An Overview of Climate Change

Updated August 10, 2021

The STEM Volunteer Program (stemvolunteers.org), a program of the American Association for the Advancement of Science, recruits STEM professionals to assist K-12 STEM teachers in their classrooms. It was initiated in 2004, and currently has around 200 volunteers assisting teachers and students in 5 school districts in the DC metropolitan area.

Climate Change is a major concern for many of our members. Several of our volunteers participated in the preparation of this overview on climate change. This document is intended for K-12 STEM teachers and their volunteers who want to introduce students to Climate Change—its consequences and issues. The document includes brief introductions to the key components and, in recognition of teachers' workloads, uses pictures, graphs, and a minimum of text.

We hope that the information can serve as a guide to better understanding for teachers, volunteers, and students. For those teachers who are using Project-Based Learning or something similar to engage students in an extended investigation to solve a real-world problem, we include a list of driving questions that could be part of a project exploring climate change at the end of the overview.

Thanks for reading this overview. If you have questions or comments, please contact donaldrea@aol.com.

Donald Rea, Leader, AAAS STEM Volunteer Program

Environmental Changes

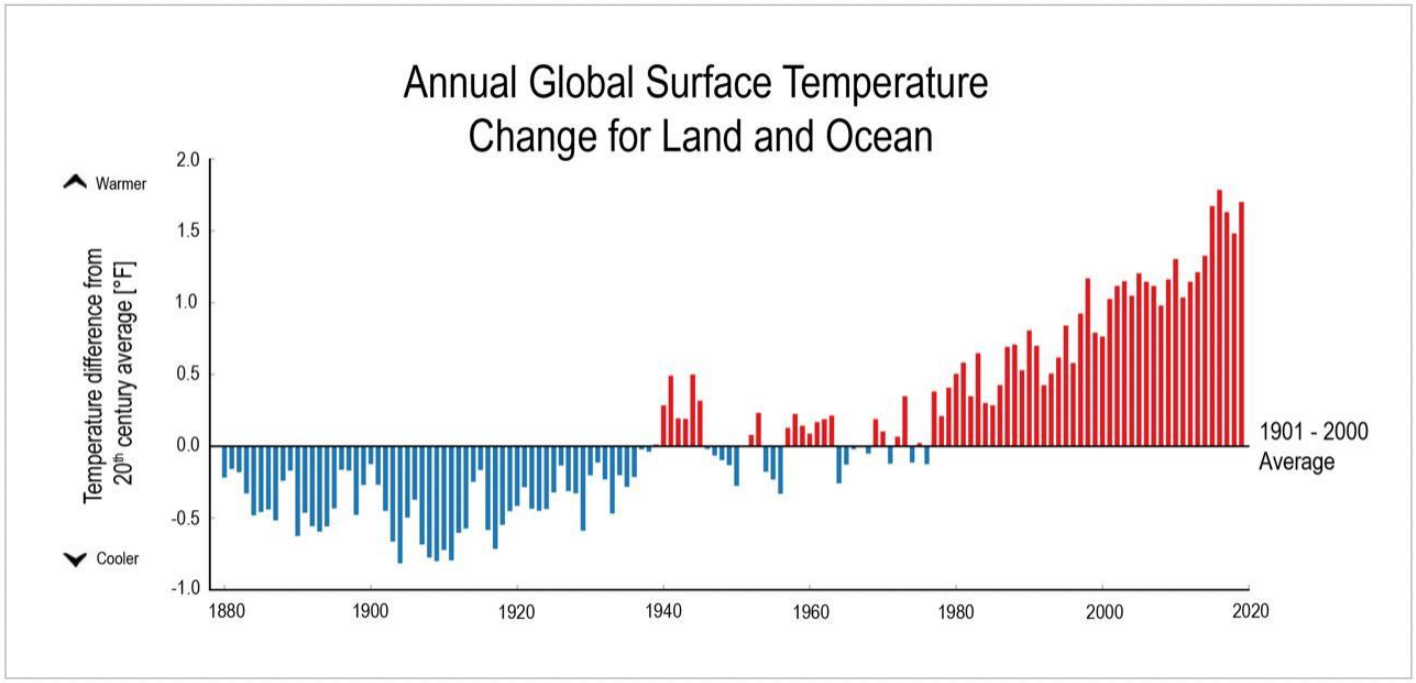
From the Fourth National Climate Assessment:

- Global annually averaged temperature measured over both land and oceans has increased by about 1.8°F (1.0°C) according to a linear trend from 1901 to 2016, and by 1.2°F (0.65°C) for the period 1986–2015 as compared to 1901–1960.
- The last few years have also seen record-breaking, climate-related weather extremes. For example, since the Third National Climate Assessment was published,[1] 2014 became the warmest year on record globally; 2015 surpassed 2014 by a wide margin; and 2016 surpassed 2015.[2,3]
- Sixteen of the last 17 years have been the warmest ever recorded by human observations.

Source: https://nca2018.globalchange.gov

The Earth's atmosphere and oceans are warming.

The Earth's climate and ecosystems are responding to this warming of the atmosphere and oceans.



Source: https://www.globalchange.gov/browse/indicators/indicator-global-surface-temperatures

Heat records are being broken.

“July 2019 was Earth's hottest month in 140 years of recordkeeping,” according to a just-released analysis from NOAA.

The agency said that global average temperatures across all land and ocean surfaces in July 2019 were the highest of any month in its database, which extends back to 1880.

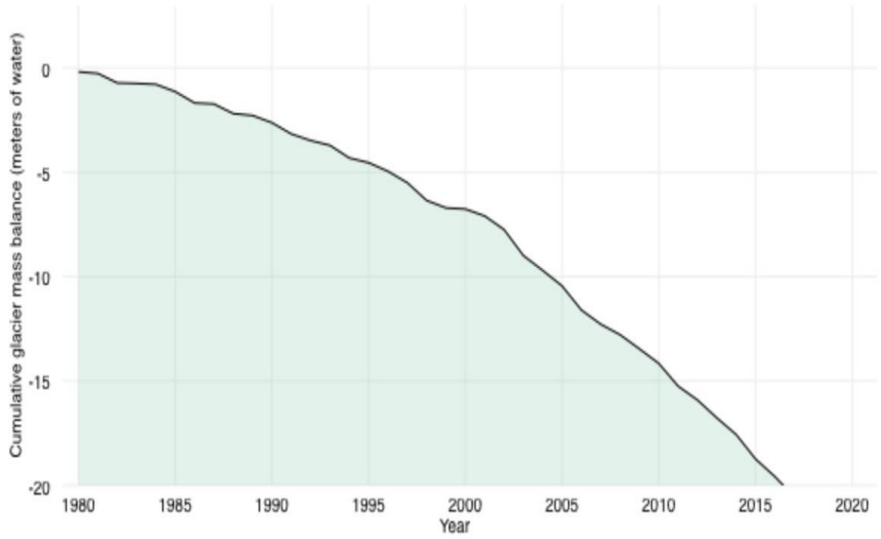
July 2019’s global average temperature was 1.71 degrees Fahrenheit above the 20th-century average of 60.4 degrees. That topped July 2016, the previous all-time-hottest month, by 0.05 degrees.

Source: https://weather.com/news/climate/news/2019-08-15-july-earths-hottest-month-record-noaa-stateof-climate-report

Glaciers around the world are receding.

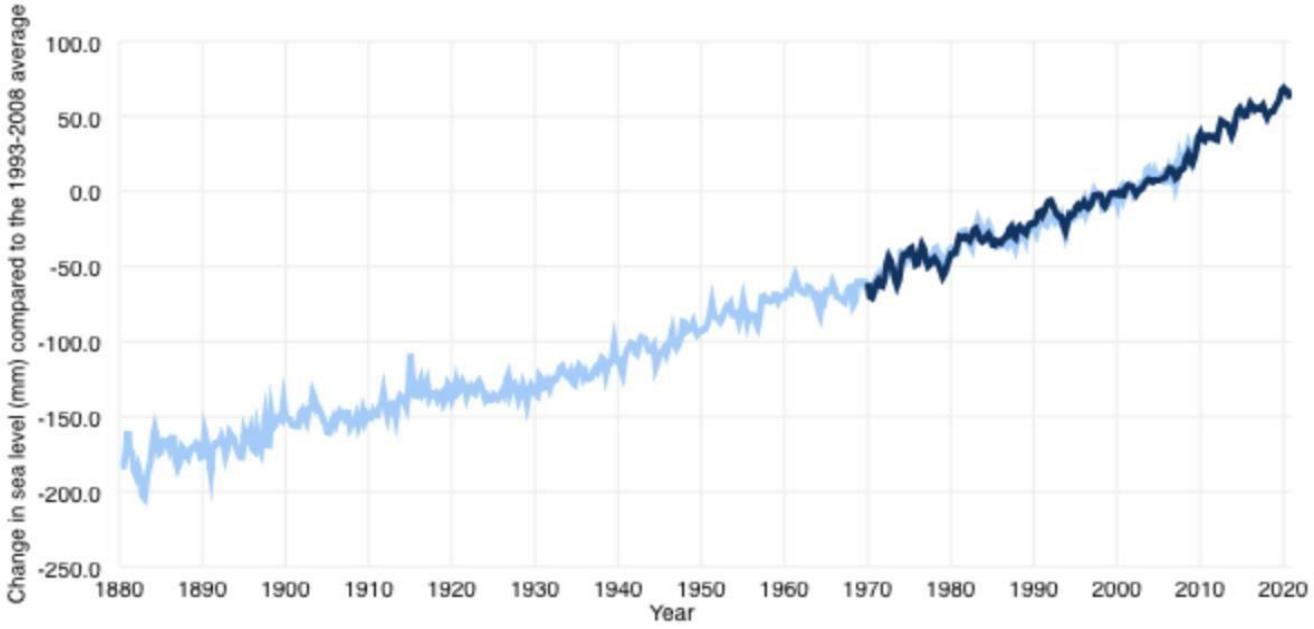
Among the most dramatic evidence that Earth's climate is warming is the dwindling and disappearance of mountain glaciers around the world. Based on preliminary data, 2018 is likely to be the 30th year in a row of mass loss of mountain glaciers worldwide. According to the *State of the Climate in 2018,*

> The cumulative mass balance from 1980 to 2018 is −21.7 m, the equivalent of cutting a 24-m [79-foot] thick slice off the top of the average glacier.



Source: https://www.climate.gov/news-features/understanding-climate/climate-change-glacier-mass-balance

Sea level is rising around the world.



Source: https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

Arctic sea ice extent is at a record low.

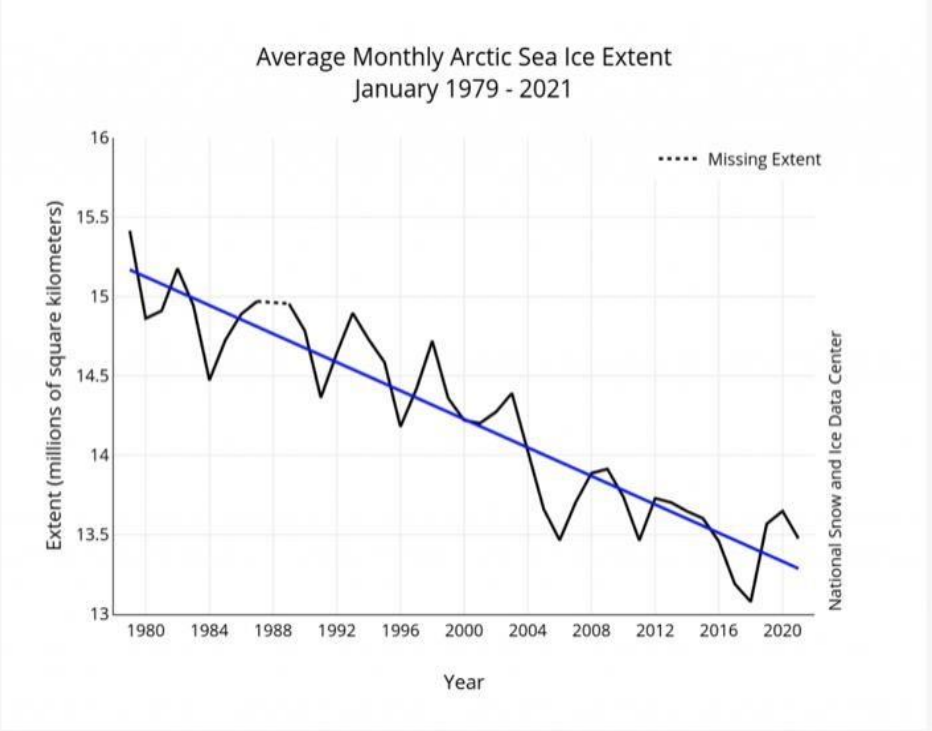
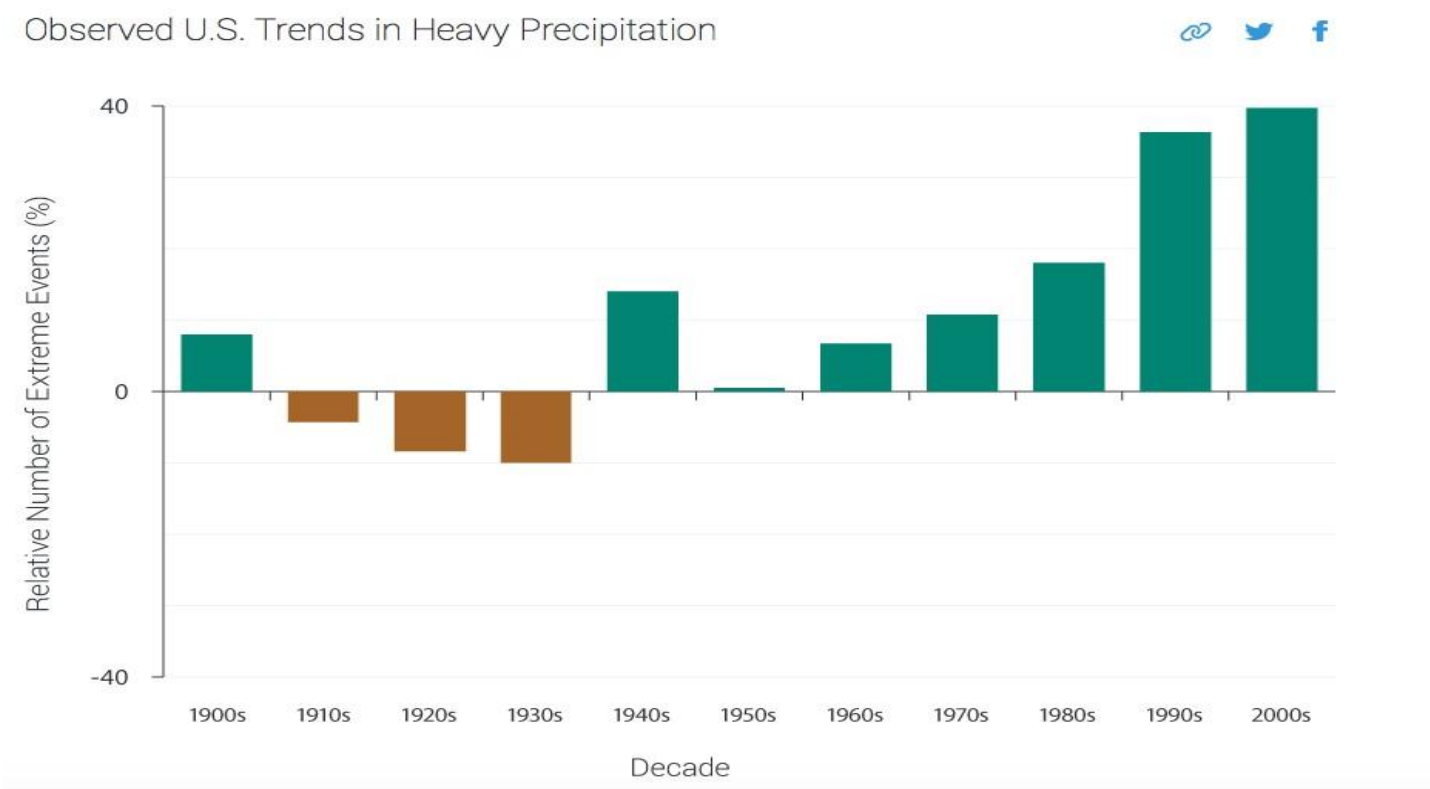


Figure 3. Monthly January ice extent for 1979 to 2021 shows a decline of 3.1 percent per decade.

Credit: National Snow and Ice Data Center

High-resolution image

Heavy precipitation is increasing.



Credit: Figure adapted from article in Bulletin of the American Meteorological Society. See caption for details.

Source: http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather

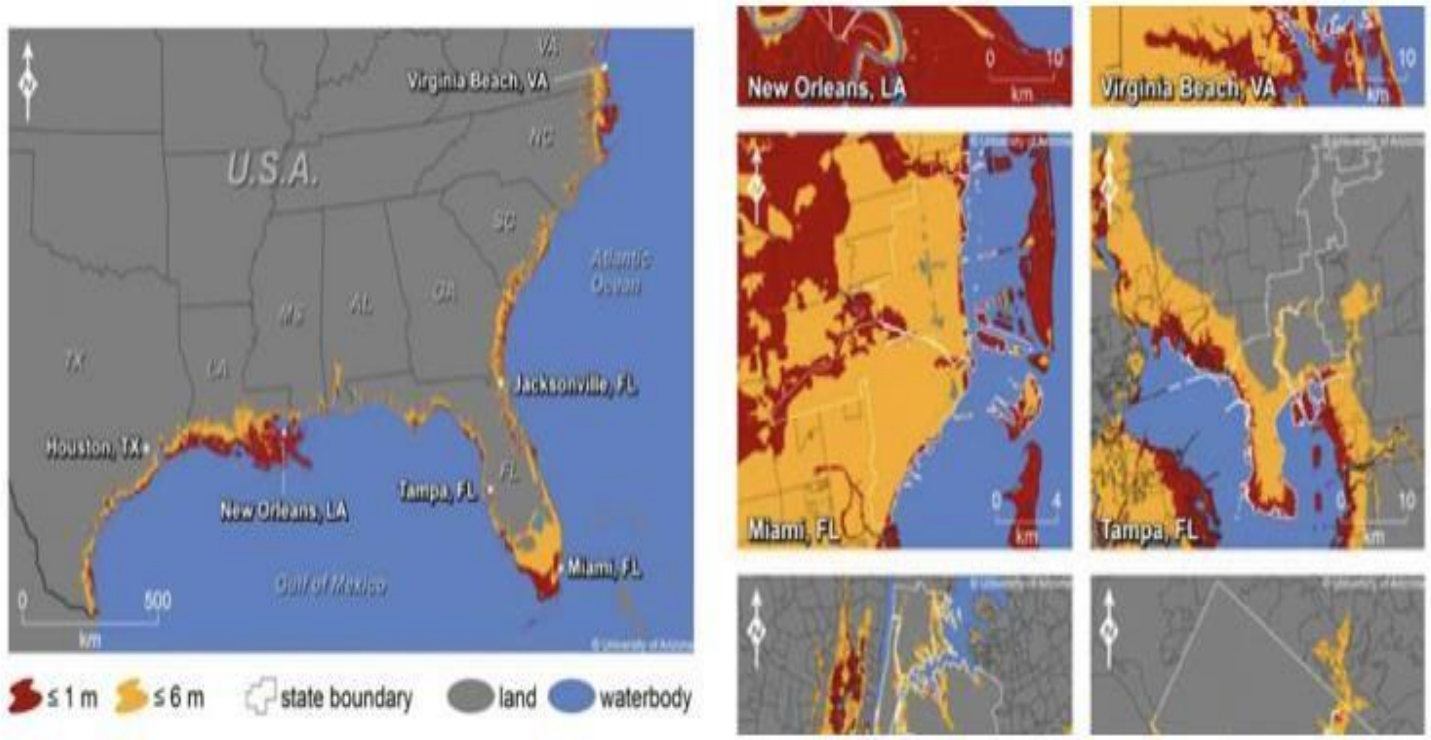
There is a megadrought in the U. S. southwest.

A “megadrought” gripping the western United States is the worst one in 500 years, scientists say. And it’s the first to be influenced by human-caused climate change.

A study published in the 17 April 2020 edition of *Science* investigates the occurrence of megadroughts in western North America over the last 1,200 years. While a megadrought has no strict scientific definition, most studies classify them as severe droughts typically lasting a couple of decades at least—longer than any drought event that occurred during the 20th century.

Source: https://www.scientificamerican.com/article/climate-change-has-helped-fuel-a-megadrought-in-thesouthwest/

The increase of the sea level will result in flooding of coastal areas.



Source: https://news.arizona.edu/story/rising-seas-will-affect-major-u-s-coastal-cities-by-2100

There are unprecedented temperatures, leading to disastrous forest fires.

'Unprecedented': the US west's wildfire catastrophe explained

The climate crisis and fire suppression underlie the disaster. Addressing it means altering society's relationship to the land

▲ The Bobcat Fire makes a run up a mountainside in the Angeles national forest on Thursday. Photograph: David McNew/Getty Images

The historic wildfires that have seized the west are delivering a dire message: the climate crisis and decades of bad environmental policies have unleashed deadly consequences.

Source: https://www.theguardian.com/us-news/2020/sep/12/california-oregon-washington-fires-explainedclimate-change

Climate change is making hurricanes more dangerous.

Hurricane Florence on September 12, 2018 as seen from the International Space Station. (Credit: NASA)

Source: https://yaleclimateconnections.org/2019/07/how-climate-change-is-making-hurricanes-moredangerous/?gclid=CjwKCAjwzIH7BRAbEiwAoDxxTpH3RMQdagXSff17qq38o7UKdoBWZnwJ8spHMZ2Fs95yYods aWTbHBoCcFMQAvD_BwE

Scientific Explanations

The changes in the environment and climate are due to increasing emissions of **greenhouse gases**, primarily carbon dioxide. The gases are called greenhouse gases because they trap heat in the atmosphere just like a greenhouse traps heat. But the heating mechanisms differ. For a conventional greenhouse, the heat transfer mechanisms are conduction and convection, while the mechanism for Earth is radiation.

How does a greenhouse work? The sun's radiation comes in through the glass roof of the greenhouse and heats the ground and vegetation which heat the air on contact. The hot air rises but is trapped by the glass. The result is heating of the greenhouse above the outside temperature.

Source: Botanical Gardens, V.L. Komarov Botanical Institute, obtained from https://en.wikipedia.org/wiki/Greenhouse

The Greenhouse Effect: How Greenhouse Gases Work to Keep the Earth Warm

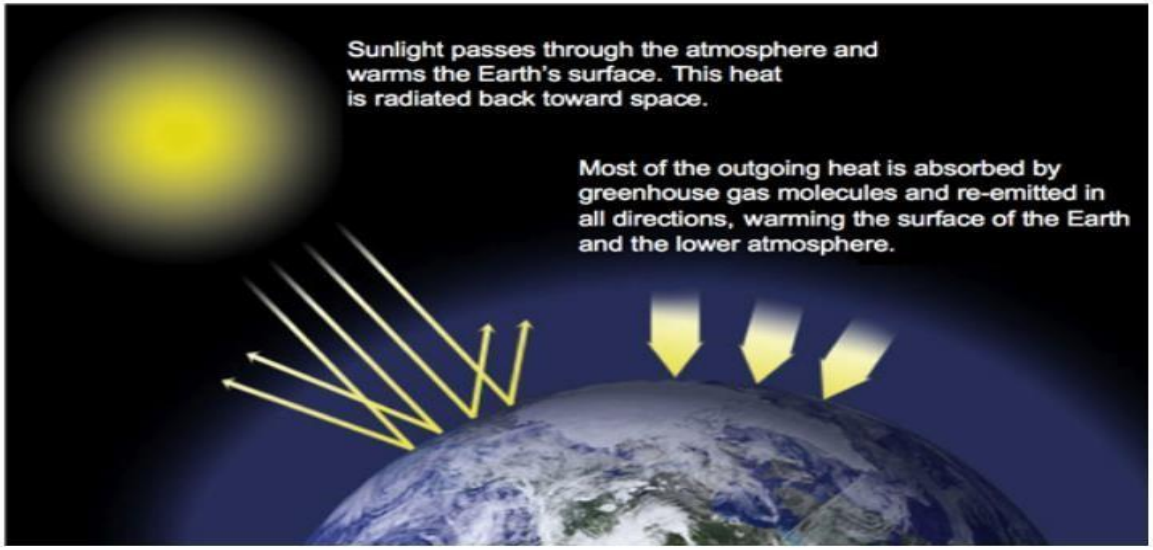
The **greenhouse effect** is the trapping of heat by gases in the earth's atmosphere.

- Earth has naturally occurring greenhouse gases.
- These naturally occurring greenhouse gases are primarily water vapor, carbon dioxide, plus to a lesser extent, methane, and nitrous oxides.
- The Earth's naturally occurring greenhouse gases work much like the glass roof on a greenhouse.
- These greenhouses gases keep Earth warm because:

1. The heat from the sun's *short wave radiation* can come in through the atmosphere.
2. The *long wave infrared radiation* (heat) from the ground and plants is trapped by the greenhouses gases and keeps us warm, keeping Earth at temperatures that are comfortable for animal and plant life.
3. Without these greenhouse gases, Earth's temperature would be about the same as on the Moon, or an average temperature of near 0°F or -18°C. The actual surface temperature is about 15°C or 59°F.

Life on Earth depends on energy coming from the sun.

About half the light reaching Earth's atmosphere passes through the air and clouds to the surface, where it is absorbed and then radiated upward in the form of infrared heat. About 90% of this heat is then absorbed by the greenhouse gases and radiated back toward the surface, which is warmed to a life-supporting average of 59 degrees Fahrenheit (15 degrees Celsius).



A layer of greenhouse gases – primarily water vapor, and including much smaller amounts of carbon dioxide, methane and nitrous oxide – acts as a thermal blanket for the Earth, absorbing heat and warming the surface to a life-supporting average of 59 degrees Fahrenheit (15 degrees Celsius).

Source: Global Climate Change: Vital Signs of the Planet, https://climate.nasa.gov/causes

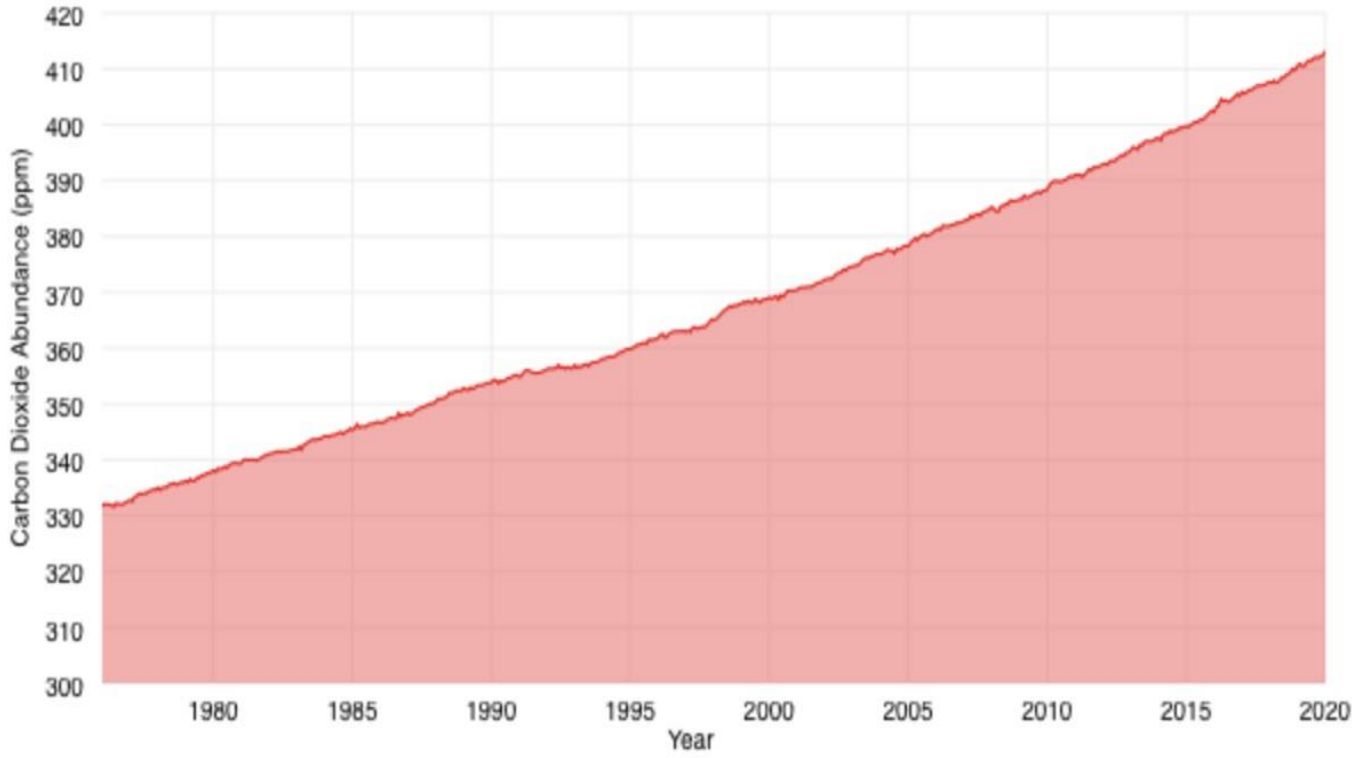
The Greenhouse Effect: Too Much of a Good Thing

The increase of Earth's temperature is primarily due to increasing concentrations of carbon dioxide in the atmosphere.

Greenhouse gases are primarily carbon dioxide, and to a lesser extent methane and other gases.

Earth's greenhouse gas increases are primarily due to human activities.

Atmospheric CO2 is steadily increasing.



Source: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbondioxide

Global methane emissions are increasing.

In her July 14, 2020 NY Times article, climate reporter Hiroko Tabuchi reports the following:

Global emissions of methane, a potent greenhouse gas, soared to a record high in 2017, the most recent year for which worldwide data are available, researchers said… .

…they warned that the rise — driven by fossil fuel leaks and agriculture — would most certainly continue despite the economic slowdown from the coronavirus crisis, which is bad news for efforts to limit global warming and its grave effects.

The latest findings, published on Tuesday [15 July 2020] in two scientific journals, underscore how methane presents a growing threat, even as the world finds some success in reining in carbon dioxide emissions, the most abundant greenhouse gas and the main cause of global warning.

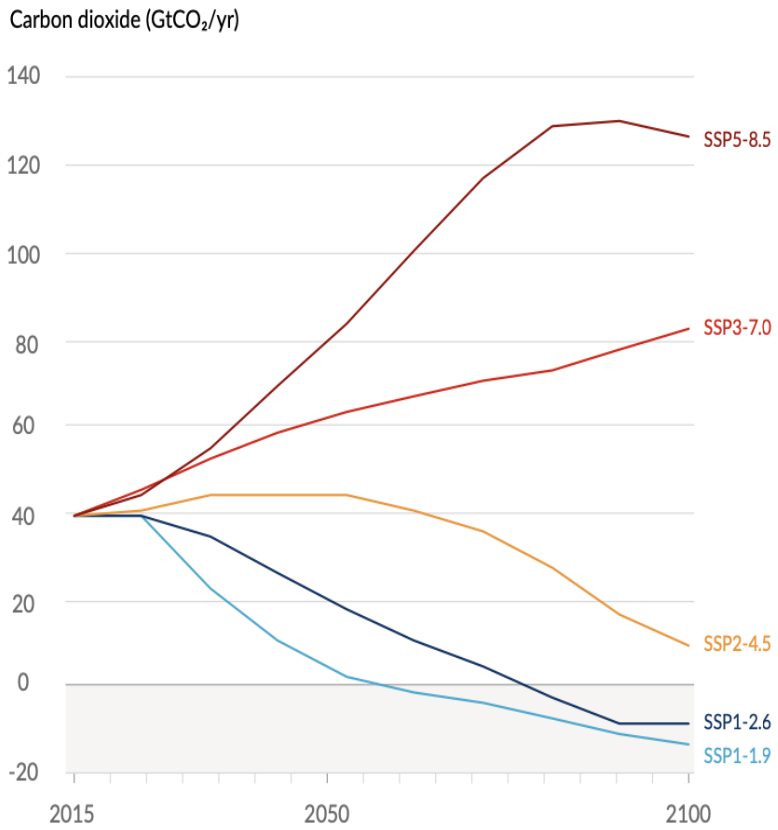
Source: https://www.nytimes.com/2020/07/14/climate/methane-emissions-record.html

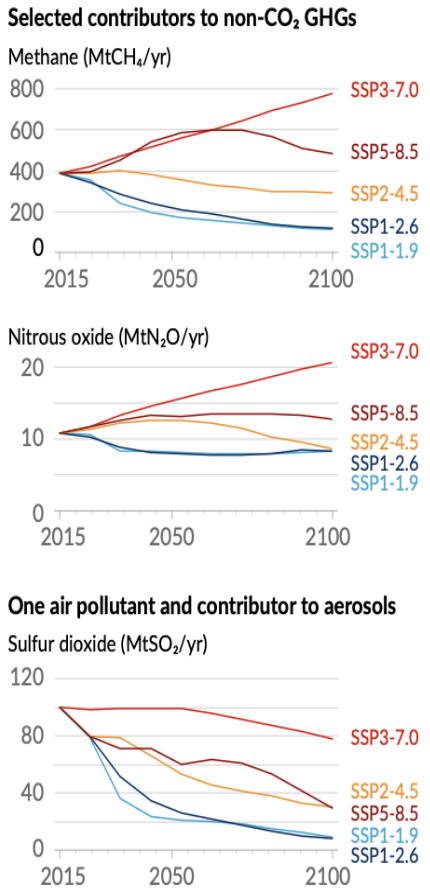
The Greenhouse Effect: Outlook for the Future

Climate Models are based on the mathematical equations that represent the laws of Earth's physics, chemistry and biology. Models can evaluate and isolate the specific causes of climate change and can explore the consequences of different scenarios of future greenhouse gas emissions, aerosol emissions, changes in land use, and other influences on climate. Models can replicate the major events of the industrial age climate, including the gradual warming as greenhouse gases have been emitted, the transient cooling effects of volcanoes, etc. Studying how climate responded to major changes in the past is a major way of checking that we understand how different processes work and that models are capable of performing accurately under a wide range of conditions.

Scenarios for predicted greenhouse gas increases:

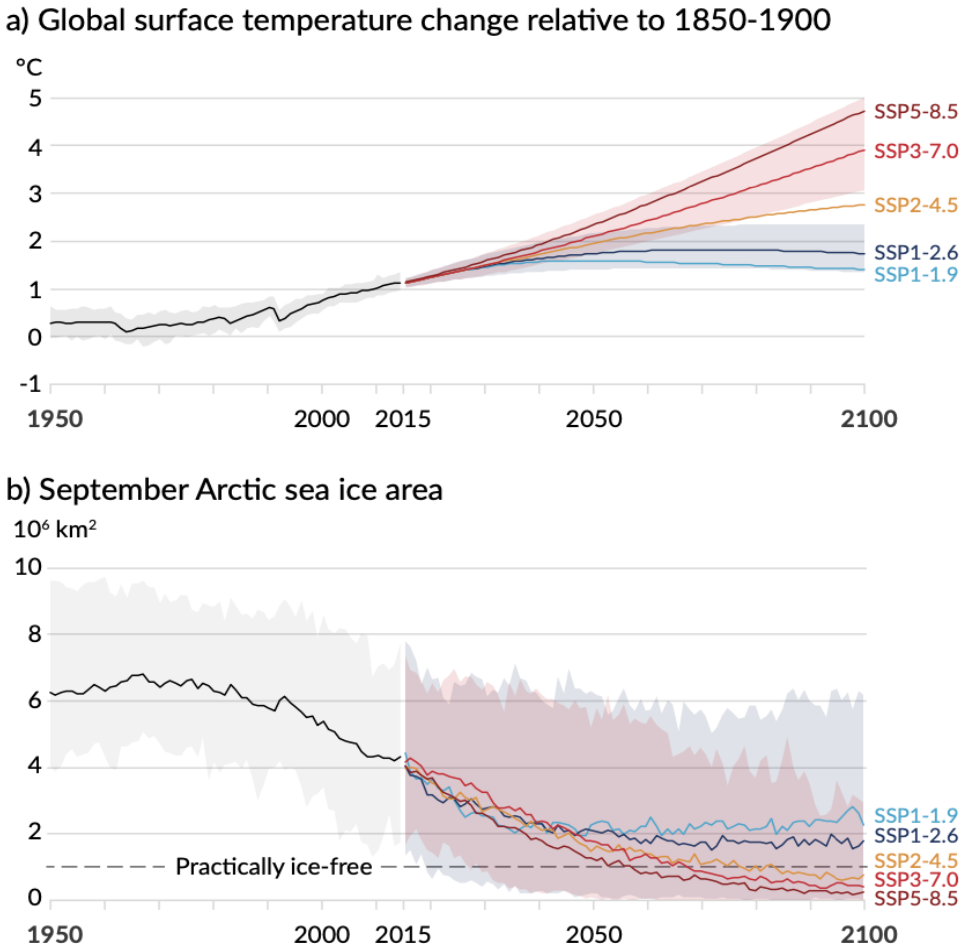
This report assesses the climate response to five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. They start in 2015 and include scenarios with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO2 emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO2 emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions (SSP1-1.9 and SSP1-2.6) as illustrated in the following figure. Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls. Alternative assumptions may result in similar emissions and climate responses, but the socio-economic assumptions and the feasibility or likelihood of individual scenarios is not part of the assessment.

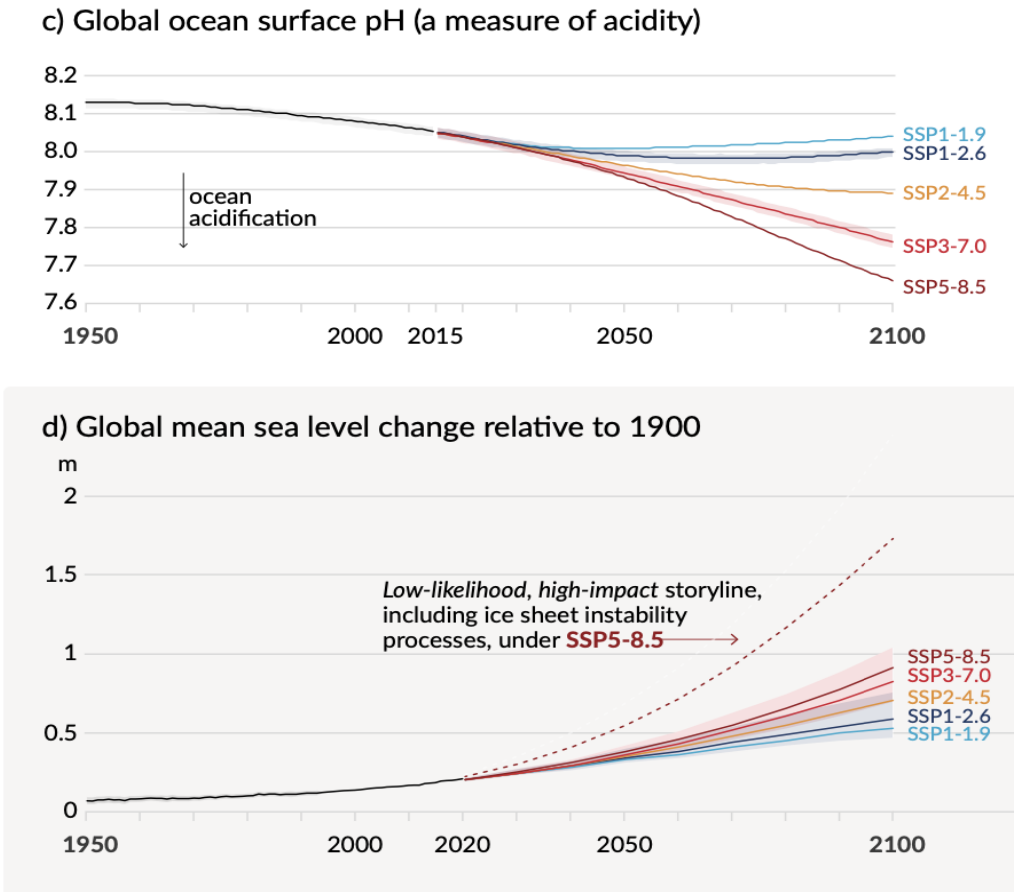




Source: https://www.ipcc.ch

Human activities affect all the major climate system components, with some responding over decades and others over centuries.





Source: https://www.ipcc.ch

Scientific Concerns: Tipping Points that Change Earth's Climate in Unpredictable Ways

A *tipping point* refers to the concept that very small inputs can sometimes cause a large change in something. A simple tipping point example is an airplane flying. Here the tipping point is a flight speed smaller than the stall speed. As long as the airplane flies faster than the stall speed of the wing the airflow over the wing stays smooth, lift is produced, and the airplane keeps flying. However, if the airplane slows slightly to just below the stall speed, the air flow becomes turbulent, the wing loses lift, and the airplane starts to fall out of the sky.

The science of tipping point global warming impacts:

- Tipping points are poorly understood, except to know that they often occur in nature.
- It is often extremely difficult to accommodate or reverse tipping points.
- This is a great worry to scientists.

Examples of tipping points are:

- the release of methane from melting permafrost in the northern hemisphere,
- the meltdown of Greenland's ice sheet is speeding up, and
- the melting of Antarctic glaciers resulting from the disappearance of the protecting ice shelves.

A Permafrost Tipping Point in the Northern Hemisphere

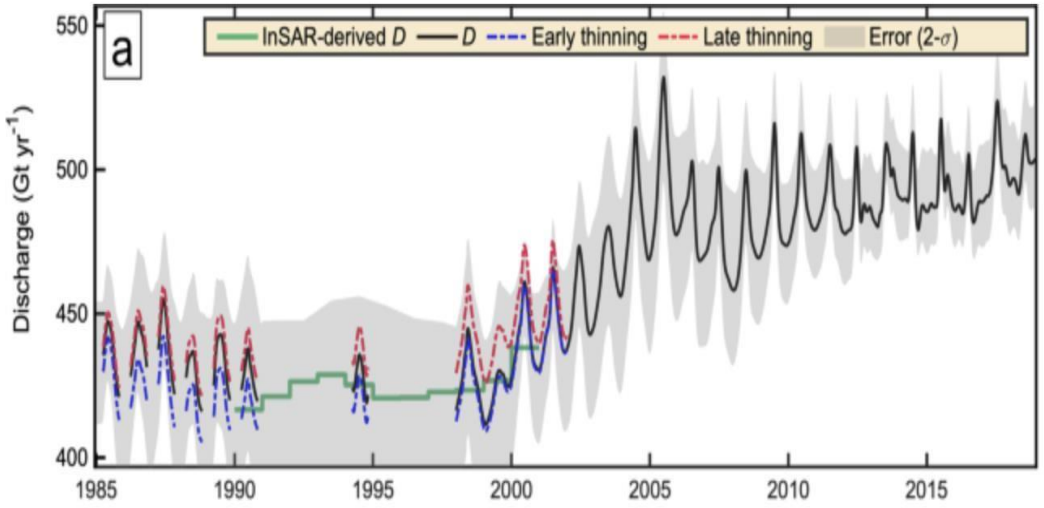
The tipping point for this process is the freezing point (0°C) of permafrost in the northern hemisphere. Permafrost is land that has been frozen stretching back to the last ice age, 10,000 years ago. As the Arctic warms at twice the global rate, the frozen soils thaw and decompose, releasing the trapped greenhouse gases into the air. Scientists estimate that the world's permafrost holds twice as much carbon as the atmosphere.

If the permafrost melts, the methane that was previously held is released, and bacteria within the permafrost generate more methane, which is a strong greenhouse gas. It is estimated that permafrost contains 1,400 billion tons of carbon; Earth's atmosphere today contains 850 billion tons of methane.

Dynamic ice loss from the Greenland Ice Sheet is driven by sustained glacier retreat.

The Greenland Ice Sheet is losing mass at accelerated rates in the 21st century, making it the largest single contributor to rising sea levels. There is a step-increase in decadal-scale ice discharge (Fig. 1a), with a ~60 Gt yr^{-1}, or 14%, increase between 1985–1999 and 2007–2018 means. After reaching a temporally local maximum in 2005, annual *D* then temporarily decreased for 3 years. Following the temporary decline, discharge accelerated again at a slower pace of 2 Gt yr^{-2} during 2008–2018, reaching a peak annual value of 502 ± 9 Gt yr^{-1} in 2017 and 2018, or 17% above the 1980's average.

Fig. 1: Net ice sheet discharge at contributions to total mass balance.



Source: https://www.nature.com/articles/s43247-020-0001-2

The Antarctica is being impacted by climate change.

Polar Warning: Even Antarctica's Coldest Region Is Starting to Melt

East Antarctica is the coldest spot on earth, long thought to be untouched by warming. But now the glaciers and ice shelves in this frigid region are showing signs of melting, a development that portends dramatic rises in sea levels this century and beyond.

BY NICOLA JONES · MARCH 28, 2019

Source: https://e360.yale.edu/features/polar-warning-even-antarctica-coldest-region-is-starting-to-melt
Also: https://www.nytimes.com/interactive/2020/04/30/climate/antarctica-ice-climate-change.html

The pole, home to a United States research base in the high, icy emptiness of the Antarctic interior, warmed by about 0.6 degrees Celsius, or 1.1 degrees Fahrenheit, per decade over the past 30 years, the researchers reported in a paper published in Nature Climate Change. The global average over that time was about 0.2 degrees Celsius per decade.

Source: https://www.nytimes.com/2020/06/29/climate/south-pole-warming-climate-change.html?searchResultPosition=1

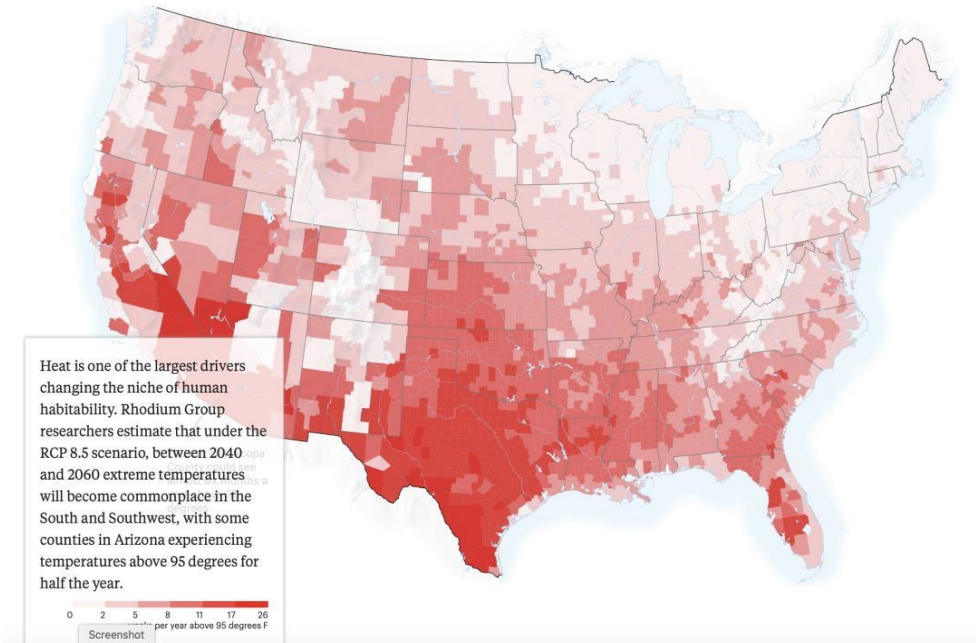
Ice Sheet Melting Is Perfectly in Line with Our Worst-Case Scenario, Scientists Warn

The Greenland and Antarctic ice sheets, which hold enough frozen water to lift oceans 65 metres, are tracking the UN's worst-case scenarios for sea level rise, researchers said, highlighting flaws in current climate change models.

Mass loss from 2007 to 2017 due to melt-water and crumbling ice aligned almost perfectly with the Intergovernmental Panel for Climate Change's (IPCC) most extreme forecasts, which see the two ice sheets adding up to 40 centimetres (nearly 16 inches) to global oceans by 2100, they reported in *Nature Climate Change*.

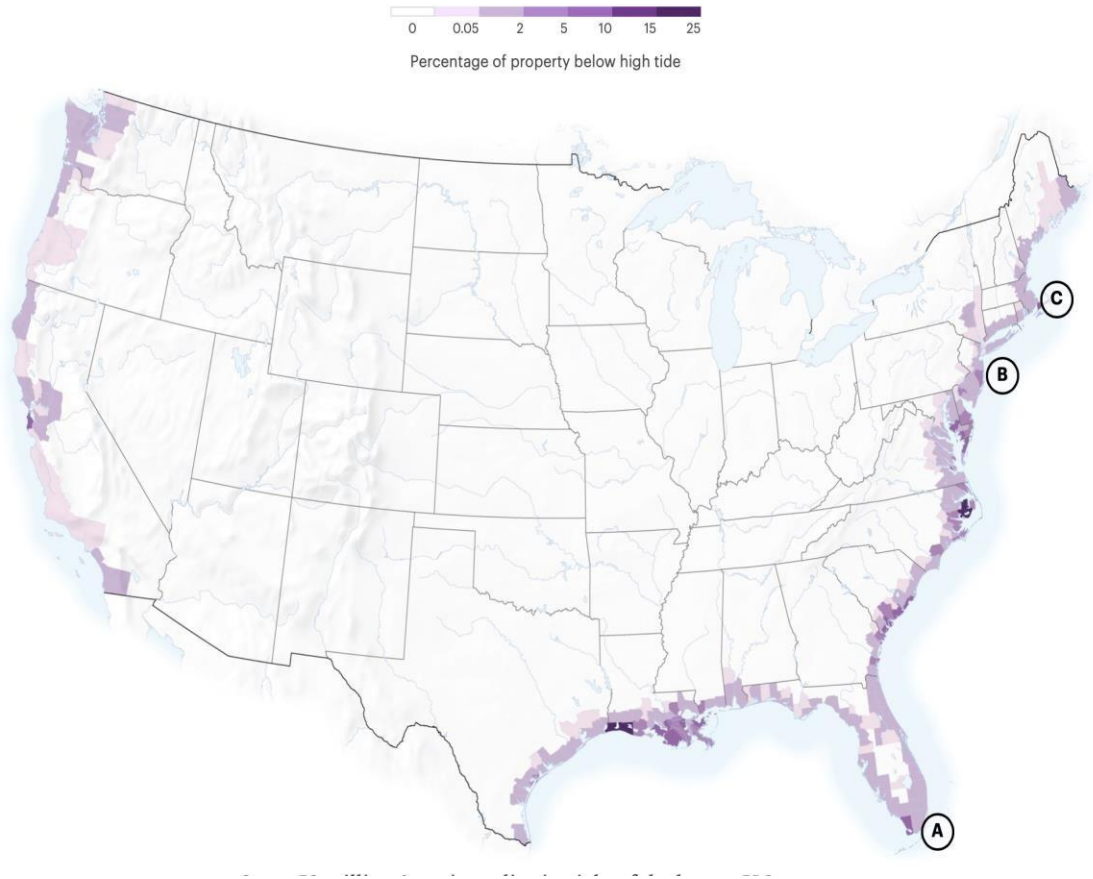
Source: https://www.sciencealert.com/ice-sheet-melting-is-perfectly-in-line-with-our-worst-case-scenarioscientists-warn

Between 2040 and 2060 extreme temperatures will become commonplace in the South and Southwest, with some counties in Arizona experiencing temperatures above 95 degrees for half the year.



Source: https://projects.propublica.org/climate-migration/

Between 2040 and 2060 many coastal areas will be flooded at high tide.



Source: https://projects.propublica.org/climate-migration/

Global progress report on climate action

We are on the brink of missing the opportunity to limit global warming to 1.5°C. If we rely only on the current climate commitments of the Paris Agreement, temperatures can be expected to rise to 3.2°C this century.

Today we still have the chance to limit global temperatures to 1.5°C. While there will still be climate impacts at 1.5°C, this is the level scientists say is associated with less devastating impacts than higher levels of global warming. Every fraction of additional warming beyond 1.5°C will result in increasingly severe and expensive impacts.

Scientists agree that to get on track to limit global temperature rise to 1.5°C, emissions must drop rapidly to 25 gigatons by 2030. Our challenge: based on today's commitments, emissions are on track to reach 56 Gt CO_2e by 2030, over twice what they should be.

Today, we need to reduce emissions by 7.6% every year. Even the most ambitious national climate action plans are far short of a 7.6% reduction. The world now needs a five-fold increase in collective current commitments. The cuts required are ambitious, but still possible.

Every day we delay, the steeper and more difficult the cuts become. By just 2025 the cut needed will be 15.5% each year, making the 1.5°C target almost impossible.

Most nations are expected to strengthen their climate commitments in 2020. To date, **71 countries and 11 regions, accounting for about 15% of global GHG emissions in total**, have long-term objectives to achieve net zero emissions, differing in scope, timing and the degree to which they are legally

binding. This leaves countries representing the remaining 85% of global GHG emissions still to make similar commitments.

At 1.5°C, over 70% of coral reefs will die, but at 2°C **virtually all reefs will be lost.**

Insects, vital for pollination of crops and plants, are **likely to lose half their habitat at 1.5°C** but this becomes almost twice as likely at 2°C.

The Arctic Ocean **being completely bare of sea ice** in summer would be a once per century likelihood at 1.5°C but this leaps to a once a decade likelihood at 2°C.

Over 6 million people currently live in coastal areas vulnerable to sea level rise at 1.5°C degrees, and at 2°C this would affect **10 million more people** by the end of this century.

Sea-level rise will be **100 centimeters higher** at 2°C than at 1.5°C.

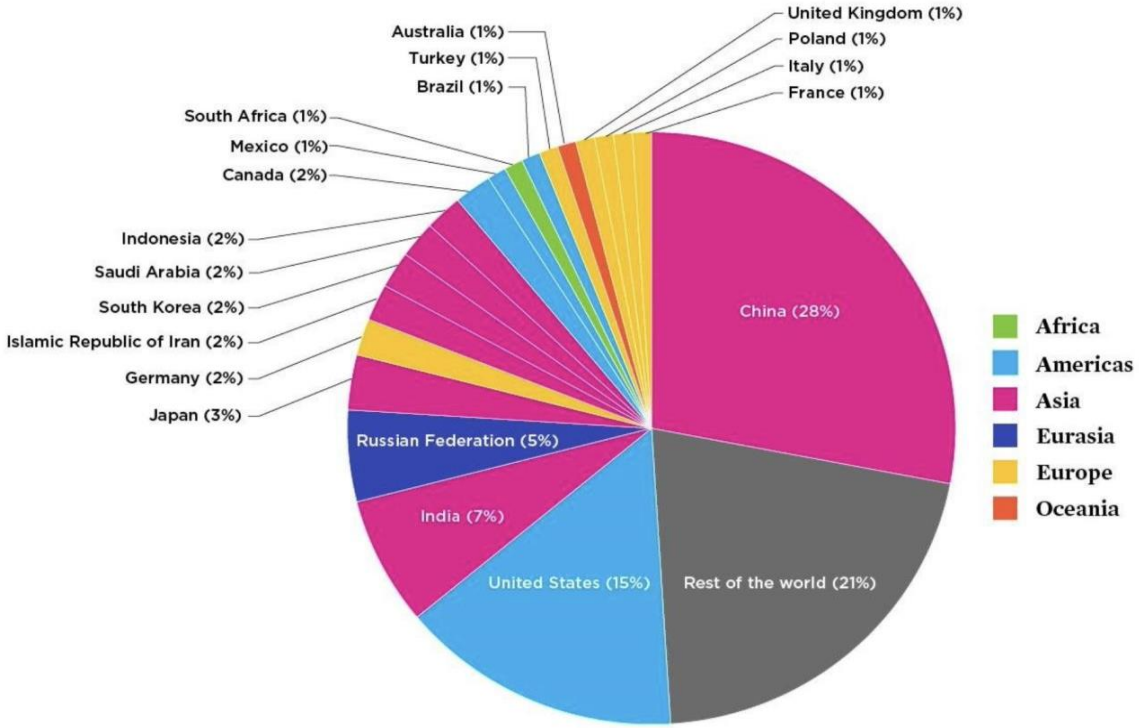
The frequency and intensity of **droughts, storms and extreme weather events** are increasingly likely above 1.5°C.

The Emissions Gap Report 2019 shows that we are on the brink of missing the 1.5°C target and condemning humanity to a future of serious climate change impacts. Countries cannot wait until they submit their updated Paris pledges in one year's time to act. They need to do much more, starting now. Cities, regions, businesses and individuals must all play their part too.

Source: https://www.unenvironment.org/interactive/emissions-gap-report/2019/

Greenhouse Gas Emissions

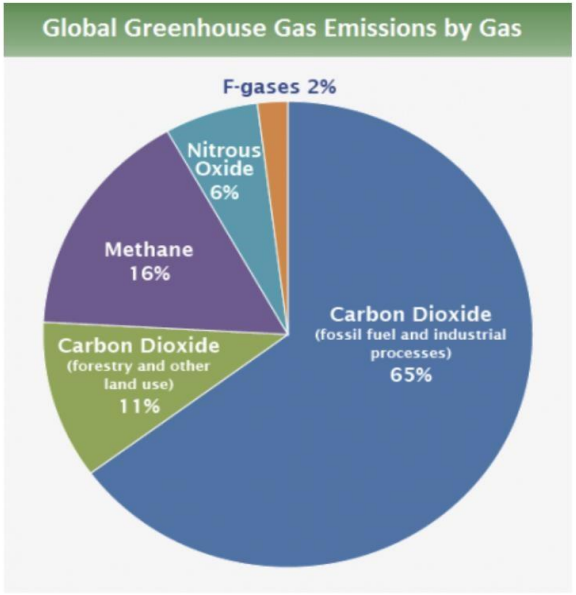
Emissions by Country



Source: https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

Global Greenhouse Gas Emissions by Gas

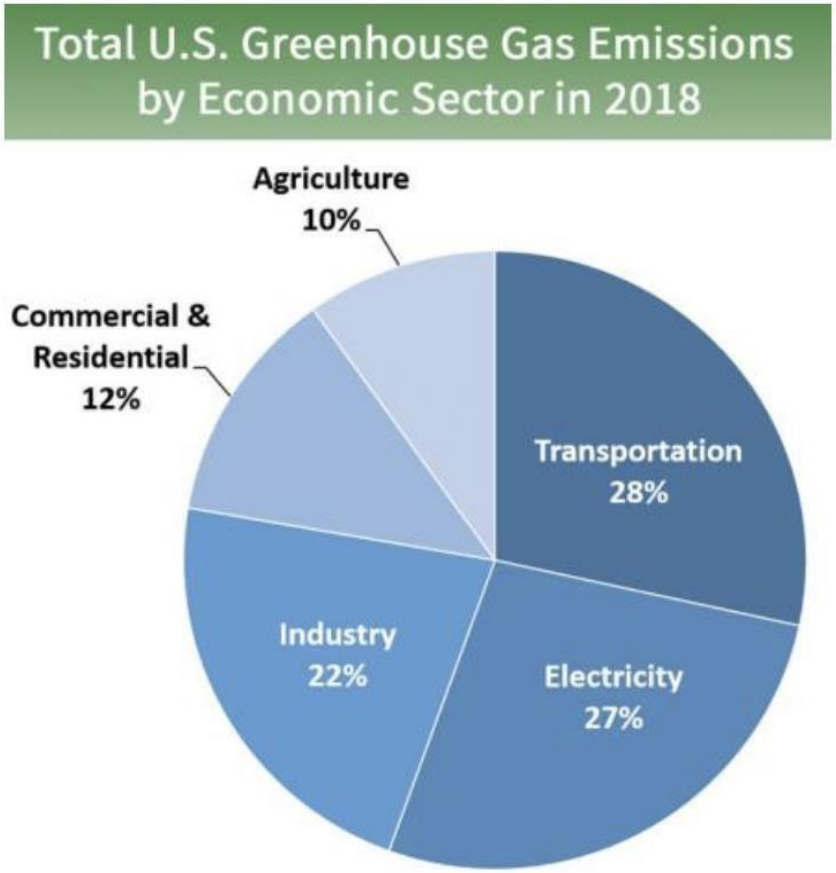
- **Carbon dioxide (CO_2)**: Fossil fuel use is the primary source of CO_2. CO_2 can also be emitted from direct human-induced impacts on forestry and other land use, such as through deforestation, land clearing for agriculture, and degradation of soils. Likewise, land can also remove CO_2 from the atmosphere through reforestation, improvement of soils, and other activities.
- **Methane (CH_4)**: Agricultural activities, waste management, energy use, and biomass burning all contribute to CH_4 emissions.
- **Nitrous oxide (N_2O)**: Agricultural activities, such as fertilizer use, are the primary source of N_2O emissions. Fossil fuel combustion also generates N_2O.
- **Fluorinated gases (F-gases)**: Industrial processes, refrigeration, and the use of a variety of consumer products contribute to emissions of F-gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).



Source: IPCC (2014) EXIT based on global emissions from 2010. Details about the sources included in these estimates can be found in the *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. EXIT

Source: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

Emissions by Economic Sector



Source: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Mitigations

Expand the Use of Carbon-free Energy

- Solar cell farms and rooftop solar panels
- Wind turbine farms
- Nuclear energy plants using modular reactors
- Bioenergy with carbon capture and storage
- Carbon capture and storage for coal and natural gas electricity production
- Develop nuclear fusion

Develop solar cell farms

Source: http://www.publicdomainpictures.net/pictures/10000/velka/1-1244734425Lwol.jpg

Utilize rooftop solar panels.

Australia is deploying renewables 10 times faster than the global average, with rooftop solar in the lead.

Source: https://www.greentechmedia.com/articles/read/what-the-us-can-learn-from-australias-roaringrooftop-solar-market

Wind turbine farms

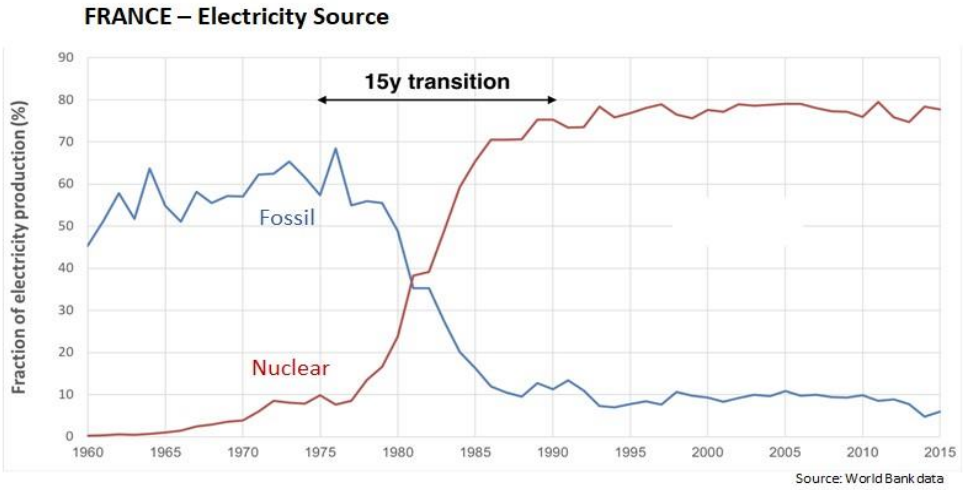
The San Gorgonio Pass wind farm in California, United States.

The Gansu Wind Farm in China is the largest wind farm in the world, with a target capacity of 20,000 MW by 2020.

Source: https://en.wikipedia.org/wiki/Wind_farm

Nuclear energy electricity plants

Increasing nuclear power is a possible pathway to quickly reduce fossil fuels on a national electric grid. France did this several decades ago. Nuclear energy is statistically the safest form of energy generation, but public fears and political opposition make it problematic. There are serious concerns about the storage of spent nuclear fuel, and about nuclear arms proliferation.

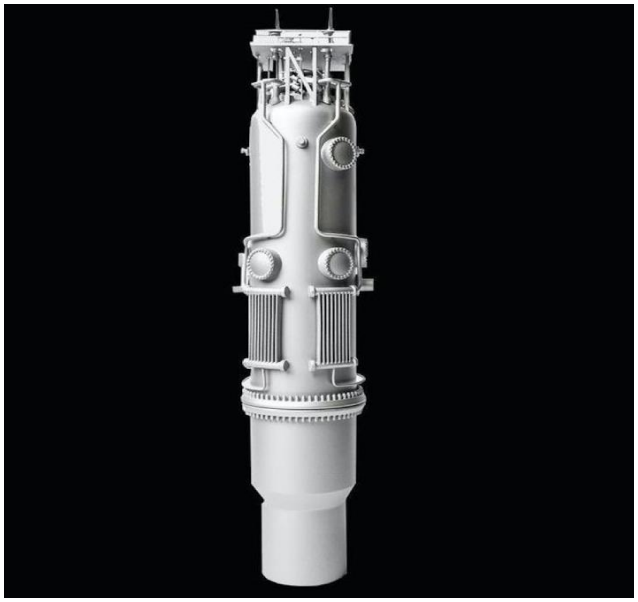


Communication from Dr. Joshua Goldstein.

For a detailed description of nuclear energy, go to the Nuclear Energy Institute, https://www.nei.org/home
A $24M federally funded program to reduce reactor costs:

ARPA-E News: Projects to Develop Advanced Nuclear Reactor Systems Operational Technology, https://arpae.energy.gov/?q=news-item/doe-announces-27-million-advanced-nuclear-reactor-systems-operationaltechnology

NuScale's modular reactor design has received a final safety report .



Source: https://apple.news/ADnN3gBC3Q_Go6_prarQ08g

Nuclear fusion electricity plants

In the sun, the fusion of hydrogen into helium is the process that produces the vast amounts of heat it generates. Research has been underway for decades to simulate the process, with the ultimate objective of producing commercial electrical energy.

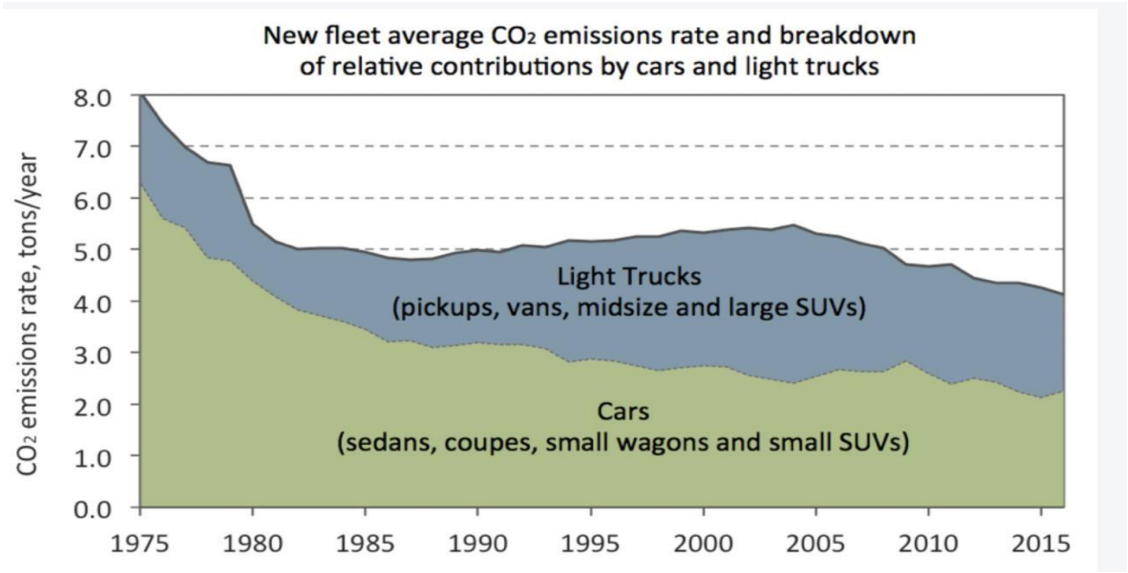
Several privately funded companies are performing developmental research using somewhat different technologies.

An overview of fusion is in https://www.iter.org/sci/whatisfusion.

Increase the energy efficiency of transportation

- Batteries and hydrogen fuel cells for autos, tracks, buses, industrial vehicles
- Hydrogen for aircraft propulsion

The Light-Duty-Vehicles sector



Source: https://www.c2es.org/content/regulating-transportation-sector-carbon-emissions

Electric vehicles

Electric Cars are Coming, and Fast. Is the Nation's Grid Up to It?

In his 29 January 2021 NY Times article, Brad Plumer writes: "Today, fewer than 1 percent of cars on America's roads are electric. But a seismic shift is underway. General Motors said Thursday that it aims to stop selling new gasoline-powered cars and light trucks by 2035 and will pivot to battery-powered vehicles. California's governor has set a goal of phasing out sales of new combustion engines statewide in just 15 years. Automakers like Tesla,
Ford and Volkswagen plan to introduce dozens of new electric models in the years ahead,
spurred on by plummeting battery prices and concerns about climate change."

Source: https://www.nytimes.com/2021/01/29/climate/gm-electric-cars-power-grid.html

Use hydrogen to replace fossil fuels

Airbus debuts hydrogen net-zero concept aircraft for 2035 launch.

Source: https://electrek.co/2020/09/21/airbus-hydrogen-net-zero-concept-aircraft-2035/

Also see: https://splash247.com/hydrogen-leading-the-way-in-new-global-zero-emission-study/

Expand the use of hydrogen fuel cells.

"Small scale fuel cells have been used by some automobile manufacturers for more than a decade. Toyota, Hyundai and Honda currently sell vehicles that combine hydrogen and oxygen to generate electricity which powers the motor. But unlike battery electric vehicles, fuel cell cars boast driving ranges comparable to those of gasoline or diesel vehicles, 200 to 300 miles. Average mileage for fuel cell cars is 58 compared to 23 for gasoline powered cars. Refueling can be done in less than 10 minutes whereas it can take several hours to recharge a battery powered vehicle. The only negative, at present, is the limited number of fueling stations selling pressurized hydrogen.

Despite being zero emissions vehicles, battery and fuel cell cars comprise less than one percent of automobiles currently on the road. The real promise for using fuel cells to lower carbon emissions lies in the power generation industry, which is by far the largest emitter of CO2 and other greenhouse gases. To that end, a number of energy companies are boosting investments in large-scale fuel cell technology to produce electricity for the power grid."

Source: https://thehill.com/blogs/congress-blog/energy-environment/287075-fuel-cells-can-help-battleclimate-change

Increase the energy efficiency of buildings.

- High-efficiency heat pumps
- Thin insulating materials
- Windows and building surfaces with tunable optical properties
- High efficiency lighting devices
- Improved software for optimizing building design and operation
- Energy harvesting sensors and controls
- Interoperable building communication systems and optimized control strategies

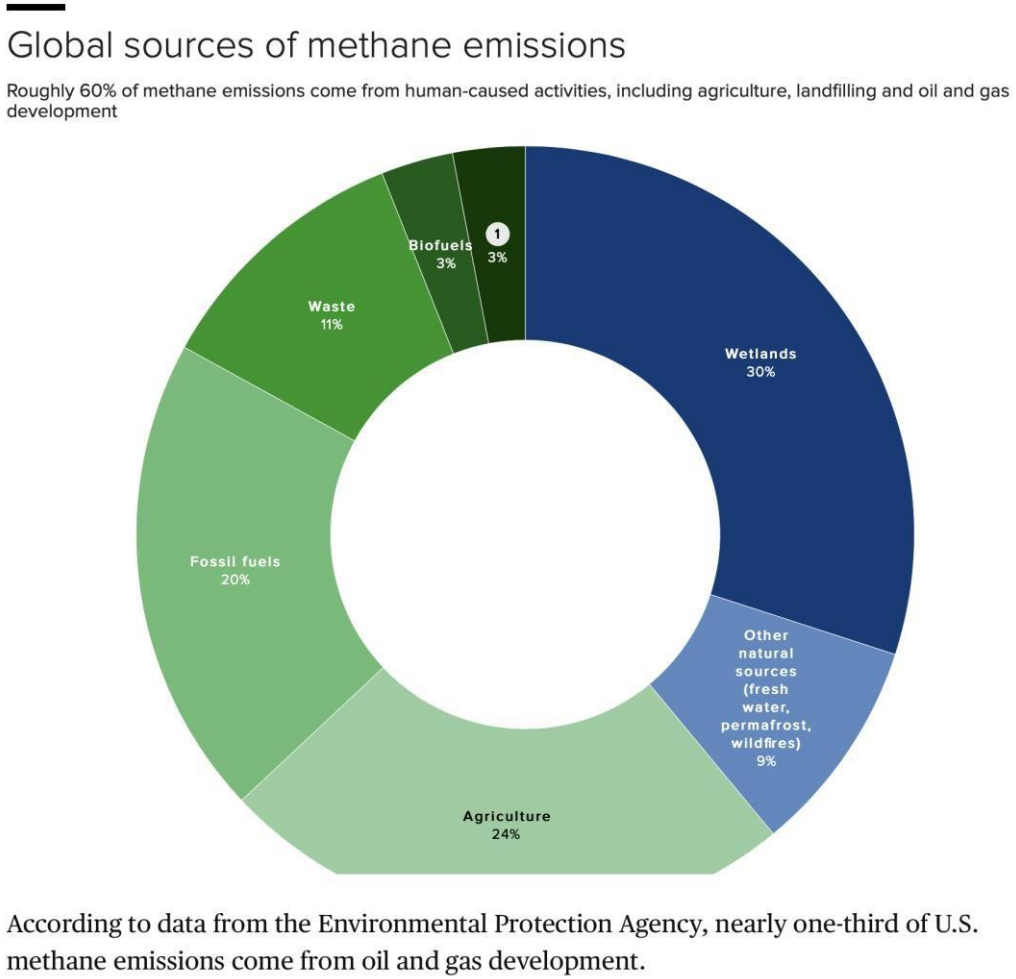
Increase the efficiency of buildings.

Chapter 5 in the 2015 Quadrennial Technology Review by the Department of Energy describes how to increase the efficiency of building systems and technologies.

The report says that the buildings sector accounts for about 76% of electricity use and 40% of all U.S. primary energy use and associated greenhouse gas emissions. Opportunities for improved efficiency are enormous. By 2030, building energy use could be cut more than 20% using technologies known to be cost effective today and by more than 35% if research goals are met. Much higher savings are technically possible.

Source: https://energy.gov/sites/prod/files/2015/09/f26/QTR2015-05-Buildings.pdf

Reduce methane emissions



Source: https://www.cbsnews.com/news/who-are-the-biggest-us-methane-emitters/

Increase the energy efficiency of industry.

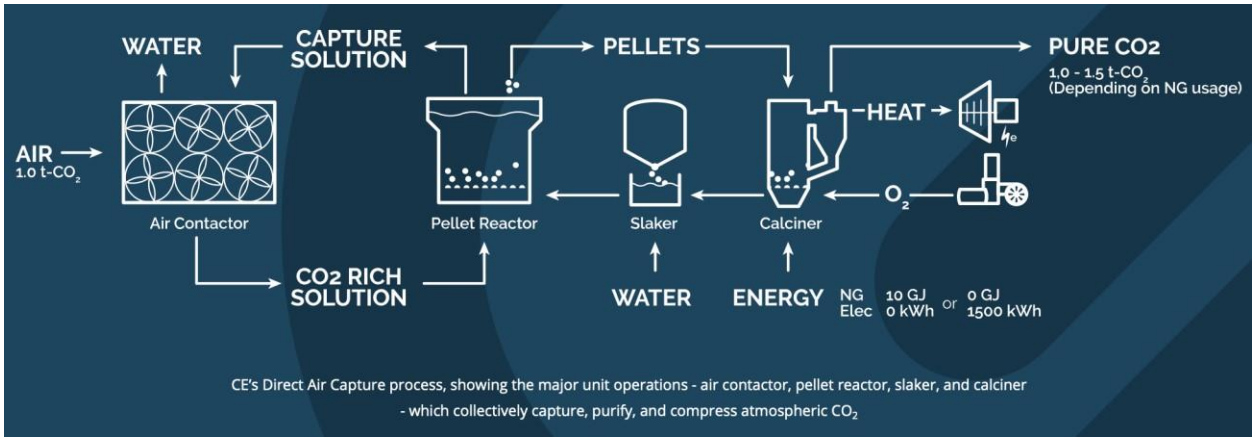
- Carbon capture and storage, and use
- Electrification using affordable low carbon source
- Decarbonization of grid
- Biomass for fuel and feedstock
- Energy management systems
- Clustering of industries
- Circular economy

Remove carbon from the atmosphere

- Restore forests
- Sequester carbon in soils
- Use chemical processes to capture carbon from the atmosphere

Capture carbon dioxide

Carbon Engineering of Canada is expanding its commercial Direct Air Capture plant from 500,000 to 1 million tons of CO2 per year.



Source: https://carbonengineering.com

Separate carbon dioxide from gas streams.

See these examples:

From the UK: https://www.sciencealert.com/scientists-create-self-growing-silver-membrane-that-separatesco2-from-other-gases?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+sciencealertlatestnews+%28ScienceAlert-Latest%29

In Switzerland: https://www.bloomberg.com/news/articles/2020-06-02/swiss-carbon-capture-startup-raises76m-in-funding-round

A new approach from Australia: https://phys.org/news/2020-06-australian-carbon-dioxide-capture.html

Restore forests.

"The right trees, planted in the right locations, could store 205 gigatons of carbon dioxide"

Source: https://www.scientificamerican.com/article/massive-forest-restoration-could-greatly-slow-globalwarming/

Sequester carbon in soils.

"It is estimated that soils can sequester around 20 billion tonnes C in 25 years, more than 10 % of the anthropogenic emissions."

Source: http://www.fao.org/soils-portal/soil-management/soil-carbon-sequestration/en/

Examples of states and cities adapting to climate change

Source: https://www.georgetownclimate.org/adaptation/plans.html

Resources

The Intergovernmental Panel on Climate Change**, https://www.ipcc.ch**

Fourth National Climate Assessment, **https://nca2018.globalchange.gov**

Highlights of the Findings of the U.S. Global Change Research Program Climate Science Special Report**, https://science2017.globalchange.gov/chapter/executive-summary/**

The National Academies of Sciences, Engineering and Medicine, **http://sites.nationalacademies.org/sites/climate/index.htm**

Drawdown, **https://drawdown.org**. It identifies 80 initiatives to reduce global warming. For each, there are estimates of reduced CO2, net coast, and net savings.

NASA: An excellent climate change Q & A, **https://earthobservatory.nasa.gov/blogs/climateqa/**

Driving Questions for Project-based Learning investigations focused on Climate Change

Grades 4-8

The following driving questions may be modified to fit the teacher's needs.

Related to causes of climate change:

A. How would you, as a Climate Scientist, explain/describe the impact of the human-enhanced greenhouse effect has on the Earth's climate?

B. How would you, as a Biologist, describe to a group of non-scientists the effects of carbon dioxide on the Earth's plants and animals?

C. How would you, as a TV weather forecaster, explain to your TV audience how the sun influences the Earth's changing climate?

D. As a Climate Scientist, you know that as the temperature of the Earth gets warmer, more water is retained in the atmosphere. How would you explain to a group of non-scientists why this is important?

Related to the effects of climate change:

E. As Climate Scientists, you know that the North Pole and surrounding areas are experiencing temperatures that are well above normal. How can you explain to a group of concerned citizens why this is important?

F. You are a Marine Biologist who studies coral reefs that are slowly dying. What would you tell a group of SCUBA divers must be done to keep the coral reefs healthy and alive?

G. What would you, as a Travel Blogger, tell a group of meteorologists visiting Greenland to look for?

Related to mitigating the effects of climate change:

H. How would you and your team of Structural Engineers design a new school building so that it has minimum impact on the climate, both during the construction phase and the operational phase?

I. What would you, as a Citizen Scientist, tell your school or community planners about how they can help reduce the impact of climate change by managing new or existing trees on their properties? Give them a plan to do it.

J. How would you, as an Engineer, explain that it is now better to get your energy from wind or solar renewable sources than it is from coal?

K. How would you, as a Climate Scientist, tell local farmers how they can use their soil to help control the climate?

L. Most of your school district's buses run on diesel fuel. As a County Planner, how would you recommend replacing these with electric school buses.

M. How can you, as a Climate Scientist, convince your friends and relatives that eating beef is not good for the climate?

N. What can you do, with your parents' help, to reduce your family's impact within your house on the world's changing climate?

Related to adapting to the effects of climate change:

O. What should you be doing, as the Governor of the State, to protect the people in your state from the effects of climate change?

P. What would you, as a Military Planner, tell the generals and admirals at the Pentagon they should expect from climate change and what they should be doing about it?

Q. What would you, as a Civil Engineer, advise small towns along the river/bay/ocean to do to lessen the impacts of climate change on their communities?

Some general questions:

R. Scientists overwhelmingly believe that humans are causing climate change. Some adults don't believe this. How would you, as a Climate Scientist, convince them?

S. How would you, as a weather blogger, tell your readers to help them prepare for extreme weather situations?

T. How would you, as a scientist, create a PSA/Commercial that informs the public about impact of human and natural factors on Earth's atmosphere and weather?

U. How would you, as the new "Kid President," inform other students about what they can do NOW to protect our planet and minimize the intensity of future weather events?

Climate Change Project Concept

Grades 3-8

Driving Question

How would you, as a TV weather forecaster, explain to your TV audience how the sun influences the Earth's changing climate?

Questions

What are the characteristics of solar radiation (energy as a function of wavelength)

How does the solar radiation interact with different parts of Earth?

- Atmosphere
- Land surface – agriculture, forest, ice fields
- Oceans

What are the impacts of these interactions?

How have these changed over the last century?

Classroom experiment

Conduct greenhouse effect classroom experiment, show effect of different ground reflectivity.