Global climate change is considered to be one of the most pressing environmental concerns of our time. This concern is due, in part, to the potential magnitude of the economic, technological, and lifestyle changes that may be necessary in response. Although uncertainty still clouds the science of climate change, there is strong indication that we may need to significantly reduce human-made greenhouse gas (GHG) emissions. Carbon capture and storage (CCS) has the potential to address this challenge, and the activities conducted through the Plains CO2 Reduction (PCOR) Partnership are playing an important role in efficiently meeting this challenge.
The natural greenhouse effect plays an essential role in our climate patterns. The effect is the result of heat-trapping gases (also known as GHGs), which absorb heat radiated from Earth’s surface and lower atmosphere and then radiate much of the energy back toward the surface. Without this greenhouse effect, the average surface temperature of Earth would be about 0°F (−18°C) instead of the much warmer 59°F (15°C),¹ and life as it is known would not be possible.

1. Sun’s rays enter Earth’s atmosphere.

2. Heat is emitted back from Earth’s surface.

3. Some heat passes back out into space.

4. Some heat is absorbed by GHGs and becomes trapped within Earth’s atmosphere. Earth becomes hotter as a result. The more GHGs in the atmosphere, the more heat is retained.
Many gaseous chemical compounds in Earth’s atmosphere contribute to the greenhouse effect. These gases absorb infrared radiation reflected from Earth’s surface and trap the heat in the atmosphere. Some occur in nature (water vapor \([H_2O]\), carbon dioxide \([CO_2]\), methane \([CH_4]\), nitrous oxide \([N_2O]\), and ozone \([O_3]\)), while others are exclusively human-made (like gases used for aerosols).

**Water vapor** is the most abundant GHG in the atmosphere. As the temperature of the atmosphere rises, it can hold more water vapor. This higher concentration of water vapor is able to absorb more heat, further warming the atmosphere. This cycle is called a feedback loop.

**Carbon dioxide** has both natural and anthropogenic (human-made) sources. \(CO_2\) plays a vital role in supporting life on Earth. The natural production and absorption of \(CO_2\) are achieved through the terrestrial biosphere (trees, soil) and the hydrosphere (ocean).

**Methane** has both natural and anthropogenic sources. Human activities such as growing crops, raising livestock, using natural gas, and mining coal have added to the atmospheric concentration of methane.

**Nitrous oxide** is produced by microbial processes in soil and water, including those reactions which occur in fertilizer containing nitrogen.

**Ozone** is formed in the stratosphere through the interaction between ultraviolet light and oxygen. This natural ozone layer has been supplemented by ozone created by human processes, such as automobile exhaust and burning vegetation.

**Chlorofluorocarbons** (CFCs) have no natural source and are used as refrigerants, aerosol propellants, and cleaning solvents. CFC production was nearly halted after it was discovered that CFCs are able to destroy stratospheric ozone.
AS part of the natural carbon cycle, people and animals inhale oxygen from the air and exhale CO₂. Meanwhile, green plants absorb CO₂ for photosynthesis and emit oxygen back into the atmosphere. This exchange, or flux, of carbon among the atmosphere, oceans, and land surface is called the global carbon cycle.³

For most of human history, the global carbon cycle has been roughly in balance. The amount of carbon in the atmosphere is approximately 800 billion tonnes (or gigatons, Gt), which is more carbon than contained in all of Earth’s living vegetation. Human activities, namely, the burning of fossil fuels, deforestation, and other land use activities, have altered the carbon cycle, resulting in a 35% rise in atmospheric concentrations of CO₂ since the Industrial Revolution.

Fluxes and pools are in Gt. Pools are noted in parentheses.
More than 100 years ago, Swedish scientist and Nobel Prize winner Svante Arrhenius postulated that anthropogenic increases in atmospheric CO₂ as the result of fossil fuel combustion would have a profound effect on the heat budget of Earth. In 1904, Arrhenius became concerned with rapid increases in anthropogenic carbon emissions.

“The slight percentage of carbonic acid in the atmosphere may, by the advances of industry, be changed to a noticeable degree in the course of a few centuries.”

–Svante Arrhenius, 1904

Since instrumental records of temperature began in 1880, the overall temperature of Earth has risen by approximately 1.62°F (0.90°C), with 2015 being the warmest year on record according to the National Oceanic and Atmospheric Administration. A majority of climate scientists attribute current changes in climate at least in part to anthropogenic (human-made) emissions, although modeled predictions of future climate change and impacts are subject to uncertainty. This observed climate change is not distributed evenly across the globe. For instance, temperature increases in the last 10 years have generally been greatest in the northern latitudes.

The map shows the average surface temperature trends for the decade 2005–2015 relative to the 1950–1980 average. Warming was more pronounced at high latitudes, especially in the Northern Hemisphere and over land.

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Major Stationary CO$_2$ Sources

- **INDUSTRIAL**
  - Cement Plant

- **PETROLEUM AND NATURAL GAS**
  - Refinery

- **ELECTRIC UTILITY**
  - Coal-Fired Power Plant

- **AGRICULTURE-RELATED PROCESSING**
  - Ethanol Plant
Carbon dioxide formed through human action is referred to as anthropogenic CO₂. The primary source of anthropogenic CO₂ emissions in North America is the burning of fossil fuels for energy. Industrial activities such as manufacturing cement, producing ethanol, refining petroleum, producing metals, and combusting waste also contribute a significant amount of anthropogenic CO₂. Collectively, these are referred to as large stationary CO₂ point sources. Nonstationary CO₂ emissions include activities such as using gasoline, diesel, and other fuels for transportation.

Changes in land use and land conversion are also considered a significant source of anthropogenic CO₂. This includes practices like plowing land, which releases some of the exposed carbon in the soil to the atmosphere as CO₂, and deforestation, which causes a loss of plant biomass.

What Is CO₂?
Carbon dioxide is a colorless, odorless, naturally occurring gas comprising one atom of carbon and two atoms of oxygen. At temperatures below −76°C, CO₂ condenses into a white solid called dry ice. When warmed, dry ice vaporizes directly from a solid to CO₂ gas in a process called sublimation. With enough added pressure, liquid CO₂ can be formed.

CO₂ has a number of industrial uses: in fire extinguishers (CO₂ displaces the oxygen the fire needs to burn), as a propellant in spray cans, in treatment of drinking water, for cold storage (CO₂ as dry ice), and to make bubbles in soft drinks. However, by far the largest use is in oil fields to enhance oil recovery.

Global GHG Emissions:
- CO₂ Energy Sector, 67%
- Electricity, 42%
- Transport, 23%
- Industry, 20%
- Residential, 6%
- Other, 9%

* Other includes commercial/public services, agriculture/forestry, energy industries other than electricity, and heat generation.
The amount of CO₂ in the atmosphere was relatively constant for 10,000 years until the Industrial Revolution in the 1800s, and the amount of anthropogenic CO₂ is projected to increase considerably. Current, the world’s economies annually emit approximately 29 Gt of CO₂ to the atmosphere from the combustion of fossil fuels to produce electricity. Increasing global populations, higher standards of living, and increased demand for energy could result in as much as 9000 Gt of cumulative CO₂ being emitted to the atmosphere.9

Growing Economy = Growing CO₂ Emissions

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As we go about our daily lives, we all expend energy—working, eating, and sheltering our families and for transportation and play.

Households in the postindustrial world enjoy a quality of life never known before. Our everyday environment is packed with energy at our fingertips. Because most of our energy comes from fossil fuels, our lifestyle currently comes with a hefty price tag—a large carbon footprint.

But fewer than one in five people on Earth live in the postindustrial world. Two in five live in rapidly emerging economies (2.3 billion people in China and India), and even more live in developing economies (over 3 billion people). Their household energy use is smaller than ours, and their carbon footprints are smaller too. However, they are moving toward a modern lifestyle, and as these countries adopt and develop new technologies, they will use more and more energy.

In 1930, the countries that now have the postindustrial economies generated nearly all carbon emissions from fossil fuels. Since then, global emissions have grown seven times greater. Now, postindustrial economies generate half. By 2030, global emissions are projected to grow by half again; most of that increase will come from modernization in the emerging and developing economies.

If the world continues to rely on fossil fuels, the share of carbon emissions from rapidly emerging and developing economies will surpass those of the postindustrial world as more and more of the world’s economies move toward maturity.

How will we support modern lifestyles globally as we address climate change?
Global carbon emissions from fossil fuels have significantly increased the amount of GHG from anthropogenic sources emitted to the atmosphere. Since 1970, CO₂ emissions have increased 90%, with emissions from fossil fuel combustion and industrial processes contributing more than 75% of the total emissions. To reduce the growing impact of GHG emissions on climate change, policies and regulations have been developed on a national and global level. All member countries of the United Nations Framework Convention on Climate Change (UNFCCC) agreed to adopt a new global climate agreement in Paris as of December 2015, to take effect in 2020. This agreement aims to limit the rise in global average surface temperature to below 2°C compared to preindustrial times to avoid the most dangerous impacts of climate change.

The illustration shows the percentage of change from 2009 to 2012 in global CO₂ emissions by country, highlighting the top 11 contributors. Although all countries in the top 11 are members of UNFCCC, all but two (the United States and the United Kingdom) have increased their CO₂ emissions, with the most notable increase of 33% coming from Saudi Arabia.

China is the largest emitter of GHG in the world, with fossil fuel burning and cement production the top contributors. The magnitude and growing annual rate of growth of China’s carbon emissions make this country a major contributor to global carbon emissions and thus a priority nation for efforts in emission mitigation.
North American CO$_2$ Sources

**CO$_2$ Source Types**
- Ethanol Plant
- Cement Plant
- Agriculture Processing
- Electrical Utility
- Fertilizer
- Industrial
- Petroleum and Natural Gas
- Refineries/Chemical
- Unclassified

**Annual CO$_2$ Output, tonnes**
- 100,000–750,000
- 750,000–2,500,000
- 2,500,000–7,500,000
- 7,500,000–15,000,000
- 15,000,000–25,000,000
The type and distribution of large stationary CO\textsubscript{2} sources across North America reflect the prevalent economy and historical development of the continent.

**Industrial Manufacturing**

Much like the Great Lakes region in the United States, the Valley of Mexico is a robust center of industrial manufacturing. Food processing, iron and steel production, as well as textile and automotive manufacturing are some of the many activities that consume large quantities of energy and produce significant amounts of CO\textsubscript{2}.

**Agriculture-Related Processing**

In addition to being the world’s largest producer and exporter of corn, the corn belt region of the United States represents the most intensively agricultural region of the Midwest. Although most of the corn is used for livestock feed, a significant portion is sent to ethanol plants in the region. Ethanol plants are a source of nearly pure CO\textsubscript{2} and thus require no specialized CO\textsubscript{2} capture and separation technologies.

**Petroleum and Natural Gas**

The large concentration of sources along the eastern edge of the Rocky Mountains associated with petroleum and natural gas production is a reflection of the amount of energy needed to extract and refine hydrocarbon resources needed for transportation, heating, and industry.

**Electrical Utility**

In 1882, the world’s first central generating plant was installed on Pearl Street in New York’s financial district. Since then, the use of electricity has grown from street lamps and in homes to supplying vast energy grids that supply power to entire cities. Although a large concentration of these sources is on the East Coast of the United States, due mostly to population, these sources are well distributed throughout North America.
Addressing climate change is a large-scale, global challenge that is compounded by our growing demand for energy. To reduce the risks associated with climate change, the amount of CO\textsubscript{2} released by human activity must be substantially reduced. A number of techniques can be employed to reduce CO\textsubscript{2} emissions, including energy conservation, using fossil fuels more efficiently, and increasing the use of renewable (i.e., wind, solar, geothermal, hydropower) and nuclear energy. But in the face of growing world populations and rising worldwide standards of living, CCS provides an opportunity to combine the continued use of fossil fuels with a significant reduction in GHG emissions. CCS lies at the intersection of energy, the economy, and the environment, which makes it a critical approach to meet our world’s clean energy needs. The PCOR Partnership is working to ensure that CCS is developed and implemented in a practical and environmentally sound manner.

Potential Impacts of Climate Change

No one knows the exact consequences of this upsurge of CO\textsubscript{2} in the atmosphere, but climate-related changes have already been observed globally. Climate change is expected to impact human health, natural systems, and the environment at large. Potential consequences include:

- Warming air and water.
- Change in the location and amount of precipitation.
- Increased storm intensity.
- Sea level rise.
- Reduced snow cover, glaciers, permafrost, and sea ice.
- Changes in ocean characteristics.

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“Predictions are hard to make, especially about the future.”

– Yogi Berra

CCS can achieve 14% of the global GHG emission reductions needed by 2050 to limit global warming to 2°C (IEA [International Energy Agency]).