PCOR Partnership

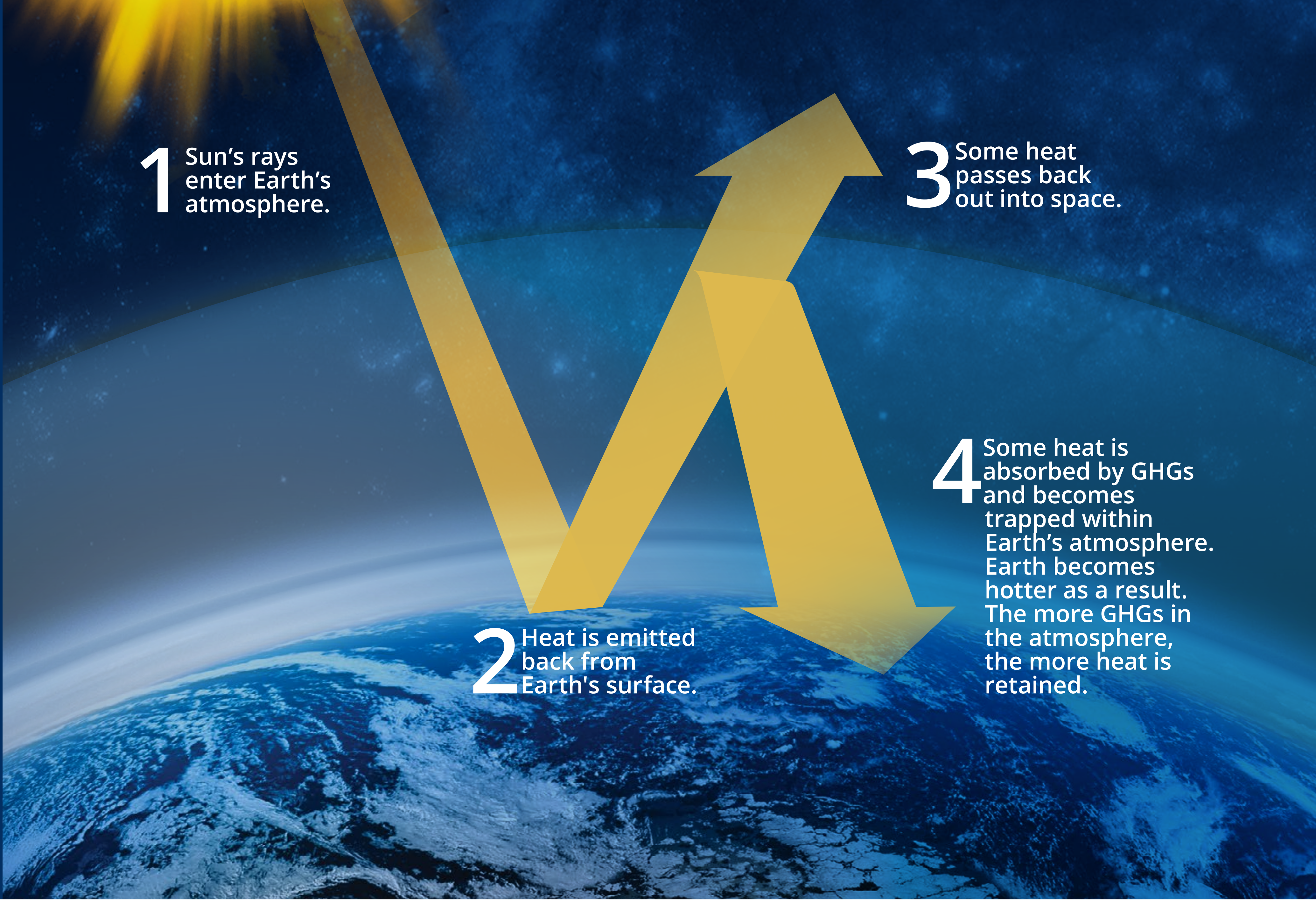
CHAPTER 1

THE CHALLENGE

Managing global carbon emissions is one of the most pressing environmental concerns of our time. Many scientists are concerned that anthropogenic (human-made) greenhouse gases (GHG)s are affecting Earth's climate. Although earth-warming gases exist naturally in the atmosphere, human activities are adding more of these GHGs, including carbon dioxide (CO_2). The challenge is to address anthropogenic GHG emissions while providing access to reliable, affordable, resilient energy around the world. Carbon capture, utilization, and storage (CCUS) can address this challenge, and the activities conducted through the Plains CO_2 Reduction (PCOR) Partnership are playing an important role in developing and deploying CCUS technologies.

GREENHOUSE EFFECT

At the heart of this challenge is Earth's natural greenhouse effect, which plays an essential role in our climate patterns. The effect is the result of heat-trapping gases (called GHGs), which absorb heat emitted from Earth's surface and lower atmosphere and then release much of the heat back toward the surface. Without this greenhouse effect, the average surface temperature of Earth would be about 0°F (or −18°C)[1] instead of 59°F (15°C), and life as it is known would not be possible.



GREENHOUSE GASES

Many gaseous chemical compounds in Earth's atmosphere contribute to the greenhouse effect.[2] These gases absorb infrared radiation emitted from Earth's surface and trap the heat in the atmosphere. Some of these gases occur in nature, while others are products of human activity.

> Human contributions of GHGs to the atmosphere may seem minor compared to the large share of water vapor and clouds. The heat-trapping capacity of these molecules is, however, much greater than water vapor, so smaller changes have a greater impact.

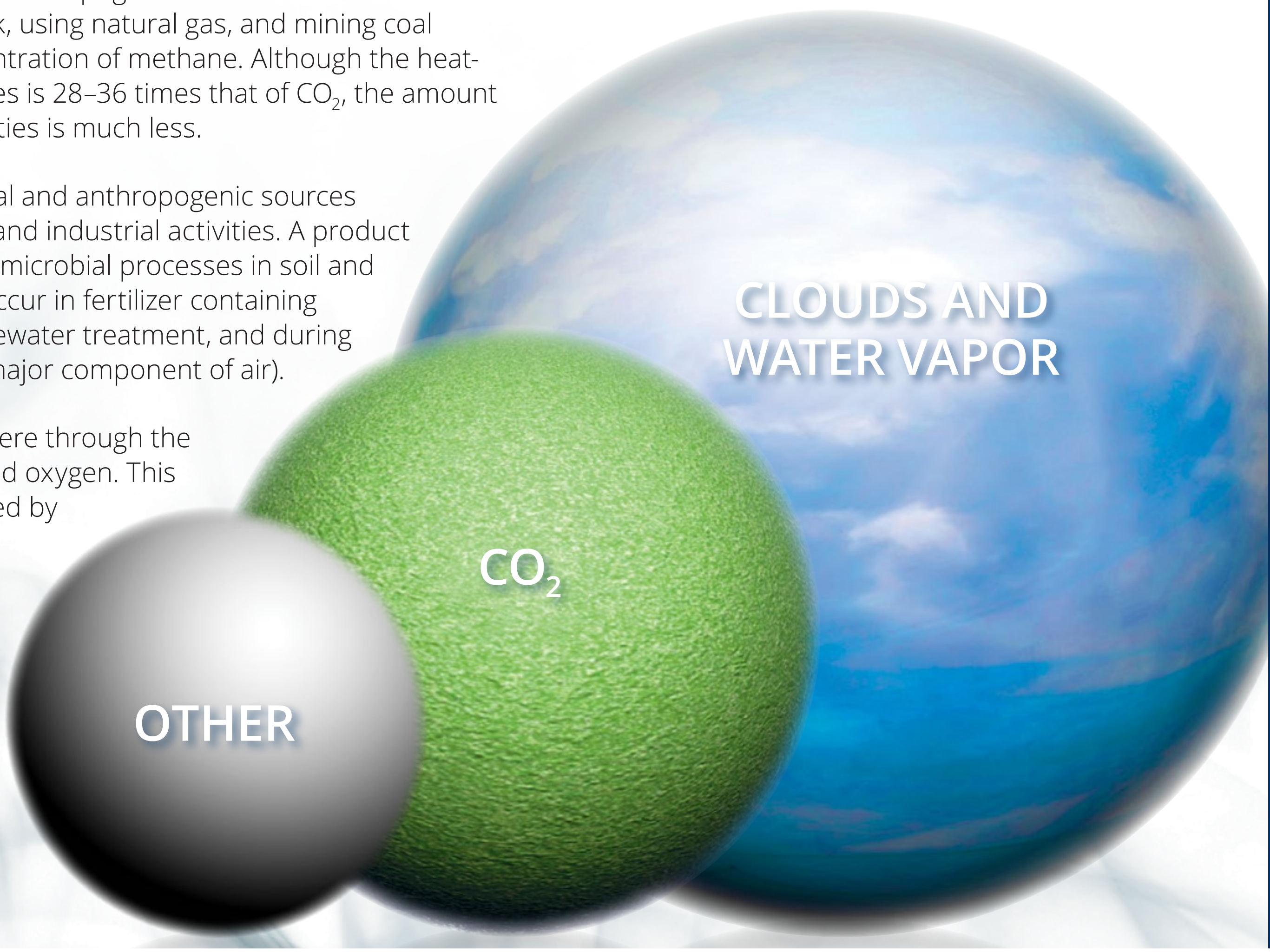
WATER VAPOR (H_2O) is the most abundant GHG in the atmosphere. As the temperature of the atmosphere rises, it can hold more water vapor. This higher concentration of water vapor is able to absorb more heat, further warming the atmosphere. This cycle is called a feedback loop. Water molecules have very little heat-trapping capacity compared to other GHGs, and thus changes to the amount of water vapor have the least impact on the greenhouse effect.

CARBON DIOXIDE has both natural and anthropogenic (human-made) sources. CO_2 plays a vital role in supporting life on Earth through the global carbon cycle. The heat-trapping capacity of CO_2 molecules is much greater than water vapor. Because its production is so prevalent in human activity, CO_2 is the major focus of GHG reduction efforts.

METHANE (CH_4) 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. Although the heat-trapping capacity of methane molecules is 28–36 times that of CO_2, the amount of methane produced by human activities is much less.

NITROUS OXIDE (N_2O) has both natural and anthropogenic sources associated with agricultural, land use, and industrial activities. A product of decomposition, N_2O is produced by microbial processes in soil and water, including those reactions that occur in fertilizer containing nitrogen, in both solid waste and wastewater treatment, and during combustion (because nitrogen is the major component of air).

OZONE (O_3) is formed in the stratosphere through the interaction between ultraviolet light and oxygen. This natural O_3 layer has been supplemented by O_3 created by human processes, such as automobile exhaust and burning vegetation.

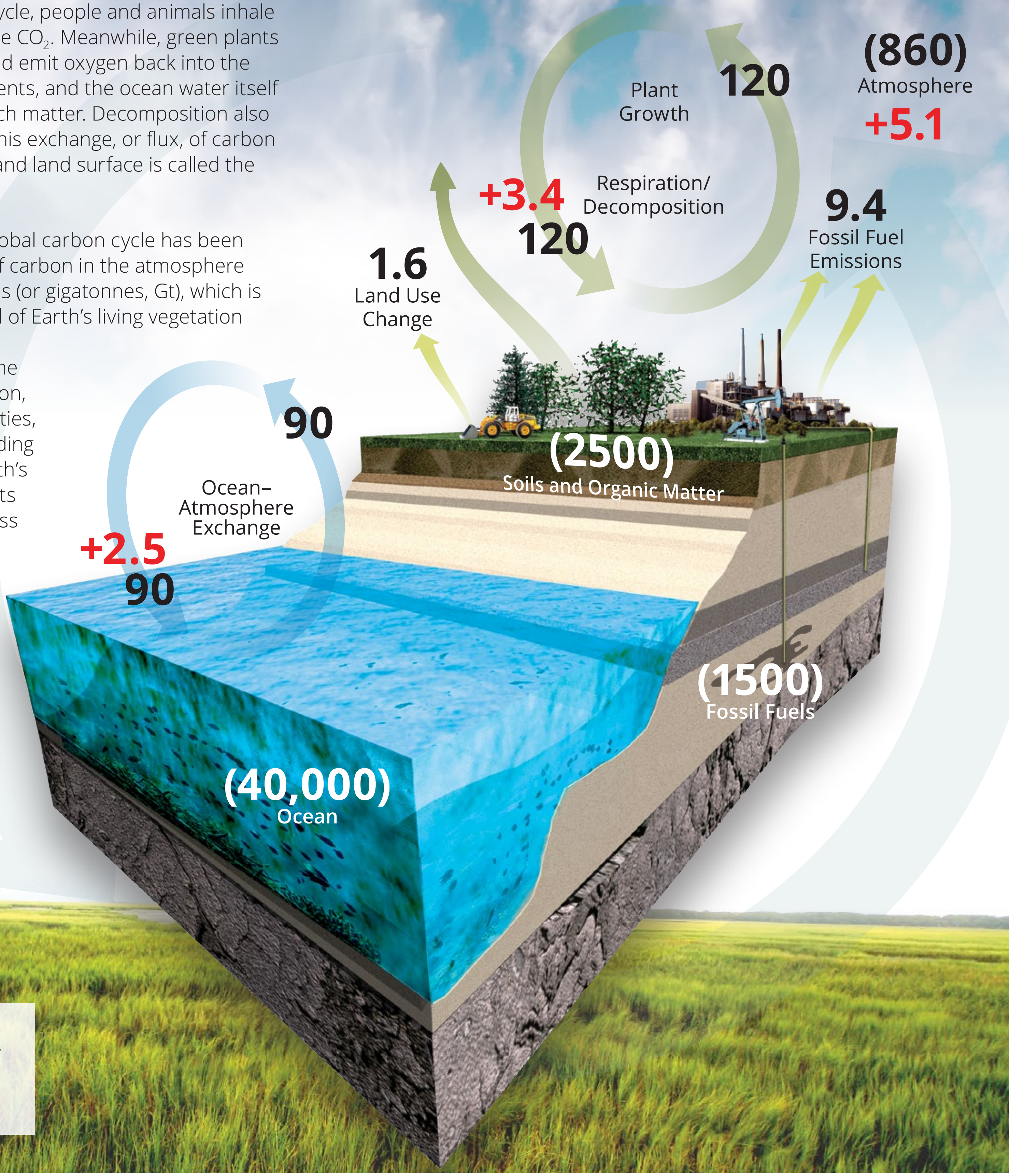


Relative total GHG effect contributions.[3]

GLOBAL CARBON CYCLE

As part of the natural carbon cycle, people and animals inhale oxygen from the air and exhale CO_2. Meanwhile, green plants absorb CO_2 for photosynthesis and emit oxygen back into the atmosphere. Marine biota, sediments, and the ocean water itself also absorb CO_2 and/or carbon-rich matter. Decomposition also returns CO_2 to the atmosphere. This exchange, or flux, of carbon among the atmosphere, oceans, and land surface is called the global carbon cycle.[4]

For most of human history, the global carbon cycle has been roughly in balance. The amount of carbon in the atmosphere is approximately 860 billion tonnes (or gigatonnes, Gt), which is more carbon than contained in all of Earth's living vegetation and roughly 80 Gt more than in 2000. Human activities, namely, the burning of fossil fuels, deforestation, farming, and other land use activities, have altered the carbon cycle, adding extra CO_2 to the atmosphere. Earth's ocean and terrestrial environments compensate for some of the excess by taking up billions of tonnes of extra CO_2 (shown in red in the figure). Still, much remains in the atmosphere, resulting in a 45% increase in atmospheric concentrations of CO_2 since the Industrial Revolution.

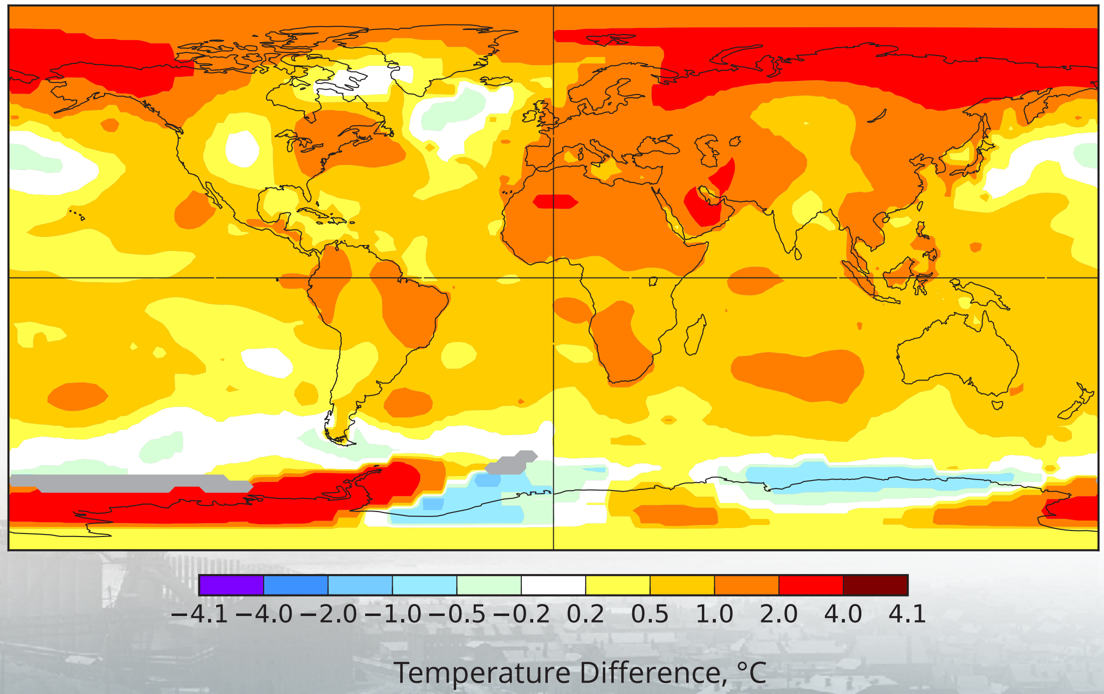


Averaged annual emissions, 2010–2019. Fluxes and pools are in GtC. Pools are noted in parentheses.

> "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 more than 2°F (1.2°C), with 2020 being the second warmest year on record according to the National Oceanic and Atmospheric Administration.[5] The world's seven warmest years have all occurred since 2014. These rising temperatures are causing wide-ranging impacts such as the loss of sea ice and ice sheet mass, sea level rise, longer and more intense heat waves, and shifts in habitats. Most climate scientists attribute these current changes in climate at least in part to anthropogenic (human-made) GHG emissions.

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.[6]



More than 100 years ago, Swedish scientist and Nobel Prize winner Svante Arrhenius postulated that anthropogenic increases in atmospheric CO_2 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.[7]

MAJOR STATIONARY CO_2 SOURCES

INDUSTRIAL

Cement Plant

PETROLEUM AND NATURAL GAS

Refinery

ELECTRIC UTILITY

Coal-Fired Power Plant

AGRICULTURE-RELATED PROCESSING

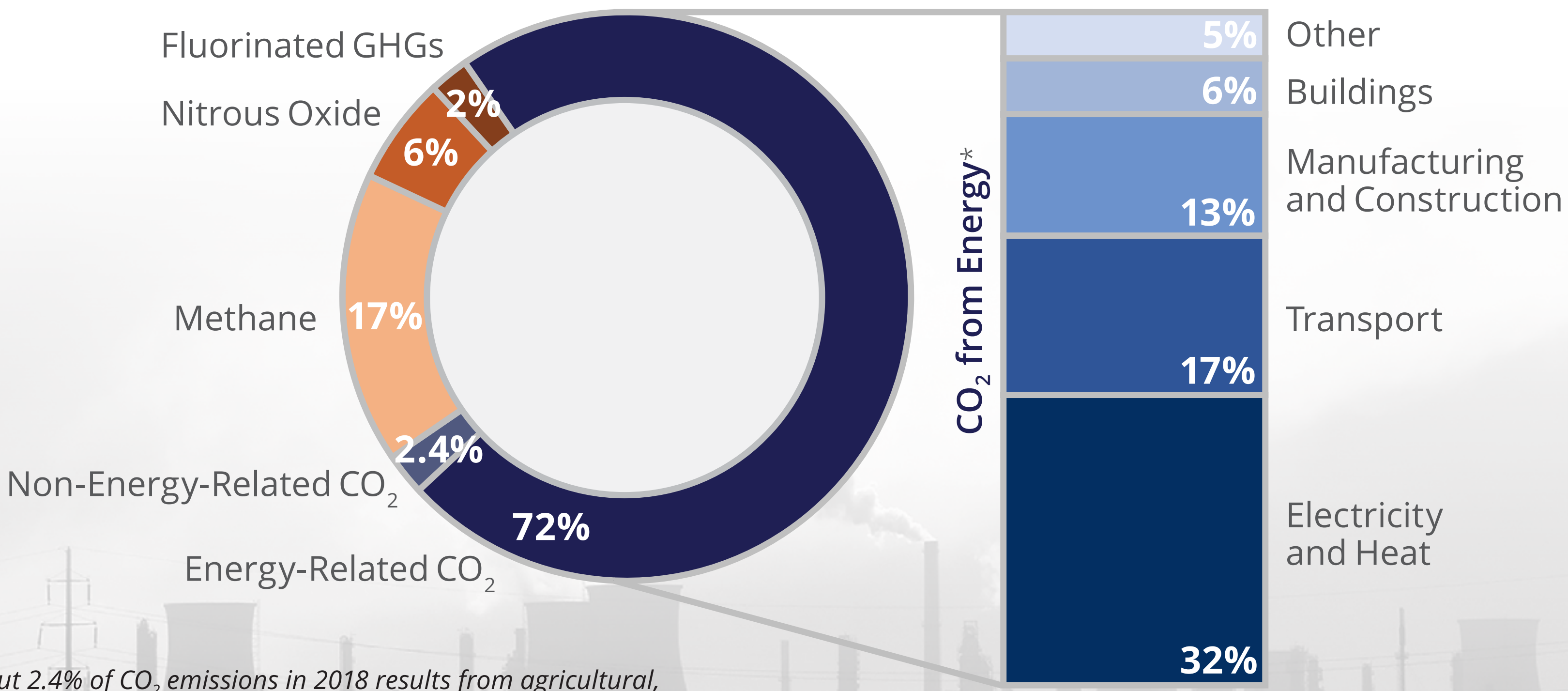
Ethanol Plant

Carbon dioxide produced through human action is referred to as anthropogenic CO_2. The primary source of anthropogenic CO_2 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 CO_2. Collectively, these are referred to as large stationary CO_2 point sources. Nonstationary CO_2 emissions include activities such as using gasoline, diesel, and other fuels for transportation.

Changes in land use and land conversion also contribute to anthropogenic CO_2 emissions. This includes practices like plowing land, which releases exposed carbon in the soil to the atmosphere as CO_2, and deforestation, which reduces plant biomass, thus reducing the plant uptake of airborne CO_2 and releases CO_2 if the biomass is burned.

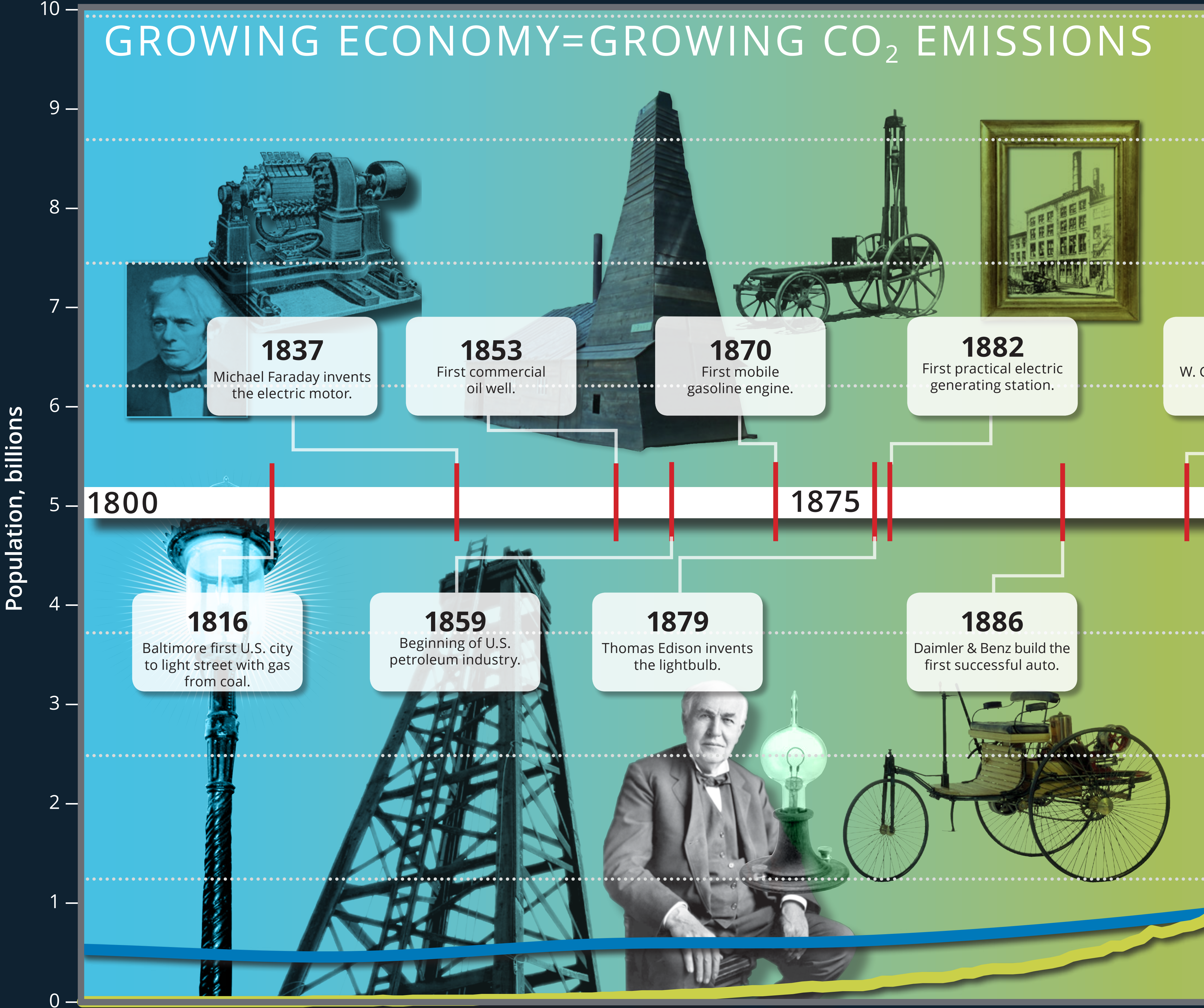
WHAT IS CO_2? Carbon dioxide is a colorless, odorless, naturally occurring gas comprising one atom of carbon and two atoms of oxygen. At temperatures below −76°C, CO_2 condenses into a white solid called dry ice. When warmed, dry ice vaporizes directly from a solid to a CO_2 gas in a process called sublimation. With enough added pressure, liquid CO_2 can be formed. CO_2 has many industrial uses: in fire extinguishers, as a propellant in spray cans, in treatment of drinking water, for cold storage (CO_2 as dry ice), and to make bubbles in soft drinks. CO_2 is also used in large quantities for enhanced oil recovery (EOR) as part of oil production in some oil fields.

2018 GLOBAL GREENHOUSE GAS EMISSIONS[8]

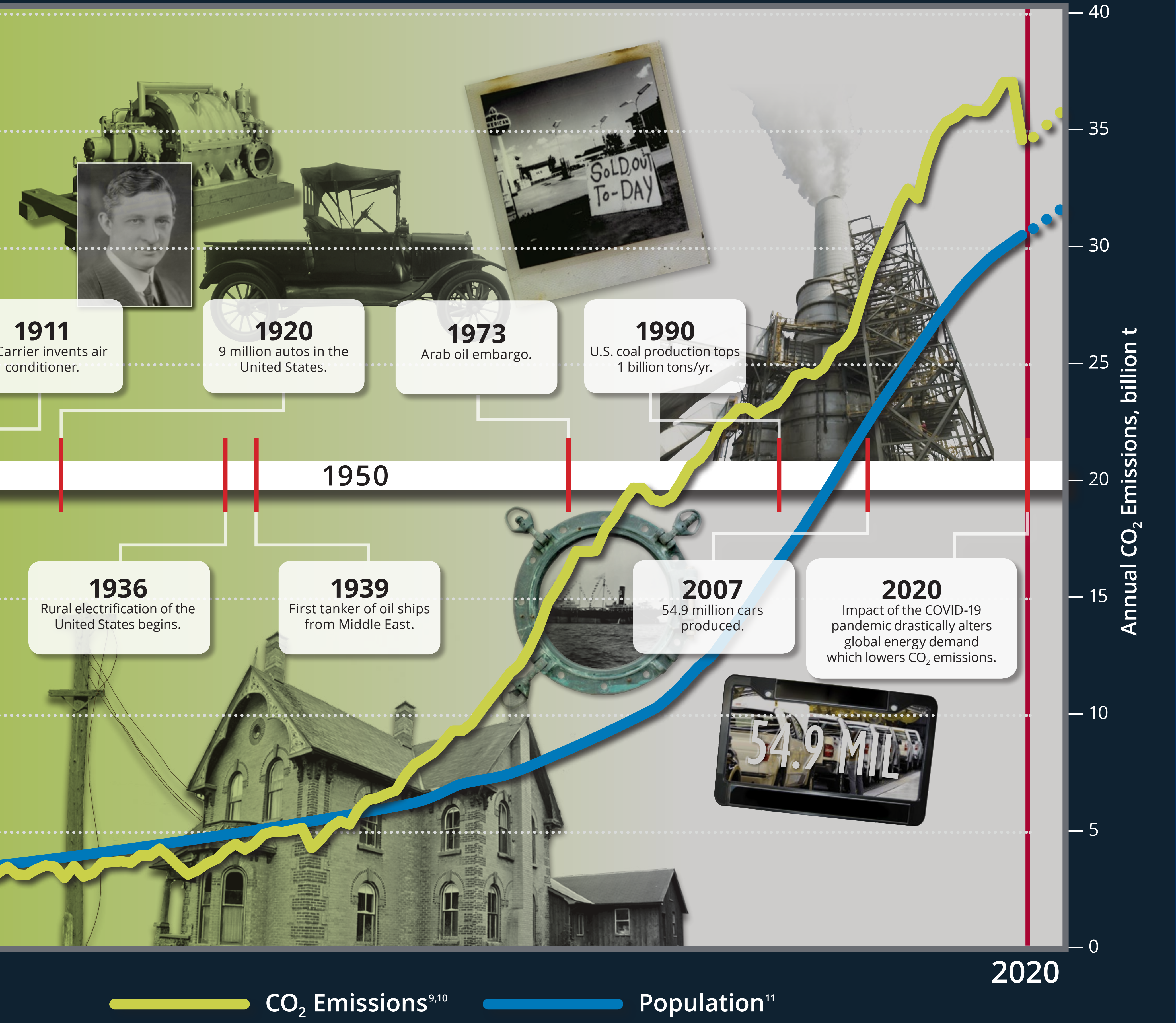


About 2.4% of CO_2 emissions in 2018 results from agricultural, land use, and forestry practices. Other GHG emissions occurred in agriculture, fugitive emissions, manufacturing and construction, waste, industry, other fuel combustion, land use changes, and forestry.

**Percentages exceed 72% because of rounding. The other category includes 3.1% industry, 1.3% other fuel combustion, and 0.5% fugitive emissions.*

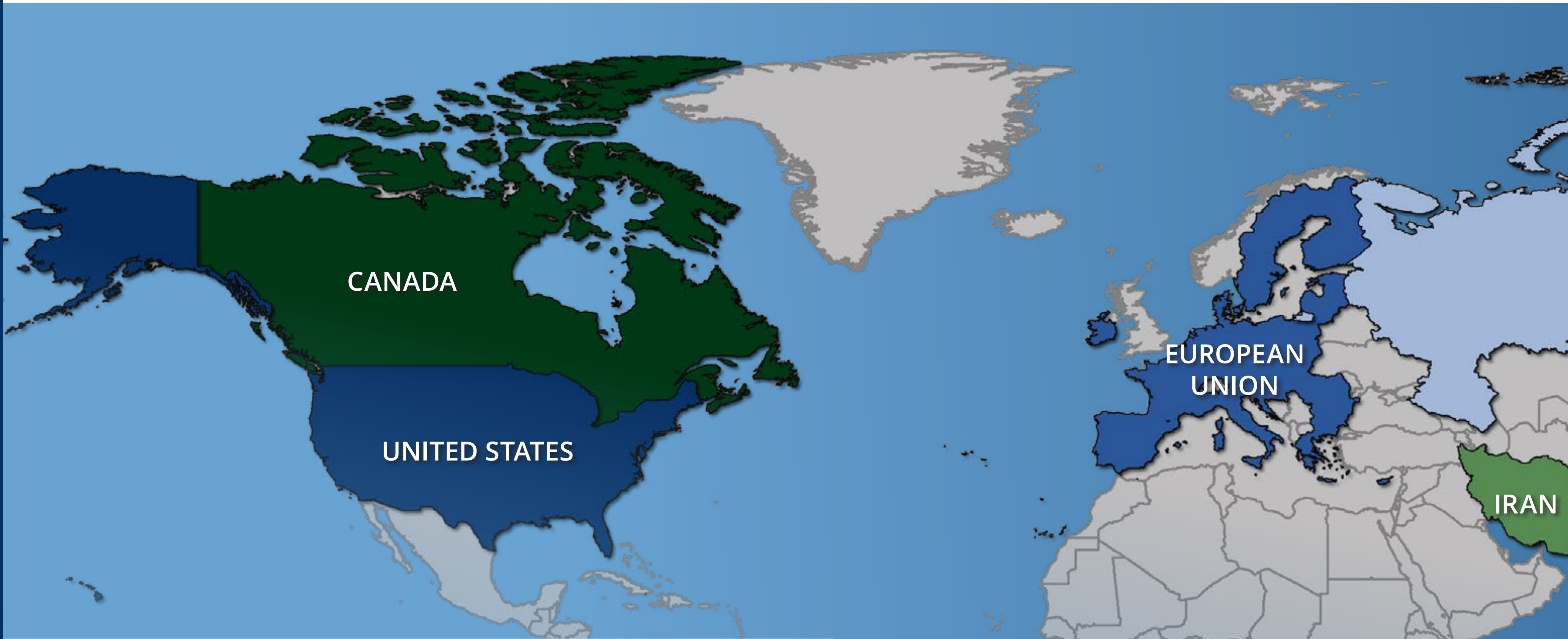


The amount of CO_2 in the atmosphere was relatively constant for 10,000 years until the Industrial Revolution in the 1800s, when the amount of anthropogenic CO_2 increased considerably. Currently, the world's economies annually emit approximately 35 Gt of CO_2 to the atmosphere from the combustion of fossil fuels to produce electricity. Increasing global populations, higher standards of living, and increased demand for energy will likely result in continued increases in global CO_2 emissions.



1911
Carrier invents air conditioner.
1920
9 million autos in the United States.
1973
Arab oil embargo.
1990
U.S. coal production tops 1 billion tons/yr.
SOLD OUT To-DAY
1950
1936
Rural electrification of the United States begins.
1939
First tanker of oil ships from Middle East.
2007
54.9 million cars produced.
2020
Impact of the COVID-19 pandemic drastically alters global energy demand which lowers CO_2 emissions.
54.9 MIL
40
35
30
25
20
15
10
5
0
Annual CO_2 Emissions, billion t
2020
CO_2 Emissions[9,10]
Population[11]

WORLD CO_2 EMISSIONS



Since 1970, global CO_2 emissions have increased nearly 150%,[12] with emissions from fossil fuel combustion and industrial processes contributing nearly 75% of the total emissions in 2018.[13] To reduce the growing impact of CO_2 emissions on climate change, policies and regulations have been developed on a national and global level.

Ten economies account for about 73% of global CO_2 from energy and industrial processes. Illustrated in the comparison, the 4.6-billion-metric-ton increase in emissions from 2008 to 2018[13] comes mainly from five of these countries, including major increases in emissions in China, India and, to a lesser extent, Indonesia as they work to modernize their economies and provide more economic opportunities for their inhabitants.

Four of the top ten emitting economies had lower CO_2 emissions in 2018 as compared to 2008. The savings from these four economies offset the 14% increase in CO_2 emissions from the rest of the world. The greatest percentages of decrease are 15% and 10% for the European Union (EU, 27 nations) and the United States, respectively.

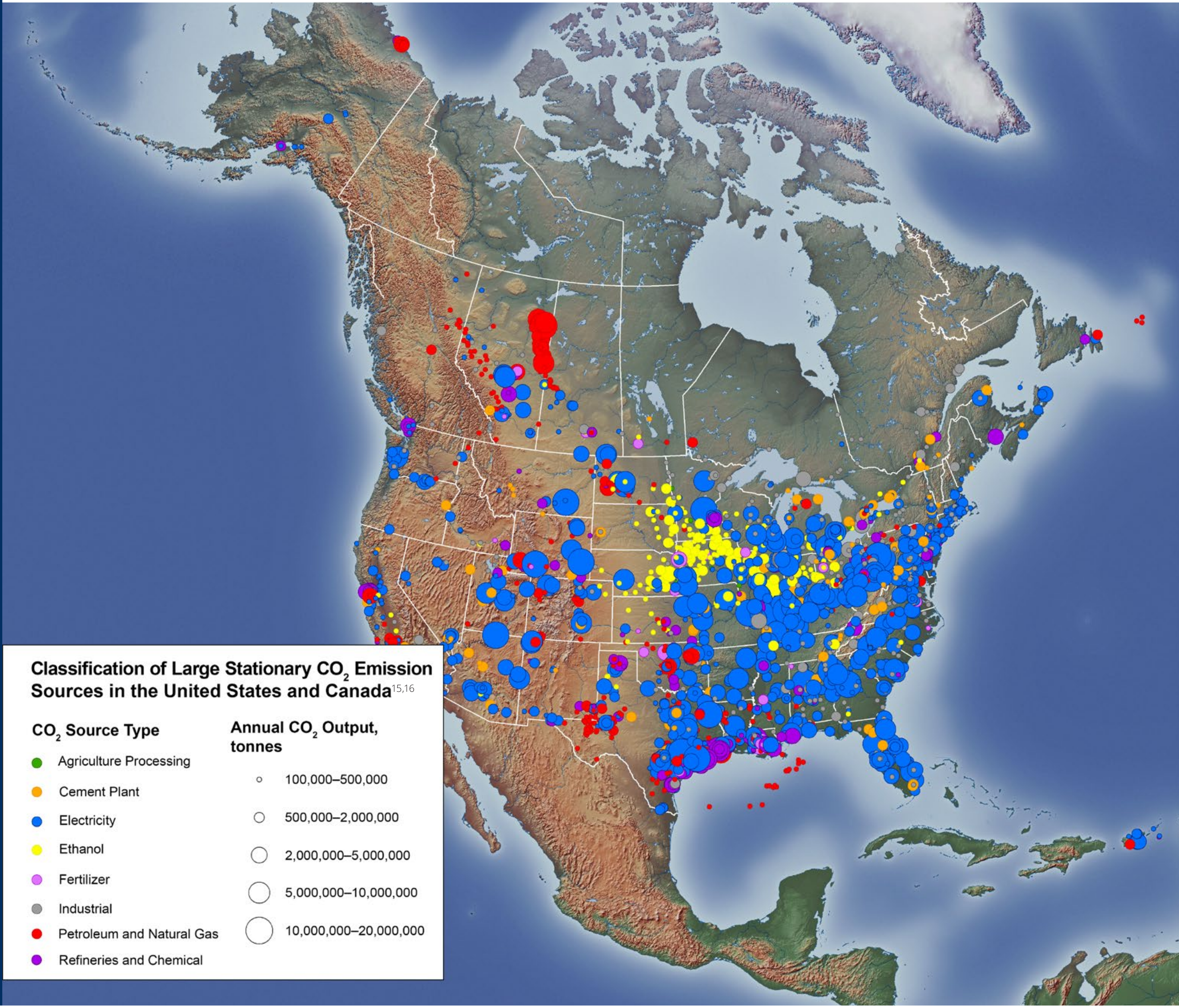
THE PERCENTAGE CHANGE OF CO_2 EMISSIONS (2008–2018)

All member countries of the United Nations Framework Convention on Climate Change (UNFCCC) agreed to adopt a new global climate agreement, named the Paris Agreement, in December 2015. This agreement aims to limit the rise in global average surface temperature to well below 2°C, and preferably below 1.5°C, compared to preindustrial levels to avoid the most dangerous impacts of climate change. The Paris Agreement requires 5-year cycles of increasing climate action to be carried out by the participating countries. As of June 2021, 192 parties have submitted their first nationally determined contributions (NDCs). The NDCs are the climate actions that each country will take to contribute to reaching the goals of the Paris Agreement. Eight parties have submitted their second.[14]

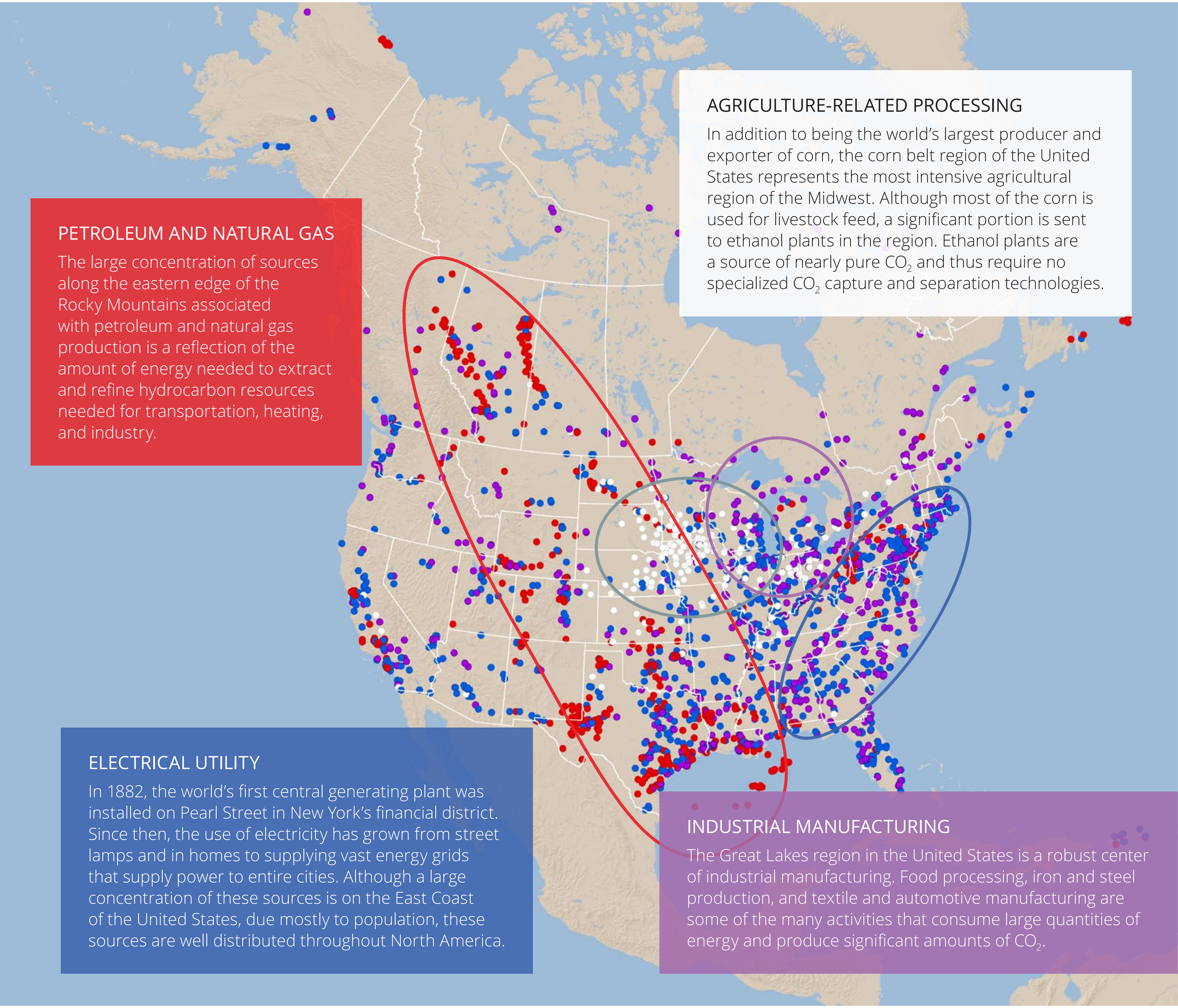
CO_2 emissions have strong ties to economic activity. Even economies with lower CO_2 emissions in 2018 may be net importers of CO_2 emissions from trade,[12] highlighting the need for a global focus on strategies to reduce emissions.

RATIO OF CO_2 EMISSIONS TO GROSS DOMESTIC PRODUCT FOR WORLD ECONOMIES (2018)

U.S. AND CANADIAN CO_2 SOURCES



U.S. AND CANADIAN PROFILE



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 intensive 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_2 and thus require no specialized CO_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.

INDUSTRIAL MANUFACTURING

The Great Lakes region in the United States is a robust center of industrial manufacturing. Food processing, iron and steel production, and textile and automotive manufacturing are some of the many activities that consume large quantities of energy and produce significant amounts of CO_2.

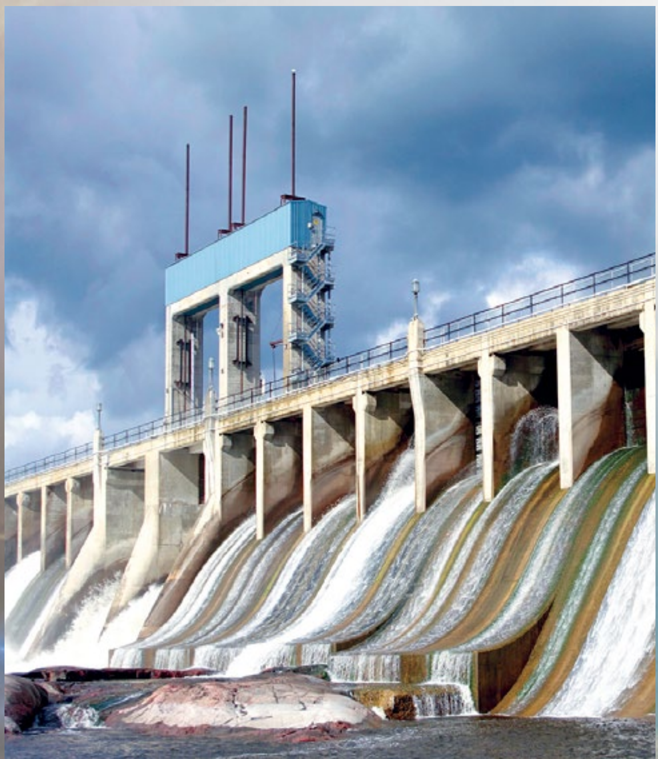
FINDING A CO_2 SOLUTION

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_2 released by human activity must be substantially reduced.

A number of techniques can be employed to reduce CO_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, CCUS provides an opportunity to combine the continued use of fossil fuels with a significant reduction in GHG emissions. CCUS 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 CCUS is developed and implemented in a practical and environmentally sound manner.

CCUS captures around 40 million metric tons of CO_2 per year worldwide, with 17 new CCUS projects coming online in 2020.[17]

Global Status of CCS Report 2020

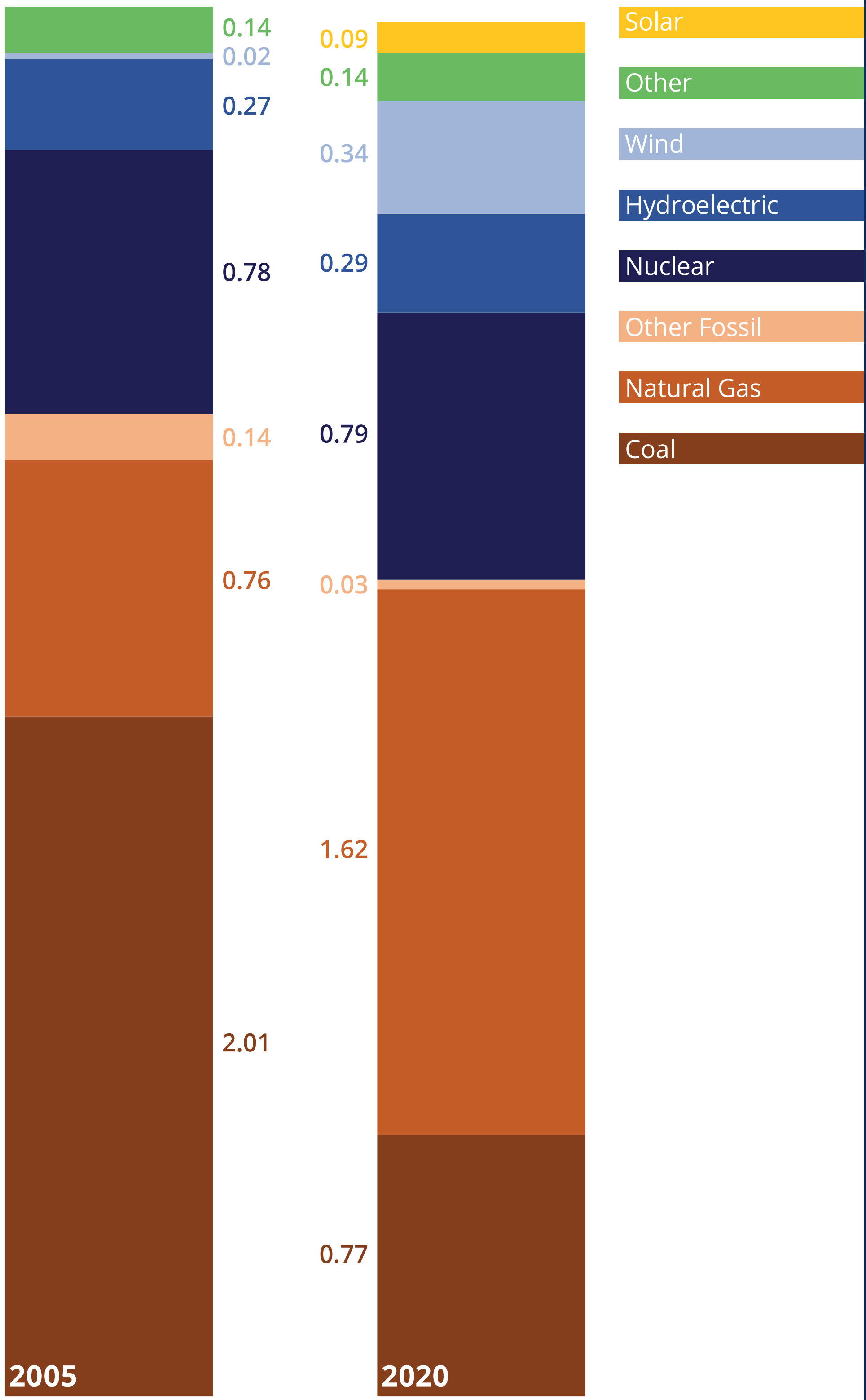


Over the past 15 years, increasing concerns over the potential impacts of climate change and increasing competition from natural gas and renewable energy sources have caused a significant shift in the U.S. energy production profile. Today coal generates about 20% of the U.S. net power generation—down from 50% in 2005. Although much of that decrease has been offset by natural gas power generation, an increasingly larger portion of power generation is coming from low-carbon renewables, such as wind and solar.

Increasing reliance on low-carbon renewable energy sources may sacrifice grid resilience and reliability. These concerns have been amplified during recent extreme weather events in the United States when much of the country was without power. A significant challenge in reducing the reliance on fossil fuels in the energy sector is to find solutions to the shortcomings of renewable energy in an economically feasible manner.

Traditional power plants equipped with CCUS technology can play an important roll to ensure that low-carbon power generation of the future can evolve without sacrificing resilience and reliability. A recent study by the International Energy Agency (IEA) concludes that when accounting for system reliability and flexibility, the competitiveness of carbon capture in the power system increases relative to other generation sources.[18] Thus CCUS-enabled power production can contribute to energy security while complementing and facilitating the increased deployment of renewables.

U.S. NET ELECTRICITY GENERATION FOR ALL SECTORS[18]
(billion MWh)



Although the total amount of electricity generated for the U.S. grid has remained relatively constant over the last 15 years, the primary energy used to generate electricity has changed dramatically. Factors in the change include the price of natural gas, tax incentives for renewables, and pressure to reduce CO_2 emissions from energy production.