Global climate change is considered to be one of the most pressing environmental concerns of our time. This is due, in part, to the potential magnitude of the economic, technological, and lifestyle changes that may be necessary in order to respond to it. Although uncertainty still clouds the science of climate change, there is a strong indication that we may need to significantly reduce human-made greenhouse gas (GHG) emissions. Carbon capture and storage (CCS) are a few methods that have 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 60°F (~33°C) colder, and life as it is known would not be possible.

1. The 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 [H₂O], carbon dioxide [CO₂], methane [CH₄], nitrous oxide [N₂O], and ozone [O₃]), 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, thus further warming the atmosphere. This cycle is called a feedback loop.

**Carbon dioxide** has both natural and anthropogenic (human-made) sources. CO₂ plays a vital role in supporting life on Earth. The natural production and absorption of CO₂ 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.

For most of human history, the global carbon cycle has been roughly in balance. The concentration of carbon in the atmosphere is approximately 800 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.
“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 1861, the overall temperature of Earth has risen by approximately 1.33°F (0.74°C), with the 1990s being the warmest decade and 1998 being the warmest year. Some scientists attribute the temperature rise to human activity, but others believe it is a result of natural climate changes that have occurred over the millions of years of Earth’s existence. A large body of the scientific community believes that global climate change is a combination of natural and human-induced causes. 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 2000–2009 relative to the 1950–1979 average. Warming was more pronounced at high latitudes, especially in the Northern Hemisphere and over land.

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.
Major Stationary CO$_2$ Sources

**INDUSTRIAL**
- Cement Plant

**PETROLEUM AND NATURAL GAS**
- Refinery

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

**AG-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 -108°F (-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 carbon dioxide 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, CO₂’s number one industrial use is in oil fields to enhance oil recovery.

*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. Currently, the world’s economies annually emit approximately 3.5 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.

Growing Economy = Growing CO₂ Emissions

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>Population 1 billion</td>
</tr>
<tr>
<td>1859</td>
<td>Beginning of U.S. petroleum industry</td>
</tr>
<tr>
<td>1861</td>
<td>First mobile gasoline engine</td>
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<tr>
<td>1870</td>
<td>First practical electric generating station</td>
</tr>
<tr>
<td>1879</td>
<td>Thomas Edison invents the lightbulb</td>
</tr>
<tr>
<td>1882</td>
<td>W. Carrier invents air conditioner</td>
</tr>
<tr>
<td>1886</td>
<td>Daimler &amp; Benz build the first successful auto</td>
</tr>
<tr>
<td>1890</td>
<td>U.S. coal production tops 1 billion tons/yr.</td>
</tr>
<tr>
<td>1893</td>
<td>Rural electrification of the United States begins</td>
</tr>
<tr>
<td>1907</td>
<td>First oil well</td>
</tr>
<tr>
<td>1912</td>
<td>First tanker of oil ships from Middle East</td>
</tr>
<tr>
<td>1916</td>
<td>First oil well</td>
</tr>
<tr>
<td>1917</td>
<td>Arab oil embargo</td>
</tr>
<tr>
<td>1940</td>
<td>First oil well</td>
</tr>
<tr>
<td>1945</td>
<td>First oil well</td>
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<tr>
<td>1950</td>
<td>First oil well</td>
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<td>1960</td>
<td>First oil well</td>
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<td>1970</td>
<td>First oil well</td>
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<td>1980</td>
<td>First oil well</td>
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<tr>
<td>1990</td>
<td>First oil well</td>
</tr>
<tr>
<td>2000</td>
<td>First oil well</td>
</tr>
<tr>
<td>2010</td>
<td>First oil well</td>
</tr>
</tbody>
</table>

Population, billions: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Annual CO₂ Emissions, Gt: 0, 2000, 4000, 6000, 8000, 10,000, 12,000, 14,000

54.9 MIB

0 1 2 3 4 5 6 7 8 9 10

Population

CO₂ Emissions

2013

ATLAS
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 our technologies and develop their own, 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 the threat of climate change?

### Postindustrial Economy: United States

A middle-class U.S. family uses fossil fuels for transportation, heating, and cooking. But most of their carbon footprint comes from the electricity they use (generated mainly from coal).

### Developing Economy: Cameroon

Most middle-class families in Cameroon cook with wood (renewable sources of carbon, i.e., carbon-neutral) and have hydroelectric power for electricity (mainly for lightbulbs and cell phone chargers). Their entire carbon footprint comes from occasional transportation by motorcycle, car, and truck.

### Emerging Economy: India

Middle-class homes in India are smaller, have fewer appliances, and have no heating systems. About half of the carbon footprint for this family comes from their transportation. Most of the rest comes from the electricity they use (most made by fossil fuels).

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**Comparing Household Carbon Footprint**

<table>
<thead>
<tr>
<th></th>
<th>Relative CO2 Emissions from Fossil Fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>India</td>
</tr>
<tr>
<td>Gasoline and Diesel</td>
<td>54%</td>
</tr>
<tr>
<td>Natural Gas and Propane</td>
<td>4%</td>
</tr>
<tr>
<td>Electricity</td>
<td>42%</td>
</tr>
</tbody>
</table>

Household comparison: Households in the postindustrial economies (like the United States) have easy access to affordable energy. As energy becomes available to households in emerging and developing economies, their carbon footprints will grow too.
Although economic growth and increases in energy use generally occur together, the degree to which they are linked varies across regions and states of economic development. The picture that emerges from these figures is one where, in general, developed countries and major emerging economy nations lead in total CO2 emissions.

In 2009, the largest five CO2 emitters (China, the United States, India, Russia, and Japan) comprised 45% of the total population and together produced 56% of global CO2 emissions and 51% of the world’s gross domestic product (GDP). Among the five largest emitters of CO2, China, Russia, and the United States have significantly reduced their CO2 emissions per unit of GDP over the last 20 years by improving energy efficiency and using more renewable fuels. Worldwide, the highest levels of emissions per GDP are observed for the oil- and gas-exporting regions of the Middle East.

As compared to emissions per unit of GDP, the range of per capita emission levels across the world is even larger, highlighting wide divergences in the way different countries and regions use energy. Developed nations typically have high CO2 emissions per capita, while some developing countries lead in the growth rate of CO2 emissions. Factors such as income per capita, climate, and population density are important determinants of CO2 emissions per capita.
North American CO₂ Sources

CO₂ Source Types:
- Ethanol Plant
- Cement Plant
- Ag Processing
- Electrical Utility
- Fertilizer
- Industrial
- Petroleum and Natural Gas
- Refineries/Chemical
- Unclassified

Annual CO₂ Output (tons):
- 15,000–750,000
- 750,000–2,500,000
- 2,500,000–7,500,000
- 7,500,000–15,000,000
- 15,000,000–20,000,000
The type and distribution of large stationary CO₂ 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 CO₂.

**Ag-Related Processing**
In addition to being the world’s largest producer and exporter of corn, the cornbelt 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 the ethanol plants in the region. Ethanol plants are a source of nearly pure CO₂ and thus require no specialized CO₂ 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. While there is a large concentration of these sources on the Eastern Coast of the United States, due mostly to population, these sources are well distributed throughout North America.
Finding a CO₂ Solution

Addressing climate change is a large-scale, global challenge that is compounded by our growing demand for energy. To stabilize CO₂ at levels that would prevent anthropogenic interference with the climate system, there needs to be a substantial reduction in the amount of CO₂ released by human activity.

A number of techniques can be employed to reduce CO₂ 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 has the potential to significantly reduce CO₂ levels more than any other single technique. 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.

CCS could process 20% to 40% of world CO₂ emissions by 2050.

Potential Impacts of Climate Change

No one knows the exact consequences of this upsurge of CO₂ 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.

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

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