Climate Change: Status, Future and Consequences for Future Generations, and Steps to Mitigate Future Consequences

Summary

2023 was the hottest year on record with an average global temperature of 1.48°C (2.66°F) higher than the start of the Industrial Revolution (~ 1850). Climate change induced extreme and catastrophic weather- and climate-events currently cost the U.S. about $150 billion a year. Billion-dollar (inflation adjusted) events now occur about six times more frequently than in the 1980's. Without a rapid reduction in greenhouse gas (GHG) emissions, more frequent and extreme events will lead to unsustainable costs for insurance companies and taxpayers and burden future generations with higher costs, lower economic growth, and social disruption.

Although the 2022 Inflation Reduction Act provides financial incentives for the U.S. to transition to a lower GHG emissions economy, the U.S. Congress needs to take additional action to address this critical issue. Policies are needed to rapidly reduce GHG emissions while ensuring energy security. Carbon dioxide emissions from fossil fuel combustion account for about 73% of U.S. GHG emissions. A steady reduction in fossil fuel use balanced by an increase in power generation from renewable and other zero-carbon energy sources is a priority. Methane is a potent near-term GHG and emissions from livestock, fossil fuel systems, and landfills should be controlled. A gradually applied, progressive fee on carbon/GHG emissions is needed to use market forces to cost-effectively drive lower fossil fuel use and GHG emissions. Finally, the U.S. needs a comprehensive plan to a world leader in the low-cost clean technologies of the future or risk permanently ceding dominance to China.

The following sections include 1.) an introduction to GHGs; 2.) an overview of historical GHG emissions; 3.) a review of projected temperature rise for different future emissions scenarios; 4.) a discussion of anticipated impacts of these scenarios on weather- and climate-events and economic and societal costs; 5.) a summary of U.S. GHG emissions sources; and discussions of 6.) actions to mitigate climate change, and 7.) policies and incentives to facilitate these actions. In this paper, explanatory footnotes are indicated by superscript roman numerals and referenced documents by superscript Arabic numerals and listed at the end of the document.

1.0 Greenhouse Gases

The warming effect on earth caused by the absorption and trapping of thermal radiation from the earth's surface by atmospheric gases is called the "greenhouse effect." Primary anthropogenic (emitted by human activity) GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halogenated compounds such as hydrofluorocarbons (HFCs). All else being equal, an increase in the atmospheric concentration of a GHG produces positive radiative forcing; that is, it causes the energy entering the atmosphere to be greater than the energy leaving the atmosphere. Global Warming Potential (GWP) compares the ability of a GHG to trap atmospheric heat relative to CO_2, the reference gas. The International Panel on Climate Change (IPCC) defines GWP as "the ratio of the radiative forcing of one kilogram (kg) greenhouse gas emitted to the atmosphere to that from 1 kg CO_2 over a period of time."[1] GWP is mass- and time period-based and a 100-year time horizon is commonly used. GHG emissions are usually reported as CO_2 equivalents (e.g., kg or metric tons (mt) of CO_2eq where kg CO2eq for GHGi = kg GHGi * GWP_{GHGi}). The U.S. Environmental Protection Agency (EPA) Inventory of U.S. GHG Emissions and Sinks: 1990 – 2021[2] primarily uses 100-year GWPs from the IPCC Fifth Assessment Report (AR5)[3] and listed in Table 1. For some GHGs, such as methane that has a much shorter atmospheric lifetime than CO_2, GWPs based on 20-year time horizon are significantly higher and sometimes used for analysis and reporting.

Table 1. Global Warming Potentials for Greenhouse Gases

Greenhouse Gas	**Global Warming Potential**	
	100-Year Time Horizon	**20-Year Time Horizon**
CO_2	1	1
CH_4	28	84
N_2O	265	264
HFCs	116 to 12,400	427 to 10,800
perfluorocarbons (PFCs)	<1 to 11,100	<1 to 8,210
sulfur hexafluoride (SF_6)	23,500	17,500
nitrogen trifluoride (NF_3)	16,100	12,800

2.0 Historical Global GHG Emissions, GHG Concentrations, and Surface Temperatures

The International Panel on Climate Change (IPCC) Sixth Assessment Report (AR6)[4], released in 2023, estimated that by 2019 emissions of GHGs by human activities had caused an increase in average global surface temperature of about 1.1°C (2.0°F) since the start of the Industrial Revolution (~ 1850). Increases are larger over land (1.59°C) than over the ocean (0.88°C). Further, the European Union Copernicus Climate Change Service (EU Copernicus) recently reported that 2023 was the hottest year on record with an average global surface temperature of 1.48°C (2.66°F) higher than the pre-industrial level and 0.17°C (0.31°F) higher than the previous global average high temperature in 2016.[5] Figure 1 from EU Copernicus shows average global surface temperatures from 1850 to 2023.

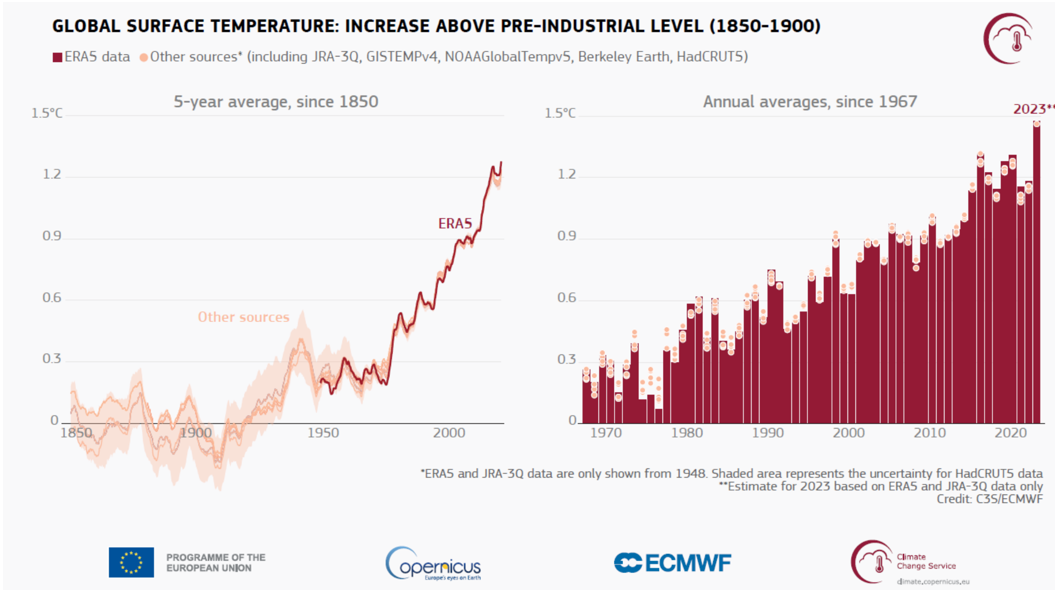
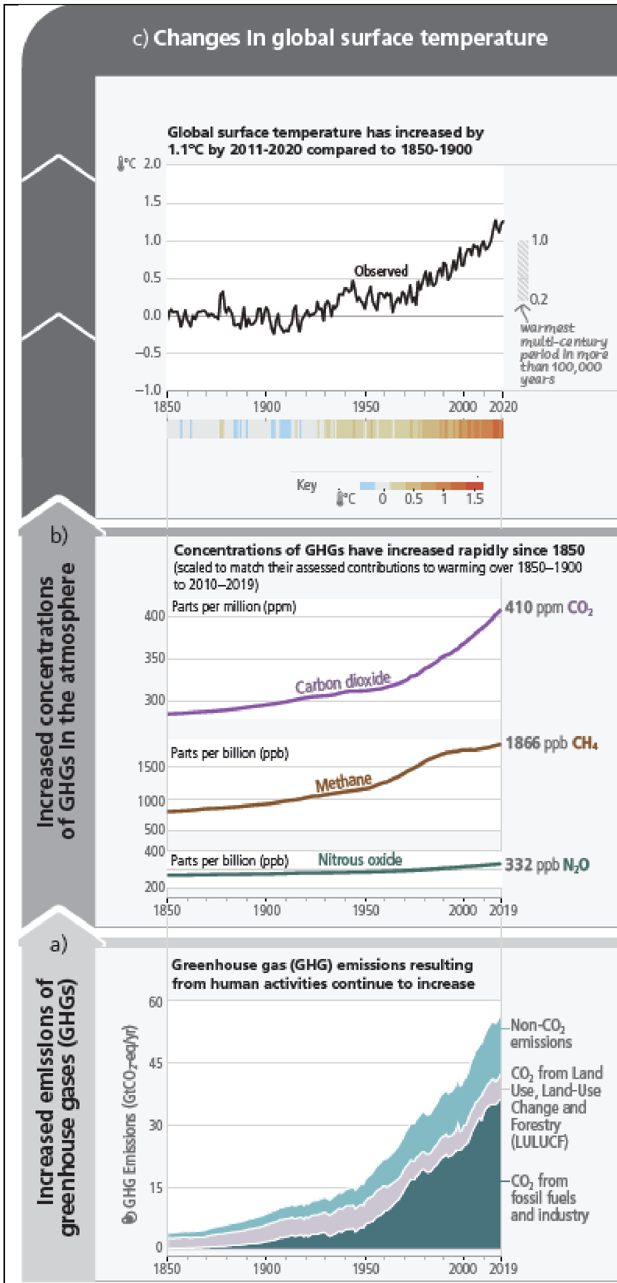


Figure 1. Average global surface temperature above pre-industrial level from 1850 to 2023[5]

Data and analysis presented in the IPCC AR6 lead to a best estimate that all the global surface temperature rise since 1850 has been caused by human activity. The AR6 states:

> "Formal detection and attribution studies synthesize information from climate models and observations and show that the best estimate is that all the warming observed between 1850–1900 and 2010–2019 is caused by humans"

Figure 2 shows the historical relationship between GHG emissions, atmospheric concentrations of CO_2, CH_4, and N_2O, and surface temperature from 1850 to 2019. The data start with the bottom graph "a" and show increased GHG emissions from human activity correlating with higher GHG concentrations (graph b) and higher average global surface temperatures (graph c).



Graph c shows average global surface temperature from 1850 to 2019. The global surface temperature increase correlates with the GHG atmospheric concentrations in Graph b. A steep and steady temperature rise starting about 1970 is observed.

Graph b shows atmospheric concentrations of CO_2, CH_4, and N_2O from 1850 to 2019. The increase in atmospheric concentrations correlates with the annual emission rates in Graph a.

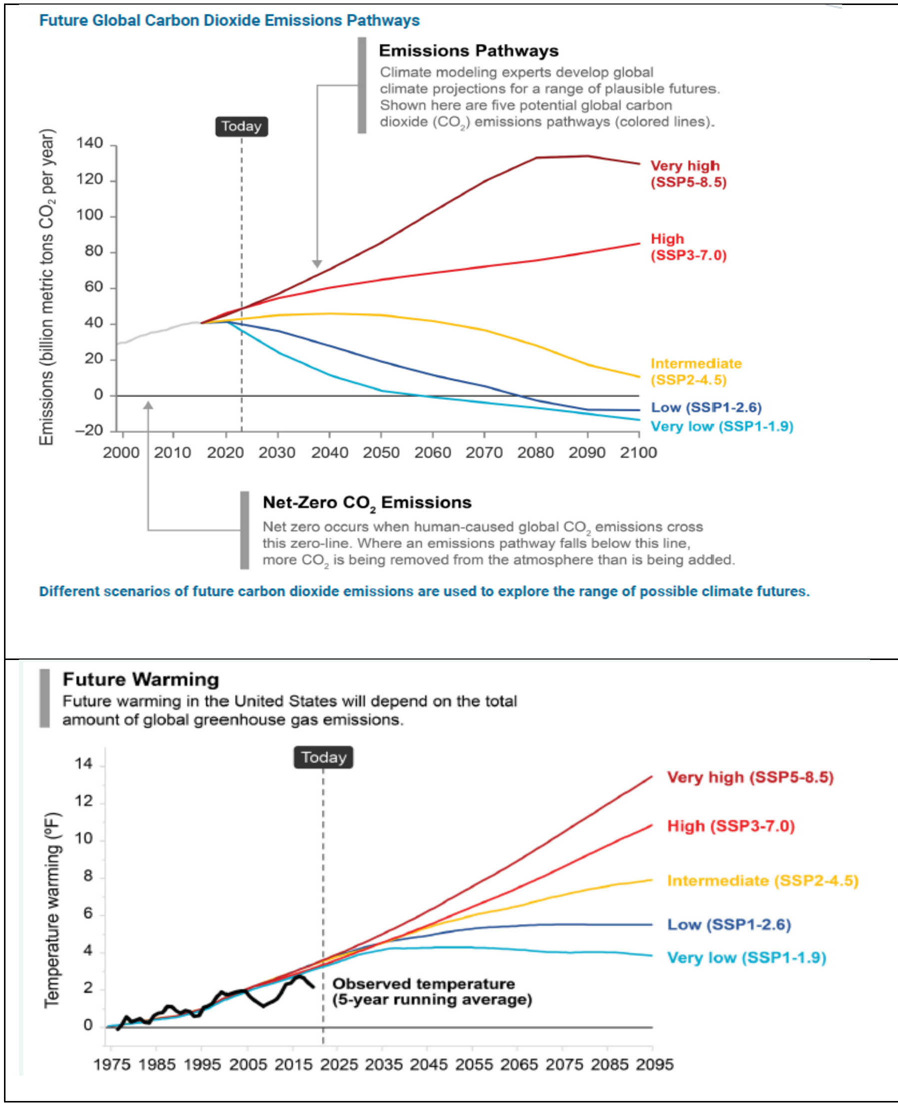
Graph a shows gigatons per year emissions of GHGs from human activities from 1850 to 2019. The majority of the emissions are CO_2 from fossil fuels combustion and industry. Non-CO_2 emissions are primarily CH_4 and N_2O. Annual emissions started to accelerate around 1945.

Figure 2. GHG emissions, GHG concentrations, and global surface temperature: 1850 - 2019[4]

3.0 Global GHG Emissions Pathways and Projected Temperatures

Figure 3 from the U.S. Global Change Research Program 2023: Fifth National Climate Assessment (5th NCA 2023)[6] shows different global CO_2 emissions pathways and associated projected warming trends for the U.S.

Very High and High CO_2 emissions scenarios include increased CO_2 emissions and fossil fuel development through the year 2100. Low and Very Low CO_2 emissions scenarios include rapidly declining and net-negative CO_2 emissions (CO_2 removal from atmosphere exceeds human caused emissions), increased use of renewable energy and nuclear energy (for the Very Low scenario), and international cooperation. CO_2 emissions mitigation and atmospheric removal strategies are further discussed in Section 6.0.



Very High Scenario (SSP5-8.5): Highest CO_2 emissions range. No mitigation. Fossil fuel development. Total global CO_2 emissions in 2100 are four times 2000 emissions.

High Scenario (SSP3-7.0): High CO_2 emissions. Limited or no mitigation. Fossil fuel development. Total global CO_2 emissions in 2100 are three times 2000 emissions

Intermediate Scenario (SSP2-4.5): CO_2 emissions reduced from current levels. Expanded renewable energy and low-carbon technology compared to 2000. Total global CO_2 emissions in 2100 are 67% less than 2000 emissions.

Low Scenario (SSP1-2.6): Rapidly declining and net-negative CO_2 emissions (human caused emissions exceeded by CO_2 removal from atmosphere) by 2100. Renewable energy increased. "Adaptive capacity reflects effective governance institutions, reduced inequality, and international cooperation."

Very Low Scenario (SSP1-1.9): Greatest global GHG emissions reduction and substantial atmospheric CO_2 removal. Steep decline in total annual CO_2 emissions, "dropping by more than 145% by 2100 compared to 2000." Shift to sustainable land use and renewable energy and nuclear energy. "Adaptive capacity benefits from international cooperation and technology sharing."

Figure 3. Different global CO_2 emissions pathways and associated projected warming trends for the U.S.[6]

4.0 Current and Projected Impacts of GHG Emissions

Current and projected impacts from climate change include more extreme and catastrophic weather- and climate-events. Increases to wildfires, sea level rise and coastal and river flooding, tropical cyclones, crop failure, drought, and heat waves are being experienced and expected to further increase if global temperatures continue to rise. Figure 4 estimates how many more times a person born in North America in 2020 will experience these climate hazards than a person born in 1965 based on different global warming scenarios. For example, if temperature rise is limited to 2.7°F (1.5°C, scenario SSP1-1.9 in Figure 3), then the average person born in 2020 will experience 1x more tropical cyclones and 2x more heat waves. But if temperature rise is 6.3°F (3.5°C, scenario SSP2-4.5 in Figure 3), then the average person born in 2020 will experience 2x more tropical cyclones and 5x more heat waves.

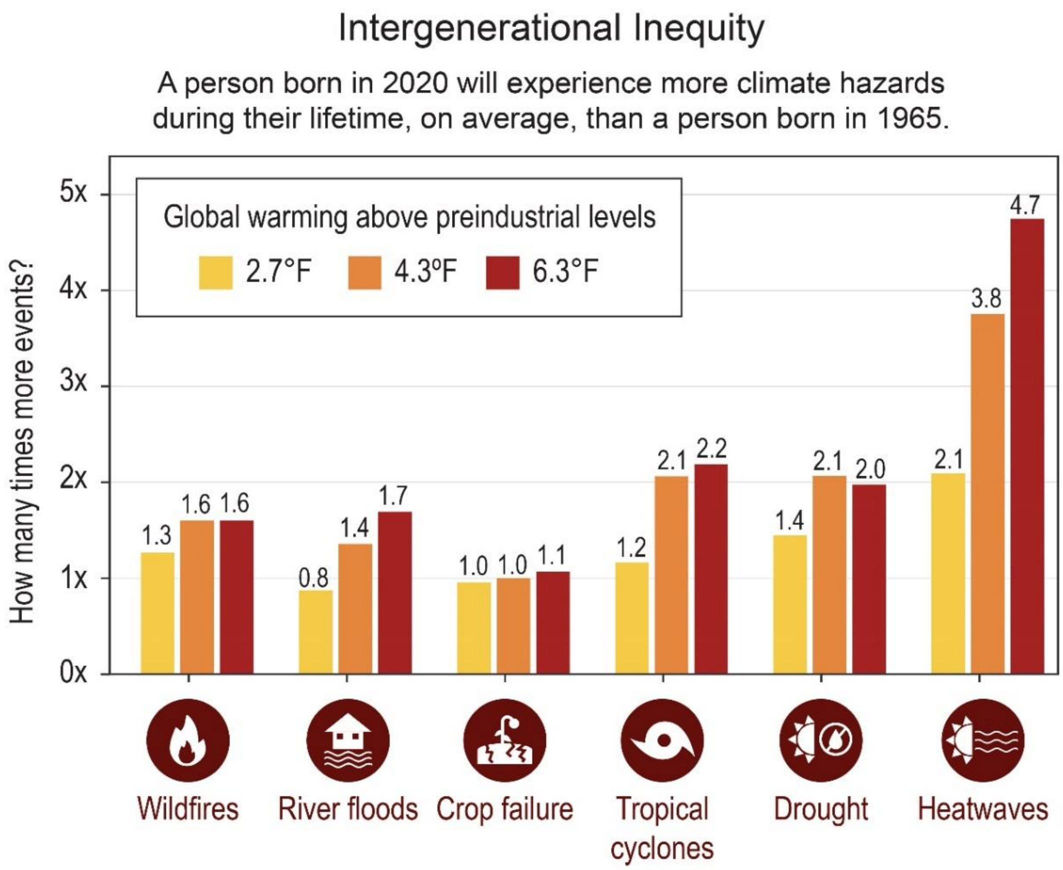


Figure 4. Average lifetime climate events experienced by person born in 2020 vs person born in 1965[6]

Such changes have large economic and societal costs. Economic costs from extreme weather events include damage to infrastructure, disruptions in labor and public services, and property value losses.

> "In the 1980s, the country experienced, on average, one (inflation-adjusted) billion-dollar disaster every four months. Now, there is one every three weeks, on average. Between 2018 and 2022, the US experienced 89 billion-dollar events (Figure 5). Extreme events cost the

> US close to $150 billion each year—a conservative estimate that does not account for loss of life, healthcare-related costs, or damages to ecosystem services." [6]

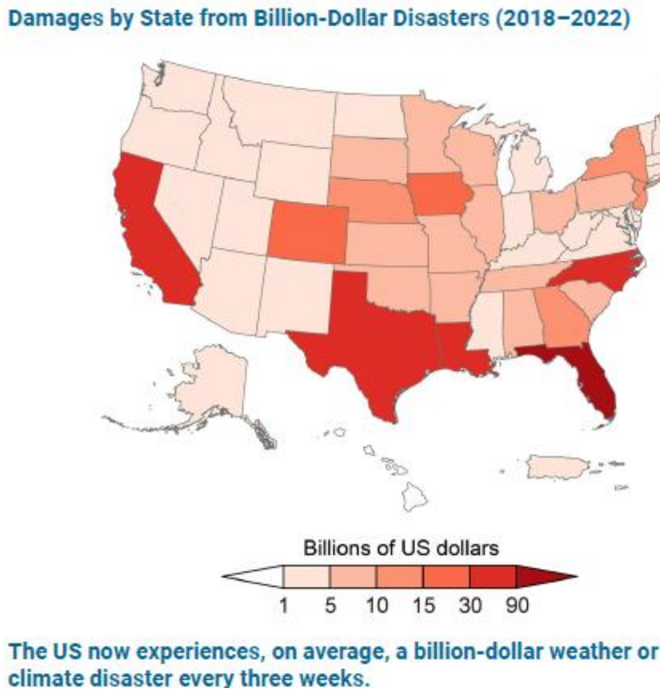


Figure 5. Damages by state from billion-dollar disasters[6]

Economic costs will increase with increasing temperatures and associated number of climate hazards. The 5th NCA 2023 states

> "2°F of warming is projected to cause more than twice the economic harm induced by 1°F of warming."

Insurance rates will increase and some areas may not be able to get homeowners insurance from private companies; for example, in Florida due to increasing number and intensity of tropical storms and in the west due to wildfires. Taxpayer-subsidized government insurance may be the only option.

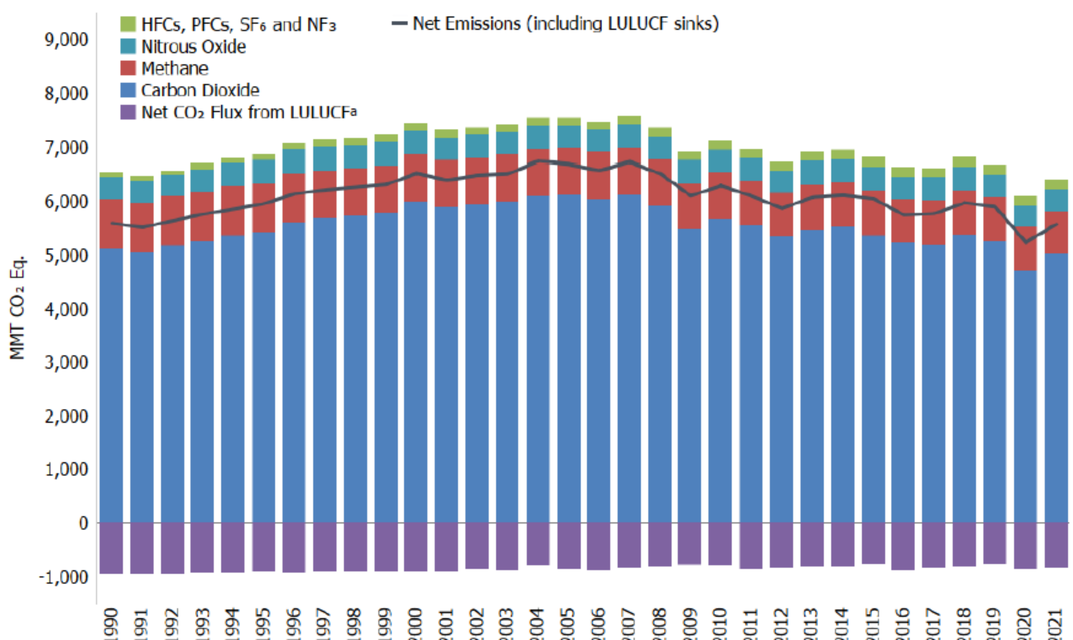
Other climate change impacts and hazards include, but are not limited to, increased migration (internal and external to the U.S.) by displaced persons; greater distribution of infectious and vector-borne pathogens (more mosquitos and ticks); poorer air quality from increased smog, wildfire smoke, dust, and pollen; and damage to ecosystems such as coral reefs. Long-term, the melting of glaciers in Greenland and Antarctica could lead to catastrophic sea-level rise.

5.0 Emission Sources: United States GHG Emissions Inventory

Figure 6 shows U.S. GHG emissions and sinks by gas from 1990 to 2021, with emissions quantified as CO_2eq based on 100-year GWPs. Gross (stacked bar) and net (solid black line) emissions are shown. Gross emissions exclude emissions and removals from Land Use, Land-Use Change, and Forestry (LULUCF). Net emissions account for net CO_2 fluxes from

LULUCF, and these fluxes are negative because LULUCF sinks (e.g., carbon uptake by forests) are greater than LULUCF emissions (e.g., forest fires). The data show:

- Gross and net emissions have decreased since peaking during the 2005 – 2007 time frame.
  - GHG emissions per capita and per $ trillion gross domestic product (GDP) have decreased (e.g., due to improved energy efficiency and lower emissions energy production); however, these decreases are offset by increased population and GDP growth and total GHG emissions reductions have only averaged about 1% per year since 2005.
- The majority of the emissions were CO_2, about 79.4% of the gross emissions in 2021. Figure 7 provides additional information about the CO_2 emissions.
- Methane emissions were about 11.5% of the gross emissions in 2021. Figure 8 provides additional information about the CH_4 emissions.
- N_2O emissions were about 6.2% of the gross emissions in 2021.
  - Agricultural soil management accounts for about 73% of the N_2O emissions and about 4.6% of total gross GHG emissions. Agricultural soil management activities include use of organic and synthetic fertilizers, livestock manure deposition, and growing N-fixing plants.
- HFCs + PFCs + SF_6 + NF_3 were about 3.0% of the gross emissions in 2021.
  - HFCs and PFCs, which are substitutes for ozone depleting substances (e.g., chlorofluorocarbons) for cooling and refrigeration, were about 92% of these emissions.



[a] The term "flux" is used to describe the exchange of CO_2 to and from the atmosphere, with net flux being either positive or negative depending on the overall balance. Removal and long-term storage of CO_2 from the atmosphere is also referred to as "carbon sequestration."

Figure 6. U.S. GHG emissions and sinks by gas (1990 – 2021)[2]

Table 2 compares estimated CO2eq emissions based on 100-year and 20-year GWPs. The largest difference is that based on 100-year GWPs, CO_2 emissions are 79.4% of the total and methane emissions are 11.5% and based on 20-year GWPs, CO_2 emissions are 64.2% of the total and methane emissions are 27.9%. These data show the importance of mitigating methane emissions in the short term.

Table 2. U.S. Gross GHG Emissions by Gas, 100-yr and 20-yr GWPs [2]

Greenhouse Gas	100-Year GWPs		20-Year GWPs	
	MMT[I] CO2eq	% of Total	MMT CO2eq	% of Total
CO_2	5,032.2	79.4%	5,032.2	64.2%
CH_4	727.4	11.5%	2,182.2	27.9%
N_2O	393.3	6.2%	391.8	5.0%
HFCs	175.1[A]	2.8%	218.9[A]	2.8%
PFCs	3.5[A]	0.06%	2.9[A]	0.04%
SF6	8.0	0.13%	6.0	0.08%
NF3	0.6	0.01%	0.5	0.01%
Total	6,340.2	100.0%	7,834.4	100.0%

A. Based on estimates of average 100-yr and 20-yr GWPs for families of HFCs and PFCs

CO_2 emissions were about 79.4% of U.S. GHG emissions (as CO_2eq) in 2021 and about 92% of the CO_2 was from fossil fuel combustion; thus, fossil fuel combustion CO_2 emissions account for about 73% of total gross GHG emissions and efforts to reduce U.S. GHG emissions need to focus on fossil fuel combustion. Other significant CO_2 emissions sources include non-energy fuel use (e.g., plastics production, about 3% of total CO_2), iron & steel production and cement production (~ 1% each of total CO_2), and natural gas systems, petrochemical production, petroleum systems, and other industrial processes (less than 1% each of total CO_2).

Figure 7 presents fossil fuel combustion CO_2 emissions by fuel type and economic sector.

- About 38% of the emissions are from transportation, 33% from electricity generation, 17% from industry fuel use, and 12% from commercial and residential sources.
- 44.4% of the emissions are from petroleum combustion, and the majority of petroleum use is for transportation. 21.6% of the emissions are from coal combustion, which is almost entirely used for electricity generation. Natural gas accounts for 34.9% of the CO_2 emissions and natural gas is used for electricity generation, industrial processes, and commercial and residential use.

[I] million metric tons

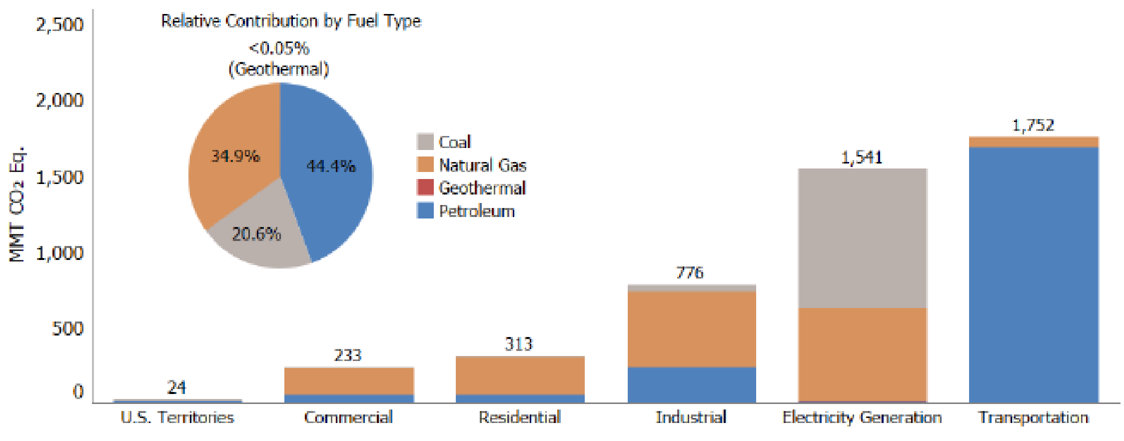


Figure 7. CO_2 emissions from fossil fuel combustion by fuel type and economic sector in 2021[2]

Figure 8 shows U.S. sources of CH_4 emissions in 2021. The largest emission sources are livestock (enteric fermentation + manure management ~ 33% of total), natural gas + petroleum systems (~30% of total) and landfills (~16% of total).

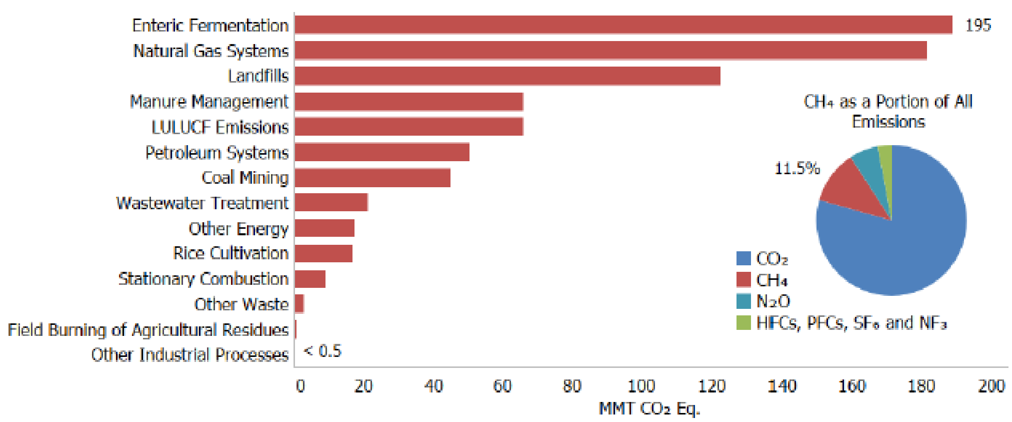


Figure 8. U.S. CH_4 emissions by source in 2021[2]

Emission sources in the energy sector accounted for 82% of total gross U.S. GHG emissions in 2021. These emission sources included fuel combustion, fugitive emissions (e.g., methane in natural gas leaks), and the use of fossil fuels for non-energy purposes (e.g., asphalt, lubricants, waxes). Agriculture emissions were about 9% of the total U.S. GHG emissions, industry emissions about 6%, and waste systems emissions about 3%. Figure 9 shows the primary sources of energy used in the U.S. in 2021. 79.3% of the energy was produced by combusting fossil fuels, and the other 20.7% was from nuclear energy and renewable energy sources (e.g., solar, wind, hydropower, biomass).

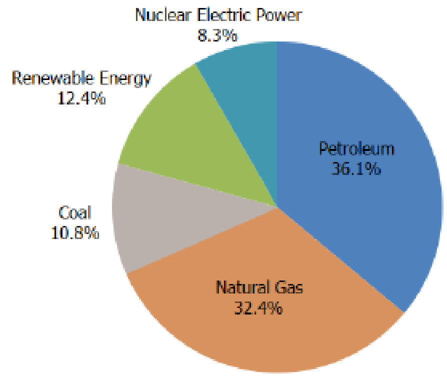


Figure 9. Energy sources in the U.S. in 2021[2]

Key points about U.S. GHG emissions include:

- CO_2 emissions are the largest GHG emissions, primarily from fossil fuel combustion for transportation, electric power generation, and industrial processes
  - Coal combustion emits more CO_2 per unit energy (~ 96 kg CO_2/MMBtu[II]) than petroleum (~ 70 kg CO_2/MMBtu for gasoline, ~ 74 kg CO_2/MMBtu for diesel) or natural gas combustion (~ 53 kg CO_2/MMBtu)
- Methane is a potent near-term GHG with an atmospheric lifetime of about 12 years and primary emission sources are livestock, natural gas and petroleum systems, and landfills
- Agricultural soil management accounts for the majority of N_2O emissions

6.0 Steps to Reduce GHG Emissions and Stabilize Global Temperature

Figure 10 shows that steep GHG emissions reductions will be required to limit global temperature rise to 1.5°C (2.7°F). Accomplishing these net emission reductions will likely require a combination of reducing anthropogenic GHG emissions and removing CO_2 from the atmosphere.

[II] million British thermal units

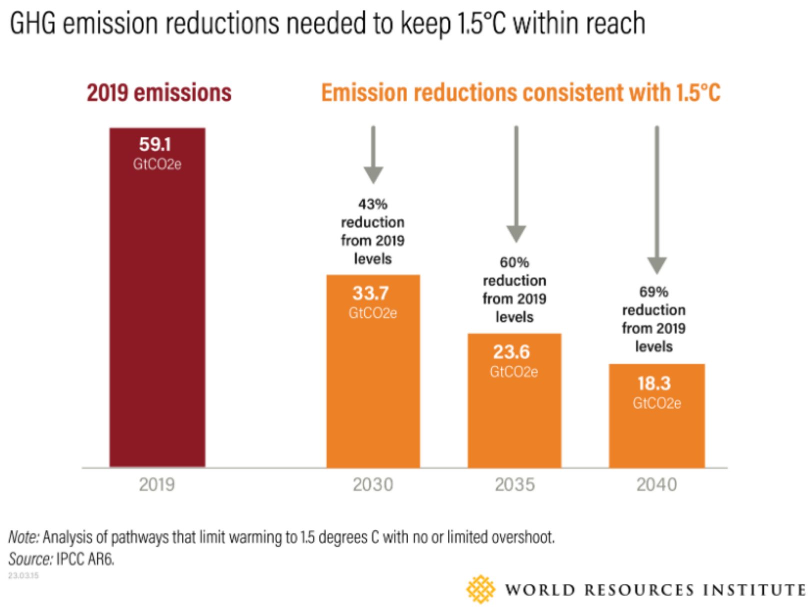


Figure 10. GHG emission reductions to limit global warming to 1.5°C above pre-industrial levels[4]

Reducing anthropogenic GHG emissions will likely require some combination of an increase in power generation from renewable and other zero-carbon energy sources[III], curtailment of fossil fuel use, an overall reduction in energy use, and a reduction in methane and N_2O emissions. To maintain energy security, the fossil fuel use decrease needs to be balanced by increased and reliable power generation from renewable and other zero-carbon energy sources. Primary actions to achieve these goals include:

- An increase in power generation from renewable and zero-carbon energy sources would include a steep increase in solar- and wind-generated electricity, increased use of zero-carbon hydrogen fuel, and possibly an increase in nuclear energy.
  - Renewable energy sources include hydroelectric, geothermal, biomass, wind, and solar and these sources provide about 12.4% of the energy used in the U.S. (see Figure 9). Solar- and wind-power generated electricity currently provide about half of this energy, or about 6% of the energy used in the U.S. This percentage is anticipated to continue to increase rapidly. The cost to produce solar- and wind-power generated electricity has significantly decreased. The levelized cost of electricity (LCOE)[IV] generated by solar

[III] The literature uses various terms to describe energy sources with no GHG emissions during energy generation. "Renewable" energy sources include hydroelectric, geothermal, biomass, wind, and solar. These are sometimes referred to as "clean" energy sources and this term is used in this paper when the reference document uses this term. "Zero-carbon" energy sources include the above renewable sources and other energy sources that do not emit GHGs during energy generation such as hydrogen combustion and nuclear. It should be noted that there are GHG emissions associated with all energy sources (e.g., during energy plant construction and operation and from mining of minerals), but lifetime GHG emissions from these "zero-carbon" sources are a small fraction of emissions from fossil fuel energy sources.

[IV] LCOE = (Present Value of Total Cost of an Electricity Project Over its Lifetime)/(Present Value of All Electricity Generated by an Electricity Project Over its Lifetime) photo-voltaic (PV) power decreased 89% from 2010 to 2022 and the LCOE generated by on-shore wind power systems decreased 69% from 2010 to 2022. In 2022, the global weighted-average LCOEs of new solar-PV and onshore wind projects were 29% and 52% lower than the cheapest fossil fuel-fired solutions, respectively.[7] High fuel prices in 2021 and 2022 contributed to these differences, but the cost to produce solar PV- and wind-power generated electricity is likely to decrease as capacity and infrastructure increase. Further, an outcome of the COP28 conference was a call for parties to triple global renewable energy capacity by 2030.[8]

- A consideration is that solar- and wind-power electricity generation only occurs when the sun is shining and the wind is blowing; thus, energy storage and/or alternative power sources are needed. Primary energy storage options include batteries and renewable energy generated hydrogen (H_2). Increasing battery storage capacity will require bolstering supply chains for lithium, rare earth metals, and other key battery components (i.e., develop domestic supplies and international suppliers other than China[9]) and improving battery technology and production capacity. Sodium ion based-, rather than lithium ion based-, batteries could be used for large, stationary battery storage systems. Sodium batteries are heavier than lithium batteries and likely not practical for mobile systems, but could be cost-effective for stationary batteries.[10]

- Hydrogen combustion only produces water and H_2 produced by water electrolysis using zero-carbon power, such as renewable energy, can power vehicles and be used for industrial processes and electricity generation (e.g., when solar- and wind-power are not available). Another zero-carbon H_2 source is methane pyrolysis, which uses high temperature to produce H_2 gas and solid carbon from methane. It may be economically viable to produce large quantities of on-site H_2 to power electricity generation and industrial plants using existing natural gas infrastructure. Such applications would have associated GHG emissions (e.g., from natural gas production and transmission), but have much smaller GHG emissions than current natural gas-fired equipment.

- Nuclear power is a zero-carbon emissions source of reliable electricity that is not dependent on sun and wind conditions and is a viable complement to solar- and wind-power generated electricity. At the COP28 Conference, U.S. Special Envoy for Climate John Kerry told the conference "you can't get to net zero in 2050 without some nuclear."[11] However, concerns about safety and waste disposal can inhibit nuclear power plant projects and these concerns need to be addressed. For example, Bill Gates founded TerraPower, which is scheduled to open a new nuclear power plant in Kemmerer, Wyoming in 2030. The power plant will be the first of its kind using liquid sodium rather than water for cooling and designed to be safe and practical for the future.[12]

- <u>Steady phase out of the use of fossil fuels</u>, which are currently the source of about 79.3% of the energy used in the U.S. (see Figure 9).

  - Coal is primarily used for electricity generation (see Figure 7). Coal use in the U.S. has decreased by about 50% over the past 15 years[13] and, generally consistent with proposed GHG emissions standards for coal-fired power plants[14], the use of coal will likely be phased out over the next 10-15 years and replaced by renewable energy and possibly nuclear energy. Retraining workers in the coal sector for renewable energy sector jobs is discussed below.

- Oil is primarily used for transportation (see Figure 7) and reduced demand for and use of oil requires a rapid transition to electric vehicles and increased mileage standards for (more efficient) gasoline and diesel vehicles. The California Advanced Clean Cars Rule II has a yearly new zero-emission vehicles sales schedule starting in 2026 such that all new cars, light trucks and sport utility vehicles sold in California by 2035 will be zero-emission vehicles.[15] Lessons learned from the implementation of this rule can be used to develop policies for widespread adoption of electric vehicles. Practical considerations for the widespread adoption of electric vehicles include building a reliable system of fast-charging stations, developing supply chains of sufficient scale to manufacture affordable electric cars, and zero-carbon electricity sources. The Inflation Reduction Act includes incentives for installing charging stations and manufacturing electric vehicles. H_2 fueled vehicles are a zero-carbon emissions option but currently do not have a significant fueling system.[16]
- Natural gas is used for electric power generation and industrial processes and in commercial and residential applications (see Figure 7). The combustion of natural gas, which is primarily methane, has much lower CO_2 emissions than coal and oil and is a bridge fuel from a fossil fuel-based economy to a zero-carbon- and renewable energy-based economy. Combined-cycle gas-fueled power plants operate at a higher efficiency and have much lower CO_2 emissions per unit energy than coal- and oil-fired electricity generation systems. A primary GHG emissions consideration for natural gas use is that methane emissions from natural gas leaks and venting during production, transportation, and distribution need to be minimized. As discussed above, methane pyrolysis has the potential to be a zero-carbon source of H_2 to power electricity generation and industry.

- <u>Reduce overall energy use by improving the energy efficiency of equipment and processes</u> throughout the economy. Options include:
  - "Improving energy efficiency in buildings, appliances, and light- and heavy-duty vehicles and other transportation modes,
  - Implementing urban planning and building design that reduces energy demands through more public transportation and active transportation and lower cooling demands for buildings,
  - Increasing the efficiency and sustainability of food production, distribution, and consumption."[6]

  An outcome of the COP28 conference was a call for parties to double energy efficiency improvements by 2030.[8]

- <u>Reduce methane emissions starting with the largest emissions sources</u>: livestock, natural gas and petroleum systems, and landfills.

- Livestock methane emissions are primarily from enteric fermentation and manure management. Enteric fermentation emissions can be reduced by adjusting the feed composition[17] and manure management practices can be implemented to capture methane emissions to be combusted or processed to renewable natural gas.
- Methane emissions from natural gas and petroleum systems are primarily from leaking equipment and vented process gas. Regulations to reduce these emissions exist and more stringent regulations could be warranted.
- Regulations exist that require capture and destruction of landfill methane, but the capture systems are not perfect. A society-wide reduction in waste generation would reduce landfill emissions. For example, composting of food waste produces a useful product (biologically-stable mulch) rather than methane and CO_2 in a landfill.
- Another relatively large emissions source, coal mining, could be mitigated as coal use is phased out, although methane seepage from abandoned mines is an emissions source.

• <u>Reduce N_2O emissions by improved agricultural soil management practices</u>, which account for the majority of N_2O emissions. N_2O is produced in soil through nitrification and denitrification processes, and the amount produced is impacted by soil moisture, temperature, carbon, nitrogen, and oxygen**.**

- Controlling nitrogen supply is the primary approach for reducing N_2O emissions. This includes use of less and slow-release fertilizers; optimizing the amount, timing, and method of fertilizer application; and use of nitrogen inhibiting plant treatments.
- Optimizing crop management practices such as tillage, irrigation, and crop rotation can also reduce N_2O emissions.[18]

• <u>Develop and implement carbon removal technologies and processes</u>.

Table 3 lists carbon removal technologies and processes with relative rankings of carbon removal potential, technical complexity, and cost. The options are listed in order of lower to higher cost. Natural processes such as growing forests, restoring ecosystems, and farming smarter have low cost and low complexity and should be prioritized for implementation. Technology approaches such as mineralizing carbon, pumping seawater, and carbon capture from the atmosphere, combustion emissions, and process emissions are more expensive and complex. Direct capture and sequestration of CO_2 emissions from combustion and other process is not listed in Table 3 – although direct capture and sequestration has high carbon removal potential, it is a relatively expensive and complex process that might be best implemented by private industry to offset a GHG/carbon emissions fee or tax (see Section 7).

Table 3. Carbon Removal Technologies and Processes[19]

Technology/ Process	Description	C Removal Potential	Technical Complexity	Cost
Farming Smarter	Carbon can be sequestered by proper management of agricultural soils. This includes targeted tilling rather than plowing entire fields and planting cover crops when not in growing season.	⟳⟳	¤	$
Growing Forests	Reforest areas that that previously had trees and plant trees in new areas. Forests are natural sinks that can sequester carbon for centuries.	⟳⟳	¤	$
Restoring Ecosystems	Marine ecosystems enhance the transfer of carbon from the ocean surface to floor via currents and food chains – when sea animals and plants (e.g., kelp) die, carbon-laden biomass sinks to the ocean floor.	⟳	¤	$
Farming Underwater	Seaweed absorbs CO_2 via photosynthesis to grow. Sinking farmed seaweed to the seafloor stores CO_2 (e.g., in sediment).	⟳	¤	$
Mineralizing Carbon	Industrial-scale accelerated bonding of atmospheric CO_2 with surface mining waste and underground rocks.	⟳⟳⟳⟳	¤ ¤ ¤ ¤	$$
Fertilizing Oceans	Adding fertilizer to surface waters increases phytoplankton absorption of CO_2 via photosynthesis and increases the carbon-storage capacity of the marine ecosystem.	⟳⟳	¤ ¤ ¤ ¤	$$
Coastal Preservation	Preserving and restoring coastal habitats (e.g., salt marches, seagrass beds) that are natural carbon sinks.	⟳	¤	$$
Mineralizing Oceans	Natural carbonization processes are accelerated by adding alkaline compounds to the ocean to bond carbon with sediments and rocks.	⟳⟳	¤ ¤	$$$
Harnessing Biomass	Grow plants, which absorb atmospheric CO_2 during photosynthesis, and burn them for energy. Then trap and store the CO_2 from combustion (e.g., sequester underground).	⟳⟳	¤ ¤	$$$
Pumping Seawater	Cold, nutrient rich seawater is pumped to the surface to promote phytoplankton growth and CO_2 absorption. Pumping down oxygenated surface water counteracts dead zone formation.	⟳	¤ ¤	$$$
Electrifying Seas	Electric current is passed through seawater to directly remove CO_2.	⟳	¤ ¤ ¤	$$$
Direct Air Capture	Large fans pass atmospheric air through solid and liquid solvents to trap CO_2. The CO_2 is then sequestered underground or otherwise managed.	⟳⟳⟳⟳	¤ ¤ ¤ ¤	$$$$

7.0 Policies and Incentives to Mitigate Climate Change

Section 6 discussed technologies and practices to reduce GHG emissions and remove CO_2 from the atmosphere. The objectives of policies and plans to mitigate climate change include:

1. Require and incentivize the implementation and increased use of these, and possibly other, technologies and practices.
2. Ensure a continued, reliable, and secure energy supply for the U.S. and continued economic growth during the transition to a lower GHG economy. That is, a steady progressive reduction in fossil fuel use balanced by an increased supply of energy from renewable (e.g., solar, wind) and other zero GHG emissions sources (e.g., hydrogen, nuclear) to maintain U.S. energy security is needed.
3. Target a GHG emissions reduction schedule consistent with the Paris Agreement emission reduction schedule discussed below.
4. Incentivize global GHG emissions reductions.
5. Make the U.S. the world leader in the energy systems of the future.

Section 7.1 discusses existing policies, laws, and agreements intended to reduce GHG emissions and mitigate climate change. Additional actions will be needed to limit global surface temperature rise, and priority policy options are discussed in Section 7.2 and a general discussion of the need for a U.S. plan for GHG emissions reduction, energy security, and clean technology development is in Section 7.3

7.1 Existing Policies, Laws, and Agreements

Existing Policies, Laws, and Agreements that impact GHG emissions in the U.S. include, but are not limited to:

- The Inflation Reduction Act (IRA) of 2022 provides financial incentives for the U.S. to transition to a lower GHG emissions economy. It includes about $400 billion in funding for a wide range of clean energy and climate spending including, but not limited to:
  - tax credits for manufacturing solar panels, batteries, wind turbines, and processing critical minerals;
  - tax credits, loans, and grants for manufacturers of electric and clean vehicles;
  - consumer tax credits, rebates, and loans for electric vehicles and home energy efficiency improvements;
  - grants, loans, tax credits, and funding for clean energy projects and technologies (e.g., for electricity generation, industry, manufacturing, transportation) and to reduce methane leaks from natural gas systems;
  - tax credits, grants, and funding to support low-GHG agriculture practices, preservation and restoration of forests, and develop sustainable biofuels.[20]

A recent report by Bristline et al "leverage(d) results from nine independent, state-of-the-art models to examine potential implications of key IRA provisions, showing economy-wide emissions reductions between 43% and 48% below 2005 levels by 2035."[21]

- The U.S. has rules to reduce methane emissions such as New Source Performance Standards (NSPS) for oil and natural gas operations. A update to this rule to further reduce emissions was signed on November 30, 2023 (see 40 Code of Regulations (CFR) part 60, subpart OOOOb). Based on this rule, a methane emissions fee is assessed on specific sources according to emissions thresholds criteria. There is a fee exemption for facilities in states complying with EPA regulations. The initial methane emissions fee is $900 per metric ton and after two years increases to $1,500 per metric ton. Based on a methane GWP of 25, $1,500 per metric ton CH_4 equals $60 per metric ton CO_2.

- The Paris Agreement is an international climate change treaty adopted in 2015 by 196 parties at a United Nations conference held in Paris. "Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels""[22] IPCC analysis is that global warming above 1.5°C will cause "far more severe climate impacts, including more frequent and severe droughts, heatwaves, and rainfall"[22]; thus, limiting warming to 1.5°C has become the preferred goal.

  > "limiting global warming to 1.5°C with no or limited overshoot requires deep, rapid and sustained reductions in global greenhouse gas emissions of 43 per cent by 2030 and 60 per cent by 2035 relative to the 2019 level and reaching net zero carbon dioxide emissions by 2050"[23]

  The Agreement is implemented by countries developing national climate plans that include emission reduction targets and actions to achieve these targets. Targets, actions, and emissions are reviewed on a 5-year cycle with more ambitious targets and associated actions for each cycle. The U.S. dropped out of the Agreement in 2020 under the Trump Administration and then rejoined in 2021 under the Biden Administration.

- COP28[V], the 2023 United Nations climate change conference in Dubai concluded in mid-December. The Draft Decision[23] released at the end of the conference noted that AR6 determined that the change in the GHG emissions reduction trajectory has been small and that current plans would only reduce GHG emissions by 2030 to about 2% less than 2019 levels. The Draft Decision noted

  > "significantly greater emission reductions are required to align with global greenhouse gas emission trajectories in line with the temperature goal of the Paris Agreement."

  Regarding GHG emissions mitigation actions, the Draft Decision

  > "*recognizes* the need for deep, rapid and sustained reductions in greenhouse gas emissions in line with 1.5 °C pathways and *calls on* Parties to contribute to the following global efforts" that include:

[V] Conference of Parties

- "Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030"
- "Accelerating efforts towards the phase-down of unabated[VI] coal power"
- "Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science"

and other actions include substantially reducing methane emissions by 2030; accelerating use of zero-emission technologies such as renewables, nuclear, and zero-carbon hydrogen; accelerating efforts to low- and net zero-emissions energy systems and transportation; and eliminating inefficient subsidies for fossil fuels.

Recognizing that these are <u>not</u> binding agreements, but rather what signees are "called on" to do, only time will tell if these actions and goals are achieved. A lack of binding agreements may foreshadow a low probability of complete success.

7.2 Additional Policy Options to Reduce GHG Emissions

The new NSPS rules and the IRA financial incentives will reduce U.S. GHG emissions, but it does not appear the U.S. will achieve the emission reduction targets of the Paris Agreement. In addition, the AR6 report determined that current emission reduction plans would only reduce global GHG emissions by 2030 to about 2% less than 2019 levels, emissions far greater than the Paris Agreement target of 43% reduction by 2030. Thus, policies and actions are needed to further reduce U.S. emissions and drive down global emissions. These include:

- <u>Implement a carbon fee with border adjustment to use market forces to promote lower fossil fuel use and GHG emissions</u> .

  An article in The Economist[24] covering the outcome of the COP28 conference summarized

  > "a global agreement is only one small step. A far bigger and harder one is to translate words on a page into action in the real world. … reducing reliance on fossil fuels will ultimately depend on making them uncompetitive. A ***combination of carbon prices and well-targeted subsidies for clean technologies*** [***emphasis added***] can help do so in the rich world."

  The IRA is a good first step for subsidizing clean technologies and eventually driving the energy costs to below those of fossil fuels. A progressive price on carbon/GHG emissions with border adjustment is also needed to use market forces to promote lower fossil fuel use and GHG emissions. Carbon pricing options include cap and trade programs such as used by the European Union[VII] and a tax/fee on fossil fuel energy producers and/or users.

[VI] Coal combustion without combustion CO_2 capture and sequestration.

[VII] The EU Emissions Trading System (ETS) covers GHG emissions from the energy, industrial, and aviation sectors, which emit about 40% of Europe's total GHG emissions. The ETS sets a limit or cap on these emissions and companies bid to purchase emission credits; thus, market forces are used to set the carbon price. Since 2005, the ETS has helped reduce emissions from industrial production and electricity and heat generation by about 37% and raising over 152 billion Euros (as of mid-2023). The emissions cap for 2030 will be 62% less than the 2005 cap. The average ETS price in 2022 was €80.18 per metric ton CO2e (about $69 per U.S. ton).[25]

A Congressional Budget Office (CBO) analysis "Options for Reducing the Deficit" [26] and a "Blueprint for tax reform in 2025" paper by the Hamilton Project[27] both recommend a carbon fee to reduce GHG emissions and Budget Deficits. The CBO plan would impose a $25 per metric ton tax on CO_2 emissions from energy related sources (e.g., transportation, electricity generation) and other GHG emissions from large manufacturing plants and increase the tax at a rate of 2% or 5% plus inflation per year. The Hamilton project proposal is that a "top down" corporate carbon fee would be paid by "a small number of business taxpayers in the coal, oil, and gas sectors" and is intended to have minimal impact on gas prices and energy bills for households. The tax would be gradually implemented over a ten-year period and increase from $15 to $65 per metric ton. The U.S. tax would be paired with a carbon border adjustment fee such that both domestic and foreign producers pay the same GHG emissions fee. For example, if the U.S. has a $20/ton carbon price and a foreign market has a $10/ton carbon price, the border fee would be $10/ton of GHGs required to produce goods from energy intensive industries such as steel, aluminum, and chemicals. This addresses competitiveness concerns for U.S. companies and incentivizes global reductions in GHG emissions and fossil fuel use. It would be a competitive advantage for energy-efficient U.S. companies and further incentivize efficiency improvements.

A carbon fee with border adjustment would result in progress towards achieving objectives 1, 2, 3, 4, and 5. An additional geopolitical consideration is that the current wars in Ukraine and Gaza are funded by oil revenues for Russia and Iran, respectively. Policies that reduce fossil fuel use and depress the price of oil could limit the capacity of these countries to fund and wage war. In addition to many lives saved, the U.S. would benefit financially by lower support for allies in conflict with petro-states and a more stable world economy.

- <u>Provide renewable energy training for workers in the fossil fuel industry</u> to promote efficient economic growth during the transition to a lower GHG economy. The clean energy sector currently employs about half of the world's energy workers and the International Energy Agency's (IEA) Net Zero by 2050 pathway projects 14 million jobs will be created by 2030 by clean energy activities and investment.[28] Many oil and gas workers may be able to quickly transition to the renewable and zero-carbon energy sector.

> "Oil and gas workers often have skills that transfer naturally to renewable energy positions. For example, chemical engineers can help produce green hydrogen to power trucks. Petroleum engineers can bring their knowledge to geothermal drilling jobs, while offshore oil workers can transfer to offshore wind, hydrogen, and carbon capture and storage facilities. Fossil fuel workers also have a litany of other qualifications—physical endurance, a strong work ethic, and the ability to get along with people—that renewable energy companies are looking for." [29]

However, many of these new jobs will not be in the same location as displaced fossil fuel workers or require the same skill set, and policies and programs are needed to address such mismatches. Current programs include the POWER Initiative and the Renewable Energy Tax Credit. The POWER Initiative, operated in the U.S. by the Economic Development Administration, helps coal-based communities change industries. Such federal assistance provides workers access to otherwise unaffordable training. Programs like the Renewable Energy Tax Credit program subsidize renewable energy for businesses and homeowners, which creates jobs and provides funding to renewable energy companies to train new workers.[29]

Figure 11 from the 5th NCA 2023 shows the potential net job growth in the U.S. from 2020 to 2050 for different transitions from a fossil-fuel economy to a net-zero economy with greater renewable energy.

- 100% Renewable corresponds to an energy future where "renewables produce 100% of energy". It is estimated that this energy future would create a net of about 5 million jobs in the next 25 years;
- Renewables Constrained corresponds to "renewables produce much less energy and nuclear and fossil energy with carbon capture and storage are prevalent;"
- High electrification corresponds to an "energy future in which nearly all buildings and transport are electrified but there are no constraints" (e.g., to percent renewables).

These data show the great potential for job growth provided the transition from fossil fuels to renewable energy can be efficiently managed with minimal disruptions to fossil fuel-based communities. Job growth in the renewable energy sector would result in progress towards achieving objectives 2 and 5.

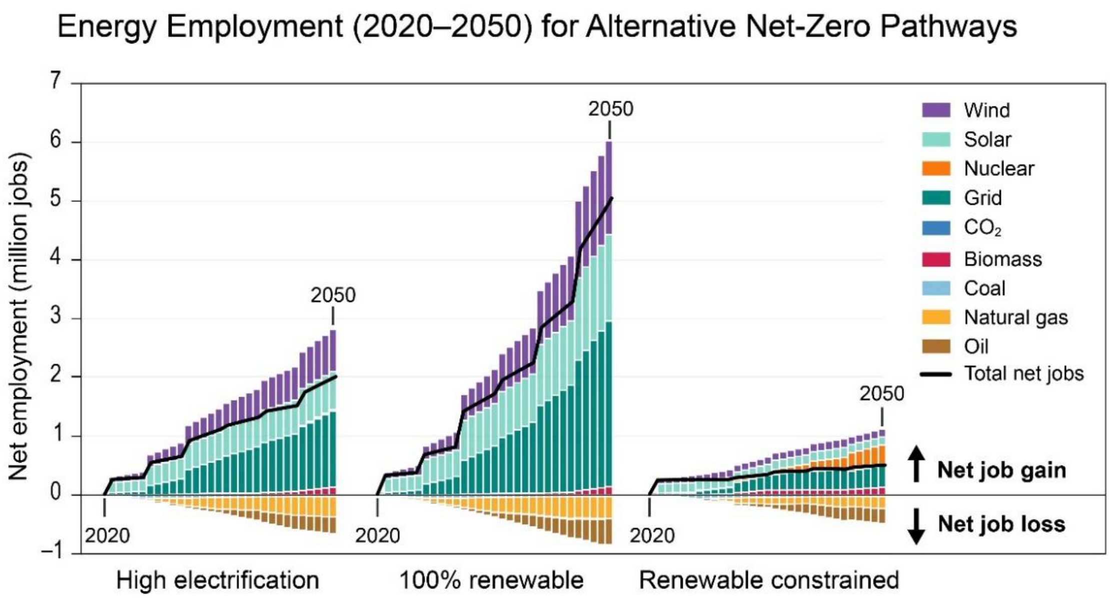


Figure 11. A transition to renewable energy is projected to increase the number of energy sector jobs in the U.S.[6]

- <u>Eliminate inefficient fossil fuel subsidies</u>. At a recent U.S. Senate Budget Committee hearing[30], it was estimated that the U.S. government pays about $20 billion a year to the fossil fuel industry, and that global subsidies to fossil fuel in 2022 were about $1 trillion despite profits of about $4 trillion. Research was presented that estimated that "pollutants from oil and gas combustion were responsible for 8.7 million premature deaths annually." The International Monetary Fund estimates that these harms combined with "costs from intensifying disasters: wildfires, floods, droughts" total $646 billion a year in the U.S. and $5.4 trillion worldwide. In addition to supporting an elimination of fossil fuel subsidies, these data support implementation of a carbon/GHG tax as discussed above. Eliminating these subsidies would result in progress towards achieving objectives 2 and 3.

- Promote an increase in low-cost natural carbon sinks. Table 3 lists farming smarter, growing forests, restoring ecosystems, farming underwater, and coastal preservation as options to increase low-cost natural carbon sinks. Policies to promote these could include designating federal lands for forests, laws to prohibit or limit development of coastal habitats, grants and/or tax incentives, and/or partial credits against the carbon fee/tax. Promoting an increase in these carbon sinks would result in progress towards achieving objectives 1 and 3.
- Pass laws to reduce emissions of methane and N_2O from agriculture systems. Compared to measuring GHG emissions from combustion and industrial processes, measurement of GHG emissions from some agriculture systems is complex, costly, and inaccurate. Thus, applying a carbon tax to many of these emissions would be problematic. Passing laws to require implementation of technologies and practices known to reduce emissions would likely be a better option. Reducing methane and N_2O emissions would result in progress towards achieving objectives 1 and 3.
- Development and implementation of carbon capture and sequestration technologies from combustion and industrial processes and from the atmosphere should be a decision by fossil fuel and other impacted industries, which might find the economics beneficial versus paying a carbon emissions fee. Developing carbon capture and sequestration technologies would result in progress towards achieving objectives 1, 3, and 5.

7.3 The U.S. Needs a Plan for GHG Emissions Reduction, Energy Security, and Clean Technology Development

The U.S. needs to develop a comprehensive plan to mitigate climate change that includes GHG emissions reduction and carbon capture targets with a milestone schedule. Priority strategies to achieve these targets include phasing out fossil fuels balanced by increased renewable energy use (energy security), steeply reducing methane emissions, and developing carbon sinks (e.g., new forests and reforestation).

The plan should also promote the U.S. as a world leader of the low-cost clean technologies of the future. At this time, China is way ahead of the U.S. in many key areas including manufacturing of lithium-ion batteries for electric vehicles, solar- and wind-power equipment, and electric vehicles. China currently has about 74% of the global lithium-ion manufacturing capacity compared to about 11% for the U.S.[31], over 80% of the global solar-PV manufacturing capacity compared to 1-2% for the U.S.[32], and about 60% of the global wind-power equipment manufacturing capacity compared to less than 10% for the U.S.[32]. In addition, about 60% of the electric vehicles sold world-wide in 2022 were sold in China[33]. As demand for renewable energy and electric vehicles increases and they become more economical than fossil fuels and gasoline-powered vehicles, the U.S. needs to reverse these trends or risk permanently ceding dominance to China. This plan would result in progress towards achieving objectives 1, 2, 3, 4, and 5.

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