, air pollution is responsible for approximately 50 million cases per year of chronic coughing in children younger than 14 years of age. Taking the health effects into consideration, concerning climate change is critical because it affects the future of society.

Contributors to Climate Change and Pollution

The transportation sector is the largest single source of air pollution in the United States today. It causes almost 67 percent of the carbon monoxide (CO), a third of the nitrogen oxides (NO_x), and a fourth of the hydrocarbons in the atmosphere.

Cars and trucks pollute the air during manufacturing, oil refining and distribution, refueling and, most of all, vehicle use. Motor vehicles cause both primary and secondary pollution. Primary pollution is that which is emitted directly into the atmosphere; secondary pollution is from chemical reactions between pollutants in the atmosphere.

There are six major pollutants: ozone (O_3), PM, NO_x, CO, SO_2, and hazardous air pollutants (toxics). The primary ingredient in smog is O_3. PM refers to particles of soot, metals, and pollen. The finest, smallest textured PM does the most damage, as it travels into the lungs easily. NO_x tend to weaken the body's defense against respiratory infections. CO is formed by the combustion of fossil fuels such as gasoline and is emitted by cars and trucks. When inhaled, it blocks the transport of oxygen to the brain, heart, and other vital organs, making it deadly. SO_2 is created via the burning of sulfur-containing fuels, especially diesel. It forms fine particles in the atmosphere and is harmful to children and those with asthma. Toxic compounds are chemical compounds emitted by cars, trucks, refineries, and gas pumps, and have been related to birth defects, cancer, and other serious illnesses. The EPA estimates that the air toxics emitted from cars and trucks account for half of all cancers caused by air pollution.

Pollution from light trucks is growing quickly. This class of vehicles includes minivans, pickups, and sport utility vehicles. Today, these vehicles represent one of every two new vehicles purchased. For this reason, California regulators and the EPA have recently created new rules requiring light trucks to become as clean as cars over the next 7–9 years.

In 2009, the ALA released a report that identified six out of ten Americans—that is, 186.1 million people—live in areas where air pollution levels endanger lives. This means that almost every major city in the United States is affected by significant amounts of pollution. What was shocking was that despite the growing "green movement," air quality in many cities has become dirtier, not cleaner over the past decade. The three most widespread types of pollution are ozone (or smog), annual particle pollution, and 24-hour particle pollution levels. "This should be a wakeup call," said Stephen J. Nolan, ALA National Board Chair. "When 60 percent of Americans are left breathing air dirty enough to send people to the emergency room, to shape how kids' lungs develop, and to kill, air pollution remains a serious problem." Some of the most significant sources of air pollution include dirty power plants, dirty diesel engines, and ocean-going vessels. All three of these worsen climate change (ALA, 2009).

In 2015, the ALA released a list of the smoggiest cities in the United States. They are in order from least to worst (ALA, 2015), as shown in Table 3.7.

Key Impacts

As the climate change issue has escalated in recent years, scientists have been able to observe the related impacts worldwide—across all continents and oceans. As illustrated in several examples, impacts have been described and future impacts have been predicted if current activity continues.

Due to the lifetimes of the various greenhouse gases, even if all activity were stopped immediately, the effects of climate change would continue to a certain extent, because

TABLE 3.7
Worst Smog Cities in the United States, 2015

Ranking	City
10	Phoenix–Mesa–Scottsdale, Arizona
9	Las Vegas–Henderson, Nevada
8	Modesto–Merced, California
7	Dallas–Fort Worth, Texas
6	Houston–The Woodlands, Texas
5	Sacramento–Roseville, California
4	Fresno–Madera, California
3	Bakersfield, California
2	Visalia, California
1	Los Angeles, California

Source: ALA, State of the air 2015, http://www.stateoftheair.org/ (accessed April 11, 2016), 2015.

past damage has already ensured those changes. There is still a time window, however, to avoid the most catastrophic of changes, if efforts, policies, and appropriate technologies are put into effect now. The chart illustrates the key impacts as a function of increasing global average temperature change (Figure 3.10). It details the changes that would be expected with water sources, ecosystems, food, the status of the coasts, and major health issues and trends of an incremental temperature increase up to 5°C. Resultant impacts expected to a region will vary based on the extent they are able to adapt, the rate of temperature change, and their socioeconomic structure. For example, locations better equipped to handle emergencies and crisis management will fare better than locations that are not. However, even being better equipped will not spare an area from feeling the ramifications of a changing climate.

FIGURE 3.10 As temperatures increase, the impacts on the earth's various ecosystems will become more intensified, stressing natural resources to their limits and resulting in possible productive failure, loss of habitat, health disasters, disruption of food and water supplies, and extinction of life. (Courtesy of NOAA.)

CONCLUSION

This chapter has served to illustrate the components and seriousness of the various greenhouse gases, their production, life cycles, and various contributions to climate change. Human activity has played a heavy hand in determining the atmosphere's composition and behavior since the onslaught of the Industrial Revolution, especially from 1850 until the present. Fortunately, Keeling had the foresight to set up a monitoring station in Hawaii and diligently tracked the atmospheric concentrations of CO_2. The results of his graph played an enormous hand in convincing the scientific community years later that climate change was real and deserved the world's attention.

As climate science entered its infancy, scientists began to see the critical role CO_2 and other greenhouse gases were playing in the larger picture. The bigger question was—could they convince the general public of what was going on and trigger what was necessary to solve the problem? Not just regulatory constraints but a major change in mind-set and the way people looked at the environment were needed. Through their subsequent research, they were able to unravel many mysteries and answer several questions, such as where carbon is sequestered (stored), how it is produced, the process by which it is released into the atmosphere, and the worldwide effects it was having.

Much progress has been made in solving and answering this question. And finally, the public at last seems to be embracing this knowledge and choosing to take action. As new discoveries are made, it is hoped that the public will stay informed and adapt to a warming world with appropriate green responses, as those decisions and responses will shape the future landscape.

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