"…climate change is no longer a long-term problem. We are confronted now with a global climate crisis. The point of no-return is no longer over the horizon. It is in sight and hurtling towards us." (António Guiterres, Secretary General of the United Nations, speaking to international climate negotiators in Madrid, Spain, December 1, 2019). "The climate crisis is the battle of our time, and we can win" (Al Gore, former vice president of the U.S., writing in the New York Times, Sept. 20, 2019). "Warming…will persist for centuries to millennia and will continue to cause further long-term changes in the climate system." (IPCC, 2018). "Collective efforts at all levels,…in the pursuit of limiting global warming to 1.5ºC, taking into account equity as well as effectiveness, can facilitate strengthening the global response to climate change" (IPCC, 2018).

While the impact of human activities on the climate such as fossil fuel combustion has been documented since the early 20th century, recent concern has grown due to the potential magnitude of social, environmental, and economic impacts from global climate change. The consensus on global climate change is building; it is no longer a long-term problem, but rather a modern global crisis. There is collective global awareness that significant near-term responses are needed to mitigate climate change and to minimize impacts. Organizations, from global collectives like the United Nations to our own Appalachian State University, are now presented the challenge and the opportunity to play an integral role in combating global climate change. We are an institution that values sustainability and environmental quality, and we ask ourselves: what can the University contribute to the confrontation with global climate change? What can we accomplish toward this challenge? In a problem that is clearly global in scale, slowly building global concern but lacking in cohesion, what are our obligations and the possibilities for Appalachian State University?

In order to focus our attention appropriately and to implement effective and successful strategies, we must have a keen understanding of the nature of the problem. This understanding builds a shared consensus and commitment that is embodied at the highest levels of management and is supported by the full student body. Our climate action plan needs clarity, purpose, and scope. To define our plan within the global climate change issue, we must start with a little atmospheric chemistry.

The Earth's atmosphere and the greenhouse effect

The Earth's atmosphere is composed of a mix of gasses plus a variety of fine particles and droplets. Of the gaseous components, the content of water vapor can vary from 0 to about 4%. The dry atmosphere is approximately 78% nitrogen, 21% oxygen, and 0.9% argon. The small remainder is about 400 parts per million carbon dioxide (CO_2) plus small quantities of neon, helium, methane, ozone, and other trace constituents. These percentages represent the portion of gaseous molecules in the air, not the portion of the weight of molecules. Although the fraction of CO_2 molecules may seem very small (about 400 out of every 1,000,000 gaseous molecules), the CO_2 molecules are very important to the thermal properties of the atmosphere because they absorb infrared radiation.

Of the sunlight shining on the Earth, about 29% is reflected back to space and 71% is absorbed by the atmosphere (23%) and the surface (48%). To maintain stable surface temperatures, the amount of energy that enters Earth's atmosphere must be equal to that which returns to space. Energy leaves the Earth's surface through evaporation of water, convection of air, and thermal infrared radiation. The net amount of energy leaving the surface as thermal infrared radiation amounts to about 17% of the incoming solar radiation. Incoming visible solar radiation passes through the atmosphere freely while infrared radiation is absorbed by gases such as CO_2, water vapor, and methane. These heat-absorbing gases are known as greenhouse gases; they absorb thermal infrared energy and warm the Earth's atmosphere, a phenomenon known as the greenhouse effect. Without greenhouse gases in the atmosphere, the Earth's surface would have a very cold average temperature of around -18^{O}C (-0.4°F). However, the more greenhouse gases that are concentrated in the atmosphere, the warmer the global average temperature will be. These active ingredients of the atmosphere play an important role in the energy balance of the atmosphere, even at low concentrations.

Human influences on the Earth's Atmosphere and the global climate

The chemistry of the Earth's atmosphere is changing due to natural and human processes. These changes have significant consequences. Continuous monitoring of the atmosphere since 1958 shows that the concentration of CO_2 has increased from an average of 316 parts per million in 1959 to 411 parts per million in 2019. This increase of CO_2 in the atmosphere has been directly linked to the burning of carbon-rich fossil fuels such as coal, oil, and natural gas. Equation 1 shows what happens when natural gas (methane and oxygen) is burned.

CH_4 (methane) + $2O_2 \rightarrow CO_2 + 2H_2O$ + heat (equation 1)

This burning of a fossil fuel adds both CO_2 and water vapor to the atmosphere (both are greenhouse gases). The water vapor joins the global water cycle and will return to the surface as precipitation, while some of the CO_2 continues to accumulate in the atmosphere for many years. In fact, long-term observations show that the accumulation of CO_2 in the atmosphere accounts for about half of the carbon released from fossil-fuel burning.

Carbon circulates actively on Earth in what is called the global carbon cycle, from photosynthetic uptake by plants to respiration by humans, other animals, and heterotrophic bacteria. Carbon can also be sequestered, or stored, by accumulating in soils and dissolving in the oceans. All of these processes serve to disperse the carbon that is being discharged to the atmosphere. Some of the processes, however, operate over long time frames. The net consequence of the global carbon cycle over the scale of human lifetimes is that growth of atmospheric CO_2 has been about half of the CO_2 released from combustion of fossil fuels (Figure 1 – Mauna Loa and CO_2 emissions curve). Evidence for this connection between fossil fuel combustion and increases in atmospheric CO_2 include: the spatial patterns of atmospheric CO_2 (e.g. the CO_2 concentration is higher in the Northern Hemisphere where most fossil fuels are burned); the isotopic composition of atmospheric CO_2 shows changes due to shifts in ^{12}C, ^{13}C, ^{14}C isotope ratios that align with fossil-fuel emissions; and small decreases in atmospheric oxygen content (see equation 1). This evidence assures us that the increases in atmospheric CO_2 content are a direct consequence of fossil-fuel burning.

The circulation of carbon in the global carbon cycle is complex, and it is difficult to establish an exact relationship between the discharge of CO_2 to the atmosphere and the amount of increase in atmospheric CO_2. It is also difficult to fully understand the exact relationship between an increase in atmospheric CO_2 and changes in the climate system. Nonetheless, three papers published in early 2009[1,2,3] demonstrated that mathematical models can represent this carbon-climate coupling and accurately represent the net mean temperature response of the Earth system to cumulative human-related CO_2 emissions. At time scales of decades to centuries, the increase in the Earth's mean surface temperature can be estimated from the net cumulative emissions of CO_2. This result does not depend on atmospheric CO_2 concentration or on the path of change in CO_2 emissions. Because both CO_2 concentration in the atmosphere and Earth surface temperature depend on things like the rate of the mixing of carbon and heat into the deep oceans, this simple relationship aggregates both climate feedbacks and carbon cycle feedbacks to give a robust relationship. The result of this modeling exercise is that "global mean temperature change [can] be inferred directly from cumulative carbon emissions",[2] and this is "remarkably insensitive to the emissions pathway"[3]. One estimate was that cumulative emissions of 1 trillion metric tons of carbon (1 Tt of C, or 3.7 Tt of CO_2) would raise global mean surface temperature by 1.5 ºC (1.0-2.1 ºC). The other was that 1 Tt of C emissions would lead to peak warming of 2 ºC (1.3 – 3.9 ºC). For perspective, in 2019, global CO_2 emissions were approximately 10 billion metric tons of carbon (10 Gt of C, or 37 Gt of CO_2) from fossil-fuel burning, in the addition to the CO_2 contribution from forest clearing and other greenhouse gases such as methane.

Note that temperature is not the only perturbation of the global climate system due to increased atmospheric CO_2. Climate changes driven by increasing atmospheric CO_2 will involve changes in all climate variables, from the quantities and spatial distribution patterns of rainfall, diurnal temperature patterns, the frequency of extreme events like hurricanes and heat waves, and the distribution of winds. However, change in mean Earth surface temperature is a simple metric often used as a gauge of the magnitude of climate change generally.

History of climate change policy and global emissions pathways

The bottom line is that unless human society limits the amount of CO_2 in the atmosphere, we can expect to see increasing changes in the global climate system that are largely deleterious to our society, economy, and health. The changes will be largely harmful because they represent such departures from the conditions under which human and human cultural systems have developed and become accustomed.

Figure 2 below shows the IPCC pathways of CO_2 emissions that succeed in limiting the increase in global mean surface temperature to 1.5 ^{O}C. The IPCC emphasizes that the impacts associated with a 1.5 ^{O}C temperature rise are notably less than from a 2 ^{O}C rise. In order to limit the temperature rise to 1.5 º C it is necessary that human-driven emissions are reduced soon and reduced very much, basically to zero by around 2050.

Figure 1

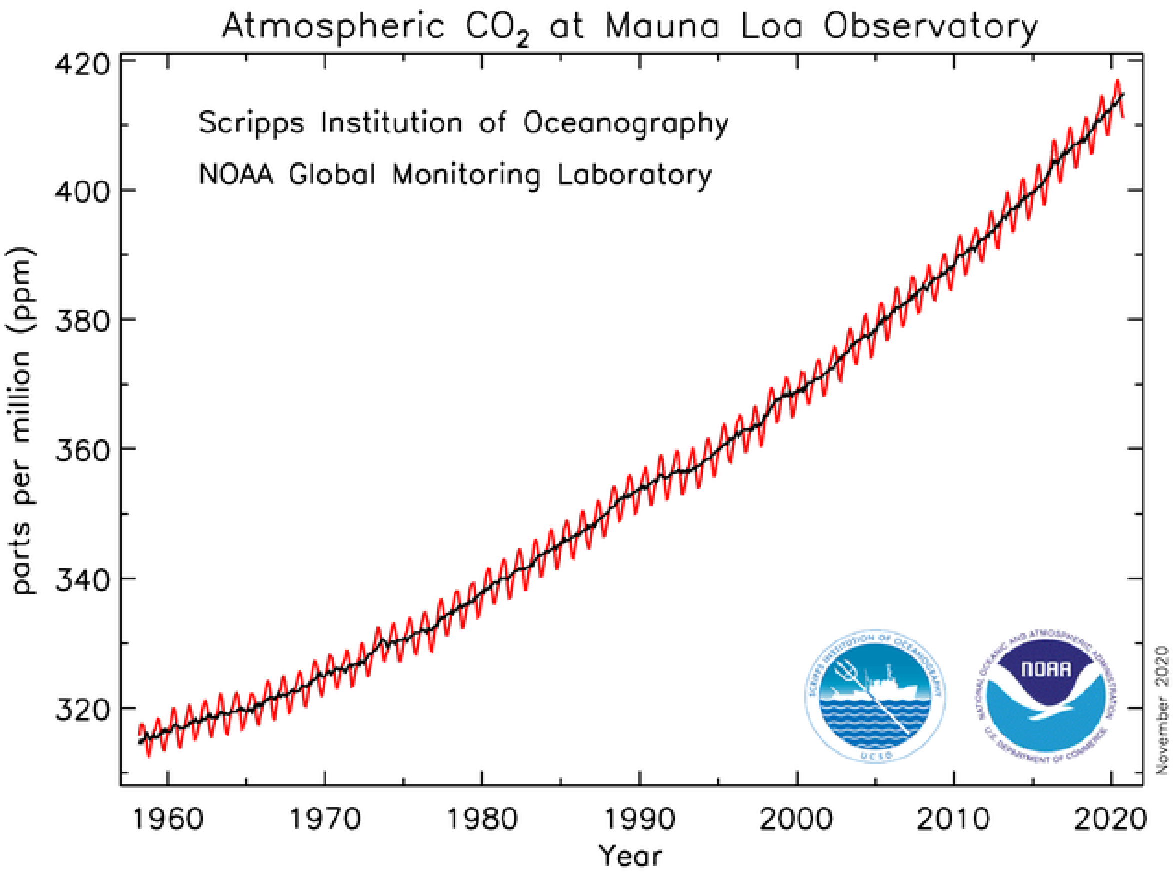
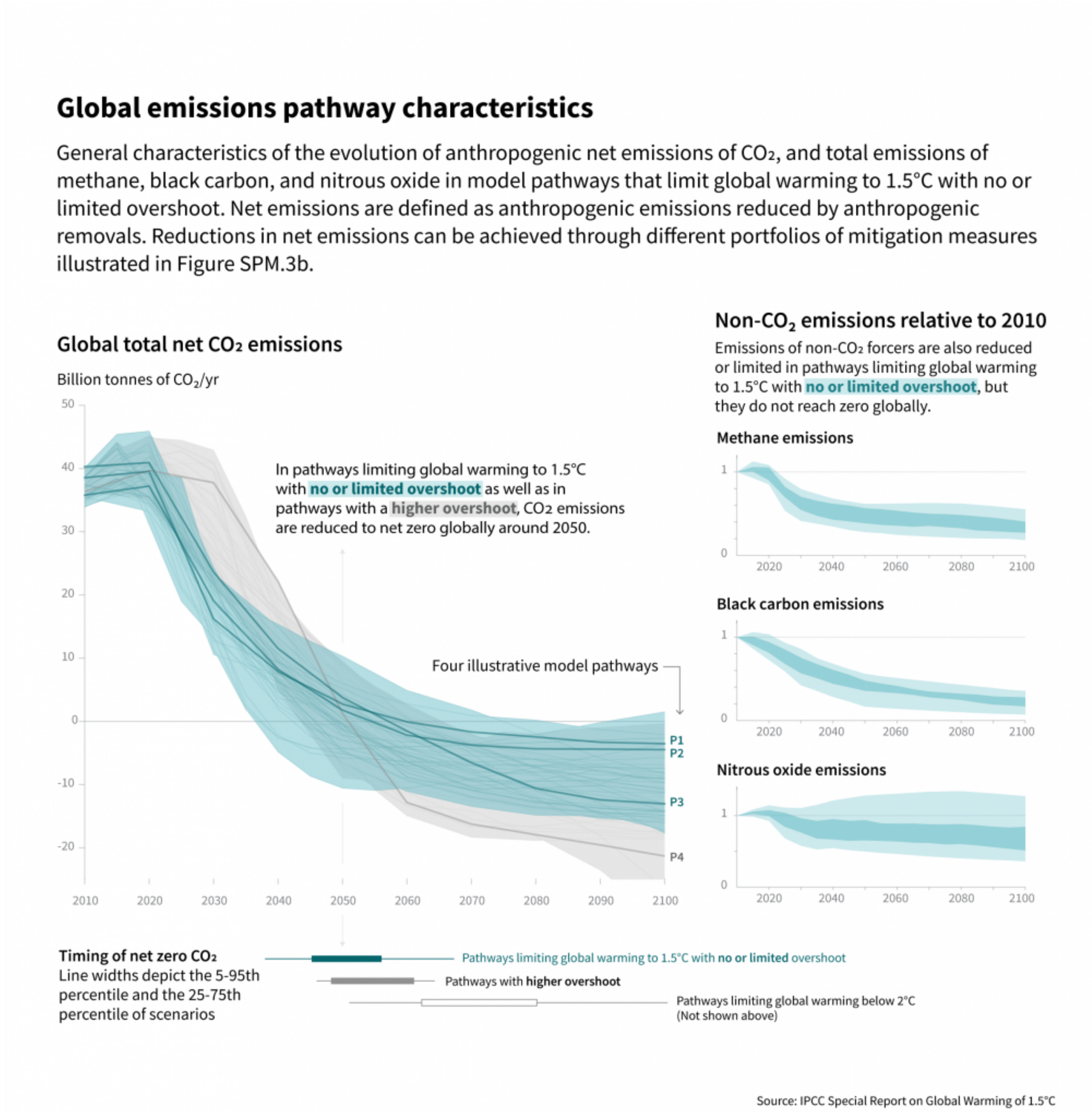

Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Global Monitoring Laboratory
parts per million (ppm)
420
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
Year
NOAA
November 2020

Figure 2



Footnotes

1.) Meinshausen et al
2.) Matthews et al.
3.) Allen et al.
4.) IPCC 1.5