A Review of Sustained Climate Action through 2020

United States

7th National Communication

3rd and 4th Biennial Report

A Review of Sustained Climate Action through 2020

United States

7th National Communication

3rd and 4th Biennial Report

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

2014 NC	2014 6th National Communication
2016 BR	2016 2nd Biennial Report
ACCO	Association of Climate Change Officers
AEO	Annual Energy Outlook
AI	Artificial intelligence
ALFRESCO	Alaska Frame-Based Ecosystem Code
APIK	Adaptasi Perubahan Iklim dan Ketangguhan
BAB	Be A Buddy
BECP	Building Energy Codes Program
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Management
BRACE	Building Resilience Against Climate Effects
BRIC	Building Resilient Infrastructure and Communities
C	Carbon
CARPE	Central Africa Regional Program for the Environment
CASCs	Climate Adaptation Science Centers
CE	Committee on the Environment
CEM	Clean Energy Ninisterial
CEM BfPIn	Biofuture Platform Initiative
CEM CCUS	Carbon Capture Utilization and Storage Initiative
CEM H2I	Clean Energy Solutions Center, Hydrogen Initiative
CESC	Clean Energy Solutions Center
CFCs	Chlorofluorocarbons
CH4	Methane
CIRA	Climate Impacts and Risk Analysis
CLEAN	Climate Literacy and Energy Awareness Network
CO2	Carbon dioxide
COFIDE	Development Bank of Peru
CRA	Collaborative Research Action
CREAT	Climate Resilience Evaluation and Awareness Tool
CRF	Common Reporting Format
CRP	Conservation Reserve Program
CRSCI	Climate Ready States and Cities Initiative
CTCN	Climate Technology Center and Network
CTSL	Clean and Advanced Technologies for Sustainable Landscapes Program
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior

DOS	Department of State
EC-LEDS	Enhancing Capacity for Low Emission Development Strategies
ECV	Essential Climate Variable
EERE	Energy Efficiency & Renewable Energy
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
ERDC	Engineer Research and Development Center
ESGF	Earth System Grid Federation
EVs	Electric vehicles
FAA	Federal Aviation Administration
FARG	Federal Adaptation and Resilience Group
FASOMGHG	Forest and Agricultural Sector Optimization Model with Greenhouse Gases
FEMA	Federal Emergency Management Agency
FFII	Forest Finance and Investment Incubator
FHWS	Federal Highway Administration
FIA	Forest Inventory Analysis
FOROM	Global Trade Model
FSA	Farm Service Agency
GAO	Government Accounting Office
GAW	Global Atmosphere Watch
GCMs	General circulation models
GCOS	Climate Observing System
GCOS	Global Climate Observing System
GCRA	Global Change Research Act
GDP	Gross domestic product
GEB	Grid-Interactive Efficient Buildings
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GPP	Green Power Partnership
GSN	Surface Network
GTM	Global Timber Model
GUAN	GCOS Upper Air Network
GW	Gigawatts
GWP	Global warming potential
HEARTH	Health, Ecosystems and Agriculture for Resilient Thriving Societies
HFCs	Hydrofluorcarbons
HUD	Housing and Urban Development
IGBZ	Integrated Gorongosa and Buffer Zone
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use

ISEIs	Informal science education institutions
ISGAN	International Smart Grid Action Network
JPSS	Joint Polar Satellite System
K	Kindergarten
Km2	Square kilometers
KWh	Kilowatt-hours
LDC	Least-developed countries
LEM	Light-emitting diode
LFGTE	Landfill-gas-to-energy
LPO	Loan Program Office
LRG	Integrated Land and Resource Governance
LULUCF	Land use, land use change, and forestry
MDB	Multilateral development banks
MI	Mission Innovation
Mi2	square miles
MIPs	Model Intercomparison Projects
MMT	Million tonnes
MMtCO2e	Million metric tons of carbon dioxide equivalent
MOSAiC	Multidisciplinary Drifting Observatory for the Study of Artic Climate
MRV	Monitoring, reporting and verification
MSW	Municipal solid waste
MW	Megawatts
N2O	Nitrous oxide
NAP	National Adaptation Planning
NASEM	National Academies of Sciences, Engineering and Medicine
NCA	National Climate Assessment
NCA4	Fourth National Climate Assessment
NEON	National Ecological Observatory Network
NESDIS	National Environmental Satellite Data and Information Service
NF3	Nitrogen trifluoride
NGSS	Next Generation Science Standards
NICE Future	Nuclear Innovation: Clean Energy Future Initiative
NIFA	National Institute of Food and Agriculture
NMVOCs	Volatile organic compounds
NNOCCI	National Network for Ocean and Climate Change Interpretation
NPS	National Park Service
NREL	National Renewable Energy Laboratory
NSTC	National Science and Technology Council
OAP	Office of Atmospheric Programs
ObsIWG	Observation Interagency Working Group
OCOF	Our Climate Our Future

OCS	U.S. Outer Continental Shelf
ODS	Ozone depleting substances
OECD	Organization for Economic Development
OIB	Operation IceBridge
OMG	Oceans Melting Greenland
ONE-SL	Offset National Emissions through Sustainable Landscapes
PACE-R	Partnership to Advance Clean Energy-Research
PFCs	Pefluorocarbons
PIER	Private Investment for Enhanced Resilience
PMI	President's Malaria Initiative
PRIME	Pastoralists' Areas Resilience Improvement through Market Expansion
RD&D	Research, design, and development
REAP	Rural Energy for America Program
REGIS-ER	Resilience and Economic Growth in Sahel-Enhanced Resilience
RFS	Renewable Fuels Standard
RGGI	Regional Greenhouse Gas Initiative
RPA	Resource Planning Act
RUS	Rural Utilities Service
SCEP	Strategic Clean Energy Partnership
SF6	Sulfur hexafluoride
SHADOZ	Southern Hemisphere ADditional OZonesondes
SIDS	Small island developing states
SNAP	Significant New Alternatives Policy
SO2	Sulfur dioxide
SSP2	Shared Socioeconomic Pathway 2
START	SysTem for Analysis, Research and Training
STEM	Science, Technology, Engineering and Math
TCI	Regional Transportation and Climate Initiative
TEC	Technology Executive Committee
TFI	Task Force on Green House Gases
TGCC	Tenure and Global Climate Change
TMLA	Total manufactured layer area
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNFCCC	U.N. Framework Convention On Climate Change
USCRN	U.S. Climate Reference Network
USDA	United States Department of Agriculture
USFS	U.S. Forest Service
WCRP	World Climate Research Programme
WFF	World Fab Watch
WM	With measures

7TH NATIONAL COMMUNICATION

INTRODUCTION

Climate change is the greatest existential threat we face tODAy. It challenges nearly every facet of our society, our economy, and our wellbeing. The effects are already being felt throughout the United States, from communities on our islands and low-lying coasts to those on the slopes of our highest mountains, and by rural residents and city dwellers alike. Unfortunately, the effects of climate change most disproportionately affect those who are already most disadvantaged. These same dynamics are felt around the world, from the smallest tropical islands to the Arctic.

The Biden-Harris Administration has recognized the urgent need to resume United States leadership in combatting the climate crisis and shepherding the global transition to clean energy. Beginning on the first day of the Administration, President Biden made tackling climate change a top priority at home and abroad. Transparency is a core element of this leadership – on the actions we take, the support we provide to others, and the impacts of climate change on the United States.

In this light, we are pleased to present this combined 7th National Communication, and 3rd and 4th Biennial Report, to the U.N. Framework Convention on Climate Change (UNFCCC). These reports were originally due in 2018 and 2020, respectively. As such, the document reflects policies, measures, and support provided during the periods that correspond to those reports. Updated contextual information has also been provided throughout the reports to provide the most accurate depiction of continued climate action in the United States over this period.

The information contained in the National Communication and Biennial Reports reflects not only the policies and programs of the federal government between 2016-2020, but also the sustained leadership by U.S. subnational governments, Tribal Nations, businesses, and civil society in ensuring climate action continued throughout this country over this whole period. This—and market trends—drove continued reductions in greenhouse gas emissions over the whole period.

This historically-focused document is complemented by the National Climate Strategy, which outlines the U.S. plans for achieving our nationally determined contribution (NDC) in 2030, and the Long-Term Strategy, which provides a summary of pathways to reach net-zero emissions across the U.S. economy by no later than 2050. These two documents reflect the ambitious commitment of our nation to use all the tools within our power to combat climate change at home, and to catalyze climate ambition globally. We intend to report on the impacts of these renewed efforts in future reports to the UNFCCC and the Paris Agreement.

Climate change is humanity's greatest challenge but also our greatest opportunity to invest in a more equitable, sustainable, and prosperous society. Each and every one of us must step up to address this threat and seize the opportunity, to place the world on a pathway to limit global temperature rise to no more than 1.5 degrees C and avoid the most catastrophic climate impacts. The Biden-Harris Administration is committed to working with partners, in the United States and around the world, to accelerate this effort. We simply must succeed.

John Kerry
Special Presidential Envoy for Climate

Gina McCarthy
National Climate Advisor

1
EXECUTIVE SUMMARY

When we think of climate change...
dealing with this existential threat to the planet and
increasing our economic growth and prosperity are one and the same.
President Joseph R Biden, January 27, 2021

Climate change is perhaps the greatest threat to our world, the well-being of our people, the health of our ecosystems and the growth of our economies. Bold actions by the international community and the public and private sectors in all countries are essential to solve these problems particularly by the major emitters that account for nearly 80 percent of global greenhouse gas emissions.

The United States recognizes that a whole-of-government approach is needed to address this challenge efficiently, effectively, and equitably while strengthening our economy and creating good paying, high-quality jobs. Strong and predictable policy catalyzes private sector investment in solutions like clean power, fuels, and storage; electrification of transportation and buildings; low-carbon industry; and zero-emission, climate-resilient infrastructure. Polices, programs, and incentives can shape land-use decisions and protect the ecosystems that sequester and store carbon and provide protection against extreme weather events, while at the same time enhancing the clean production of the commodities and resources on which we depend.

President Joseph R. Biden is firmly committed to combating the climate crisis at home and abroad. On his first day in office, he began the process to rejoin the Paris Agreement to restore U.S. leadership on climate action. In his first 100 days, he hosted the first-ever global Leaders' Summit on Climate with 40 world leaders, where he announced the new U.S. nationally determined contribution (NDC) to achieve an economy-wide target of reducing net greenhouse gas (GHG) emissions by 50-52 percent below 2005 levels in 2030. Combined with strong NDCs announced by major economies and other key countries, this announcement put over half the global economy on the pace to reduce emissions to levels needed to stay within reach of a global average temperatures at or below a 1.5 degrees Celsius increase.

The United States is taking a comprehensive approach across all sectors and gases to deliver on our ambitious climate targets. Across the executive branch, Congress, and diverse subnational actors, new actions are being implemented to reduce emissions and invest in our economy. The Biden Administration is marshaling the entire federal government to address climate change in everything it does. Agencies are assessing and will be developing regulations, standards and programs rooted in existing legislation across every sector, from cutting emissions from the transportation, power, industrial, and buildings sectors to measures to enhance land and coastal carbon sinks and reduce potent methane and hydrofluorocarbon greenhouse gases.

The Biden Administration is complementing these domestic actions with a renewed commitment to supporting climate ambition and enhanced resilience around the world, including pledges to work with Congress to quadruple our annual public climate finance to developing countries by 2024.[1] As part of this overall quadrupling goal, the Biden Administration plans to increase adaptation finance six-fold.

These federal actions are complemented by a groundswell of support for climate action across the country, which is also reflected in the dramatic expansion of climate actions taken by non-Federal actors. Over the last several years U.S. states, territories, cities, and tribal governments have enhanced their climate commitments. At least 24 states, and Puerto Rico, have committed to reducing collective net greenhouse gas emissions at least 26-28 percent below 2005 levels in 2025 and 50-52 percent in 2030, and to collectively achieving overall net-zero greenhouse gas emissions as soon as practicable, and no later than 2050. At least nine states, along with Washington, D.C., and Puerto Rico, have passed legislation to implement 100 percent clean electricity policies and economy-wide greenhouse gas pollution-reduction programs.[2]

Beyond this, thousands of mayors, state and city legislatures, tribal leaders, private sector leaders, county executives, faith leaders, university presidents, and investors have committed to ambitious climate action in line with the Paris Agreement.[3] Collectively, these entities have significant policy authorities under the U.S. federal system and, by connecting with diverse populations and resources, can significantly bolster and accelerate emissions reductions across the country. The leadership of this broad, deep coalition of stakeholders will continue to be needed to address the climate crisis with the ingenuity, dedication, and resources it deserves in order to create a safer, more equitable, and resilient zero carbon future for the American people and the world.

This 7th National Communication, and the combined 3rd and 4th Biennial Report contained in Annex 1 of this document, present efforts to address climate change undertaken by a range of stakeholders in the United States over the last five years, helping to drive continued economic growth, high-quality job creation, greater equity, and innovation. The document reviews our sustained progress in reducing emissions over the past decade, which has continued despite changes in leadership at the federal level, and highlights our efforts to support other countries interested in making a similar transition to a more prosperous, equitable, and resilient future. While this report focuses on primarily on policies in place by December 2020, the Biden Administration is also releasing a National Climate Strategy and a Long-Term Strategy that outline how its new policies and measures will put the U.S. economy on track to meeting its 2030 NDC target, and to achieving net zero emissions no later than 2050. Future reports will communicate progress against these goals.

Following Chapter 1 containing this Executive Summary, Chapter 2 describes the national circumstances of the United States, including shifts in our energy sector brought about by national and subnational policies, cost reductions and investments in renewable energy, advances in fuel efficiency, the sharp fall in the costs of solar and wind energy, increased demand for natural gas as a transitional fuel, the shift to a service economy, and changes in forests and land use that are affecting emissions and removals.

Chapter 3 summarizes United States' national greenhouse gas inventory report submitted in April 2021. This report showed a 13.1 percent decrease in U.S. net greenhouse gas emissions from 2005 to 2019, and with accompanying summary tables and charts.

Chapter 4 includes information on U.S. policies that are relevant to efforts to mitigate climate change. This chapter reflects broad-based efforts by previous administrations to promote clean and renewable energy, improve energy efficiency, advance transportation technologies, reduce pollution stemming from industrial processes, reduce carbon dioxide emissions from power plants and industrial sources, stimulate the adoption of improved agricultural technologies, protect and enhance forests and other ecosystems, and spur research and development. This chapter also reflects the sustained efforts of our states, territories, cities, tribal nations, companies, and civil society organizations to address climate change. These are a sampling of the prior efforts that have yielded declining U.S. greenhouse gas emissions over the past decade, even as our economy grew. Our forward-looking efforts are covered in more detail in the National Climate Strategy.

Chapter 5 reflects the projections through 2035 of expected greenhouse gas emissions and removals associated with current policies and measures (in place through the end of 2020). These projections include a range that reflects the uncertainty around the future of the terrestrial carbon sink. This chapter is complemented by additional projections included in the National Climate Strategy.

Chapter 6 provides information on recent scientific assessments of vulnerability to climate change and its impacts. It highlights efforts by the federal government, subnational governments, tribes, businesses, and civil society to increase the resilience of American communities, the economy, infrastructure and landscapes to impacts from extreme events and changing conditions, including those related to climate change. This chapter further highlights our efforts to support other countries in advancing climate adaptation efforts and enhance climate resilience.

Chapter 7 contains information on the support provided by the United States to help developing country partners address their climate change priorities, improve the enabling conditions that lead to more effective action, decrease emissions from all sources and strengthen sinks, reduce vulnerabilities, monitor implementation and results, and ultimately transition to a context in which such external support is not needed.

Chapter 8 provides information on American scientific leadership in research and systematic observation. U.S. leadership in this space contributed greatly to a better understanding of climate systems, greenhouse gas fluxes, and land use change, amongst other topics, and has enhanced capacities to predict and plan for extreme weather as well as baseline climate change across the country.

Chapter 9 includes highlights of activities related to education, training, and public awareness related to climate change led by the federal government, as well as a broad cohort of other U.S. stakeholders.

Annex 1 contains the joint 3rd and 4th Biennial Report of the United States, which includes all required information not reported elsewhere in the National Communication.

Annex 2 provides information on mitigation policies and measures in a tabular format. Annex 3 provides tables on support provided to developing countries to support climate action. Annex 4 provides additional methodological information related to financial support provided and mobilized. Annex 5 includes additional methodological information on the "with measures" projections included in Chapter 5.

This combined 7th National Communication, and 3rd and 4th Biennial Report, fulfills an important reporting requirement under the U.N. Framework Convention on Climate Change (UNFCCC) and presents a snapshot of U.S. climate action in the period 2016-2020. Future reports will provide a more comprehensive view on efforts by the United States to demonstrate its leadership by deploying a range of bold new commitments and programs across the federal government, building on the sustained climate mitigation and adaptation efforts of our subnational governments, businesses, and civil society partners; These efforts will create high-quality new jobs, and mobilize public and private finance to combat the climate crisis. They will also reflect our efforts to encourage other nations to move with us towards a world where communities and economies are stronger, and where global temperature rise reaches no more than 1.5 degrees Celsius above historical averages.

This document serves as the 7th National Communication (due January 1, 2018), and 3rd and 4th Biennial Reports (due January 1 2018 and January 1, 2020, respectively). The consolidated document covers all mandated information related to these reports, and contextual sections are updated with information current as of October 2021.

Endnotes

1 Relative to the average level during the second half of the Obama-Biden Administration (FY 2013-2016).

2 https://www.americanprogress.org/issues/green/reports/2019/10/16/475863/state-fact-sheet-100-percent-clean-future/.

3 See, for example, https://www.americaisallin.com/

2
NATIONAL CIRCUMSTANCES

NATIONAL CONTEXT

The United States is the largest economy in the world, and the third largest country in terms of population and geographic area.[4] As such, it faces a unique set of domestic circumstances, and plays a singular role in global systems. National circumstances that affect greenhouse gas emissions and removals include market dynamics, technological innovation, economic growth, energy production and consumption, population and density trends, use of land and natural resources, and climate and biogeographic conditions. This chapter outlines key circumstances relevant to the United States, including the structure of the government, economic profile, and energy production and use, and identifies factors that significantly impact greenhouse gas emissions and removals. It also briefly highlights significant changes to national circumstances and trends since the 2014 *U.S. Climate Action Report* (2014 National Communication, or NC) and 2016 *2nd Biennial Report* (2016 BR).

Government structure

The United States is a federal republic of 50 states, plus the District of Columbia and U.S. territories. The Constitution of the United States assigns certain powers to the federal government, with other responsibilities entrusted to the states. Local governments, as well as Native American tribal governments, are charged with governance responsibilities at the corresponding level of subnational government. Indian tribal governments exercise governmental authority over a broad range of internal and territorial affairs. This shared responsibility for policy in areas such as economic growth, energy development, transportation, land use planning, and natural resource use creates the opportunity for action and coordination at multiple levels.

The U.S. federal government is divided into three branches: executive, legislative, and judicial. Each branch of government is assigned specific authorities and plays distinct roles in creating, implementing, and adjudicating laws and regulations. This same three-branch structure is also replicated at the state level, and often at lower levels of government as well. This structure creates a system of "checks and balances" which shapes the development and implementation of policy. Jurisdiction for addressing energy, environment, and climate change-related issues within the federal government cuts across each of the three branches.

FEDERAL GOVERNMENT

Executive Branch

The executive branch of the federal government is responsible for implementing and enforcing the laws of the United States. The scope of its responsibility covers a wide range of areas including enacting regulations through the rulemaking process, supporting innovation and research and development, implementing foreign policy, maintaining federal highway and air transit systems, and managing federal lands.

The President of the United States is the head of the executive branch, and is advised by the Vice President and a Cabinet of senior officials. This Cabinet is composed of the heads of 15 executive agencies–the Departments of Agriculture, Commerce, Defense, Education, Energy, Health and Human Services, Homeland Security, Housing and Urban Development, Interior, Justice, Labor, State, Transportation, Treasury, and Veterans Affairs–as well as the White House Chief of Staff, the US Ambassador to the United Nations, the Director of National Intelligence, and the US Trade Representative, and the heads of the Environmental Protection Agency, Office of Management and Budget, Council of Economic Advisers, Office of Science and Technology Policy, and Small Business Administration.

For the first time, under the Biden Administration the President is advised by a National Climate Adviser and a Special Presidential Envoy for Climate. In recognition of the seriousness of the climate crisis, these positions were newly created to lead and coordinate the development and implementation of domestic and international climate change policy, respectively.

The Executive Office of the President also includes a number of offices with relevance to environmental and energy policy including the new office of the National Climate Advisor–the Domestic Climate Policy Office–as well as the National Security Council, the Domestic Policy Council, and the Council on Environmental Quality, and a number of independent commissions, boards and agencies such as the Federal Energy Regulatory Commission.

Within the executive branch, the purview for energy, environment, and climate-related issues fall under some two dozen federal agencies and executive offices, which work together to advise, develop, and implement policies that help the U.S. government understand the workings of the Earth's climate system, increase innovation related to clean energy and energy efficiency, work towards low greenhouse gas energy systems, enhance the sustainability of land and natural resource management, and assess and respond to the adverse effects of climate change. The actions of these agencies are described in relevant chapters of this report.

Legislative Branch

The federal legislative branch is the U.S. Congress which is composed of two chambers: the Senate and the House of Representatives (House). The Senate includes 100 elected members, two from each state; Senators serve six-year terms of office. The House is made up of 435 elected members, each representing a single congressional district of an average of approximately 760,000 people.[5] Representatives serve two-year terms of office. The bicameral nature of Congress is intended to balance representation based on population, and representation based on statehood.

Both the Senate and the House have the authority to develop legislation; a completed bill must receive a majority of votes in each chamber. Congress is also responsible for raising revenue through taxation, and authorizing the use of public funds by the executive branch through the budget and appropriations process. Any difference between House and Senate bills must be reconciled before the bill can be sent to the President for signature. Legislation becomes effective upon signature by the President. As new legislation must be approved by a majority in both chambers of Congress and signed by the President, the threshold of support required to enact new laws remains high.

Committees within each Chamber of Congress are tasked with considering and developing draft legislation on specific topics. In the House, the Committees on Appropriations; Agriculture; Science, Space, and Technology; Ways and Means; Natural Resources; and Energy and Commerce, among others, consider topics relevant to climate, environment, energy and land use. In the Senate, the Committees on Environment and Public Works; Finance; Foreign Relations; Agriculture; Commerce, Science, and Transportation; Energy and Natural Resources; and Indian Affairs develop legislation on these topics and are similarly critical venues for debate.

Judicial branch

The judicial branch of the federal government is responsible for interpreting the U.S. Constitution, among other duties. The Supreme Court is the highest Court in the United States. The judicial branch plays a significant role in defining the jurisdiction of the executive branch departments and interpreting laws, including those related to energy, environment, and climate policy.

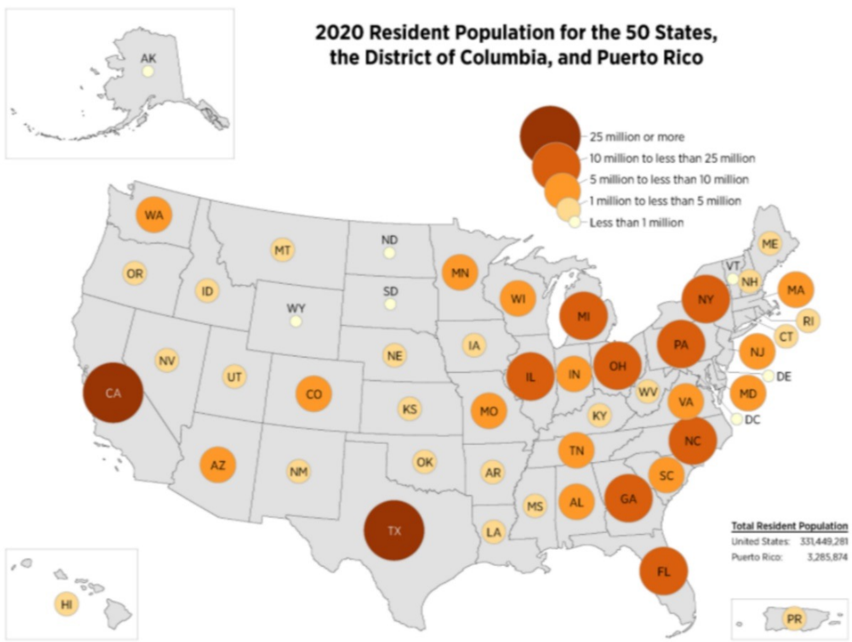
Subnational actors

As a federal system, jurisdiction for issues related to energy, environment, and climate change is shared by federal, state, local, and tribal governments. For example, while the Federal Energy Regulatory Commission regulates wholesale sales and transportation of natural gas and electricity, economic regulation of energy distribution is the responsibility of the states. States may establish energy-sector standards, mandate building energy efficiency standards, set emissions targets, plan and build transportation and energy infrastructure, establish state or regional carbon markets, and determine land use practices on state lands, among other authorities. Cities may also set emissions targets; together with states, they determine how non-federal transportation systems and other infrastructure are planned and implemented. Native American tribal governments have similar authorities for tribal lands. Many states, cities, and tribes in the United States are implementing policies relevant to climate change mitigation and adaptation. Examples of these activities are provided in Chapter 4.

POPULATION PROFILE

The estimated population of the United States as of April 1, 2020 was approximately 331.4 million,[6] making the U.S. the third most populous country in the world. This represents an increase of over 30 percent above 1990 levels. From 2019-2020, the U.S. population grew at a rate of 0.35 percent,[7] reflecting both net births and net international migration. By 2050 the total population of the United States is expected to reach nearly 400 million people.[8] This estimate reflects U.S. Census Bureau assumptions that growth rates will decline slightly over the coming decades.[9] The population is not evenly distributed across the country, as Figure 2-1 shows.[10]Rather, the distribution of the population is determined by a series of biogeophysical, climatic, social, and economic factors, as described below.

Figure 2-1 **2020 Population**



Source: 2020 United States Census[11]

Trends in population growth and density shape energy consumption, land use, transportation, housing density, and other factors which have a significant effect on U.S. greenhouse gas emissions.

C. ECONOMIC PROFILE

Following a decade of steady growth, the U.S. experienced its worst economic downturn since World War II in 2020 due to the global outbreak of Covid-19. After a sharp contraction during the Great Recession from late 2007 to mid-2009, the U.S. economy grew at an average annual rate of 2.3 percent from mid-2009 through 2019,[12] before shrinking precipitously by 3.4 percent in 2020 as the pandemic ravaged factories, businesses, and households. U.S.[13] GDP dropped from $21.37 trillion in 2019 ($65,056 per capita) to $20.89 trillion in 2020 ($63,285 per capita),[14] with unemployment spiking to over 14 percent – its highest on record since 1948 – in April 2020.[15]

The economy began to rebound during the second half of 2020 with the easing of lockdown restrictions, reopening of businesses, and introduction of a national vaccination campaign. Output reached its pre-pandemic size in mid-2021 after quarterly growth above 6 percent over the first half of the year,[16] though the shape of the recovery remains uncertain.

Due in part to reduced travel and other factors resulting in reduced energy consumption during the pandemic, U.S. energy-related CO2 emissions in 2020 dropped 11 percent from 2019 levels–the largest annual decrease on record–falling to their lowest level since 1983.[17] CO_2 emissions are projected to rise somewhat in 2021 and 2022 along with continuing economic recovery.[18] Projections suggest the 2021 and 2022 net emissions will remain lower than 2019 levels, and will be lower than would have been expected without the effects of increased efficiency and a rapid shift towards cleaner and renewable energy.

D. GEOGRAPHICAL PROFILE

With a mainland bounded by the Atlantic Ocean to the east, the Pacific Ocean to the west, Canada to the north, and Mexico and the Gulf of Mexico to the South, the United States is a large and diverse country. Its 9,192,000 square kilometers (km2) (3,548,112 square miles [mi^2]) are spread across six time zones.

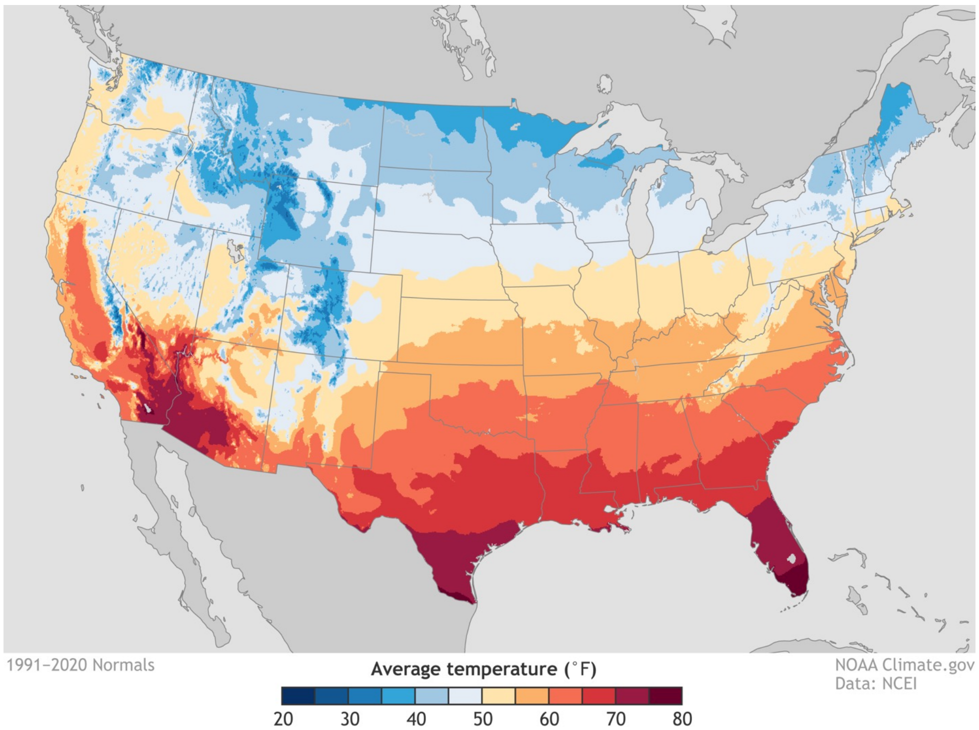
Given the size and extent of U.S. territory, its biogeophysical profile is diverse. Ecosystems range from the Arctic tundra of northern Alaska to the tropical forests of Hawaii and the overseas U.S. territories. Temperate rainforests in the Pacific Northwest give way to Mediterranean landscapes and then deserts of the Southwest. The middle of the country includes the majestic Rocky Mountains, with Alpine ecosystems on peaks more than 4,390 meters (14,400 feet) tall. Vast grassland prairies transition into rich swathes of agricultural land interspersed with temperate deciduous and coniferous forests. The Great Lakes, the largest freshwater system in the world, and great rivers such as the Mississippi and Missouri, are important features defining the middle of the country. Along the Gulf coast, riverine estuaries and wetlands gradually melt into the sea, while further inland swamps such as the Everglades create unique habitats. The eastern Appalachian Mountains mark a boundary between central and eastern lands, with temperate deciduous and coniferous forests pushing up against the beaches and marshes of the Eastern seaboard.

Approximately 60 percent of land in the United States is privately owned. Another 28 percent is owned and managed by the federal government. This area includes protected areas such as national parks, wilderness areas, wildlife refuges, and monuments; national forests; rangelands; and other public lands. Approximately 8 percent of land is owned and managed by state and local governments, and 3 percent is held in trust for Native Americans by the Bureau of Indian Affairs.[19] Currently 13 percent of lands and 26 percent of waters have permanent protections.

E. CLIMATE PROFILE

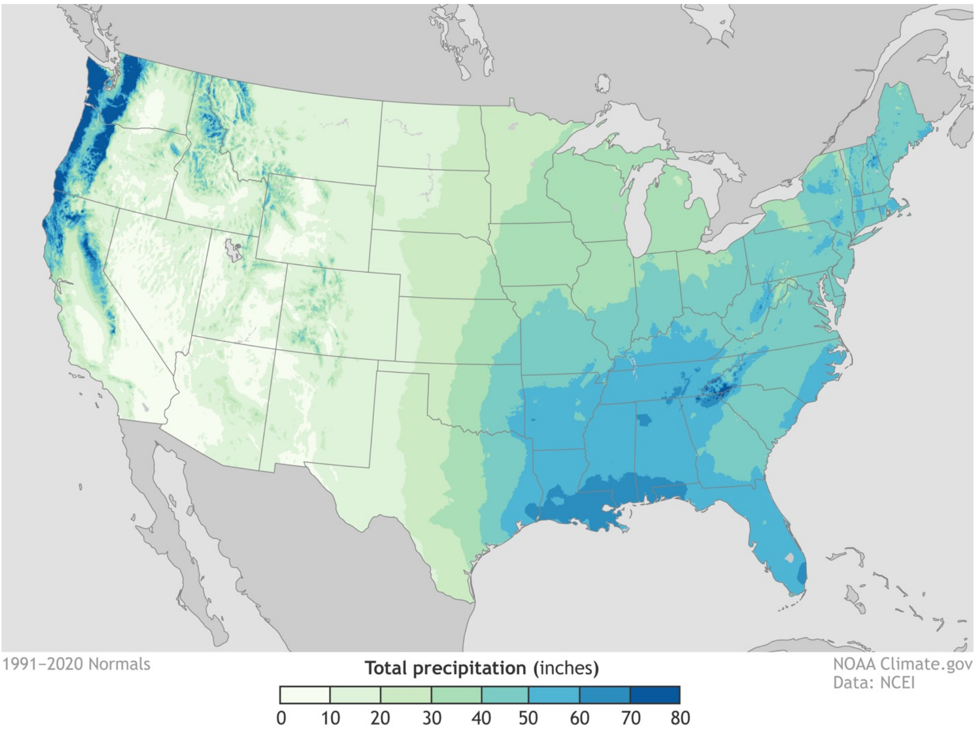
The climate of the United States reflects its geographic diversity. Average annual temperatures decrease dramatically from south to north in the continental United States, as seasonal variability increases. The average annual temperature Florida exceeds 21 degrees C (70.7 degrees F), while that of Alaska is just – 3 degrees C (26.6 degrees F). Temperature ranges can be great, with some Great Plains states experiencing differences in temperature of as much as 50 degrees C (90 degrees F) over the course of a year. Figure 2-2 illustrates the range in average termperatures over the past three decades across the contiguous United States. As very high or low temperatures require cooling or heating of buildings, average temperatures have a correlation to energy usage. A mild winter or a cool summer may correspond to lower energy usage, and thus to somewhat lower greenhouse gas emissions. This is reflected in annual estimates in the national greenhouse gas inventory, discussed in Chapter 3.

Figure 2-2[20] **U.S. Temperature(1991-2020)**



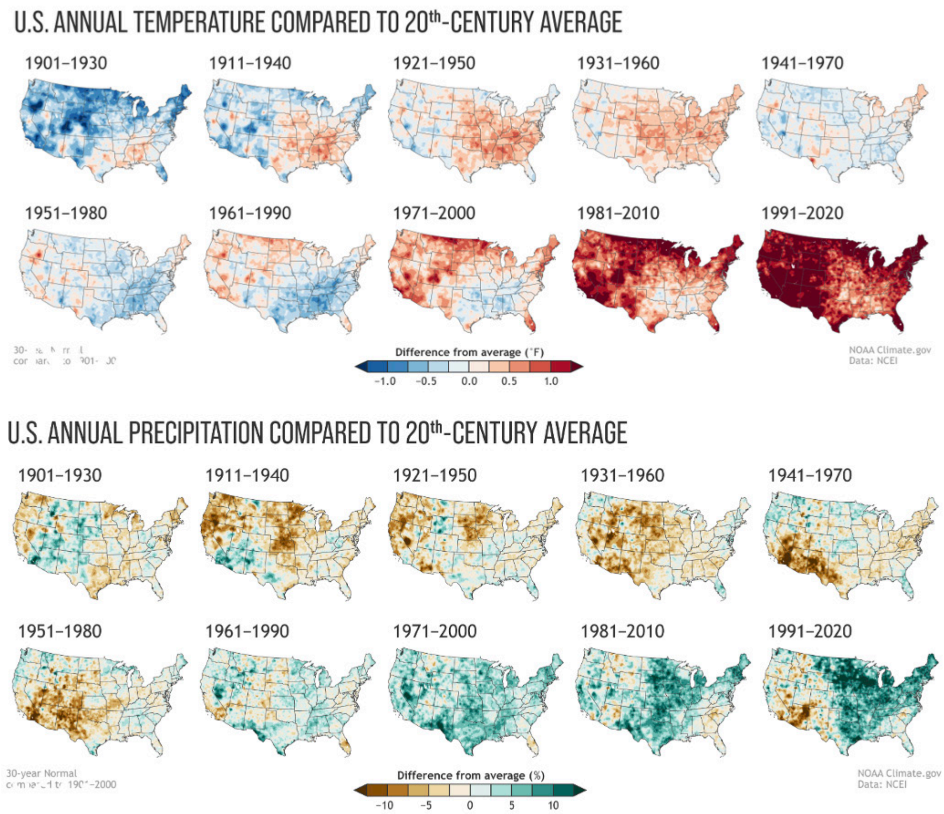
Similarly, precipitation varies across the United States in terms of quantity and seasonality. As Figure 2 depicts, while communities along the Gulf of Mexico may experience more than 127 centimeters (50 inches) of precipitation per year, parts of the Intermountain West and Southwest may receive less than 30 cm (12 in). The peak rainfall season also varies by region, though the seasonality has varied in recent years. Parts of the Great Plains and Midwest typically receive the greatest rainfall in the late spring, the West has a distinct wet season during the winter, the Deep South is affected by the North American monsoon, and many parts of the Gulf and Atlantic coastal regions see their greatest period of precipitation in the summer.

Figure 2-3 [21] **U.S. Annual Average Precipitation (1991-2020)**



Communities across the United States are already experiencing the impacts of climate change, including significant shifts in temperature and precipitation, as shown in figure 3.[22] In 2020, for example, average annual temperature for the contiguous U.S. was 54.4°F, which is 2.4°F above the 20th century average. The five warmest years on record have all occurred since 2012.[23] While trends in precipitation vary by region, overall levels have increased (see figure 2-4), and at least some of this is linked to climate warming and the "wetting" of the atmosphere that has occurred as rising temperatures cause more water to evaporate from the ocean and land surface.[24]

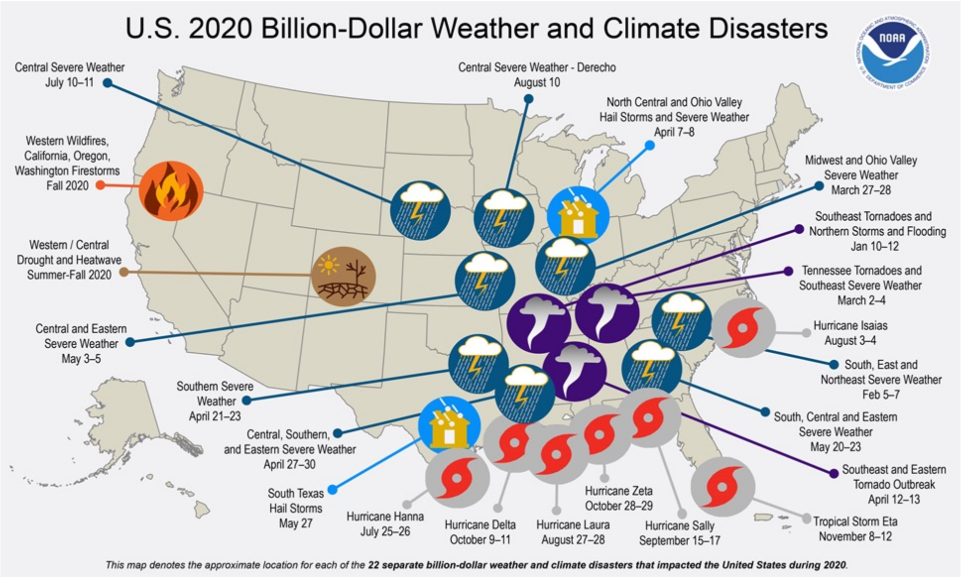
Figure 2-4 **Annual Temperature and Precipitation Compared to 20th Century Average**



Source: U.S. National Oceanic and Atmospheric Administration[25]

At the same time, more frequent and intense extreme weather and climate-related events are damaging infrastructure, ecosystems, and the social systems that provide essential services.[26] In 2020, there were eleven named U.S. storm continental landfalls – breaking the previous record set in 1916 – and thirty named Atlantic storms. The Western U.S. experienced its most active wildfire year on record (since 1983), with over 10 million acres consumed.[27] Overall, the U.S. experienced 22 separate billion-dollar weather and climate disasters (see figure 2-5), shattering the previous annual record of 16 events that occurred in 2011 and 2017. These included seven disasters linked to tropical cyclones, thirteen to severe storms, one to drought, and one to wildfires – and cost an estimated $99 billion in total damages.[28]

Figure 2-5[29] **U.S. 2020 Billion-Dollar Weather and Climate Disasters**



F. ENERGY

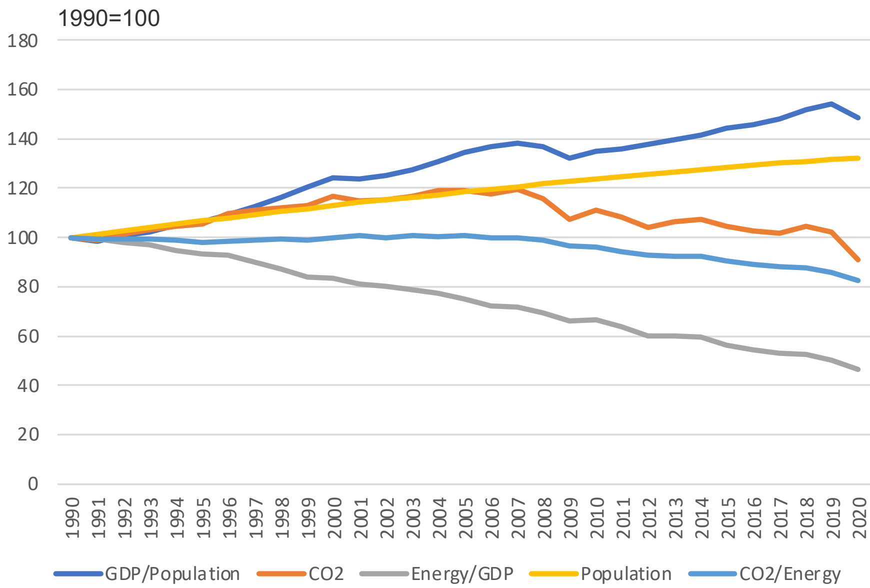
The United States is the world's second-largest producer and consumer of energy. This creates significant opportunities to mitigate greenhouse gas emissions through energy efficiency, electrification of end-uses that currently burn fossil fuels, and carbon-free energy supply. The United States is a leader in clean energy innovation and deployment, with recent increases in investment into research, development, demonstration, and deployment of clean energy, other greenhouse gas mitigating activities, and technologies to support resilience and adaptation to the changing climate.

While U.S. population and GDP per capita have increased over the past three decades, the energy and carbon intensity of the U.S. economy have declined (see Figure 2-6).[30]

- Energy intensity (energy/GDP) has decreased relatively consistently across this 30-year time frame, largely as a result of demand-side efficiency gains and productivity improvements as well as economic trends, such as the changing profile of U.S. manufacturing industries and a shift toward greater commercial sector economic activity.[31] In 2020, U.S. energy intensity of GDP was about half of what it was in 1990, and in 2050, is projected to decline by a further one-third from tODAy's levels.[32]
- Carbon intensity of energy consumption (CO_2 emissions per unit of energy used) has also decreased significantly since 1990 as the U.S. energy mix has evolved, shifting away from carbon-intensive and toward lower – and zero-carbon fuels. Key drivers include increases in natural gas production from shale and tight resources, which have lowered the cost of natural gas production and made it cost competitive with coal for electric power generation, as well as the plummeting cost of renewable energy, such as solar and wind.

- Renewables (including wind, hydroelectric, solar, biomass, and geothermal energy) are now the second-most prevalent U.S. electricity source, producing 834 billion kWh, or about 21 percent of all electricity generated in the United States.[33] This was nearly double the renewable generation in 2010. Total clean energy generation in 2020 represented approximately 40 percent of total United States electricity generation.[34]

Figure 2-6 **Index of Key Factors that Influence Energy-Related CO2 Emissions**



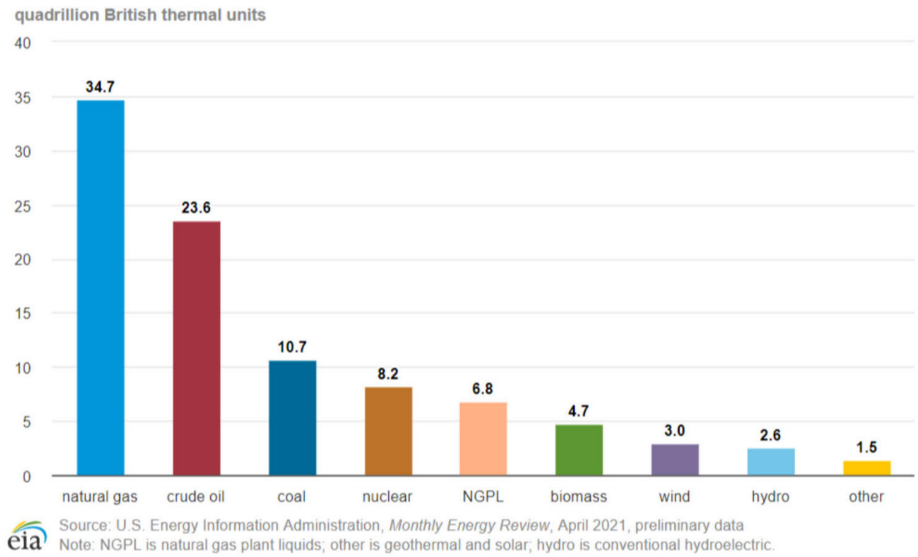
Source: U.S. EIA[35]

Energy Production and Consumption

In 2019 and 2020, U.S. domestic energy production exceeded consumption on an annual basis for the first time since 1957. After record-high U.S. energy production and consumption in 2018, energy production grew by nearly 6 percent in 2019 while energy consumption decreased by about 1 percent. Then in 2020, largely due to the Covid-19 pandemic, total energy production and consumption both declined dramatically by a record 5 and 7 percent, respectively, to 95.75 and 92.94 quadrillion BTU.[36]

In 2020, natural gas and natural gas plant liquids represented approximately 43 percent of energy produced. Crude oil and coal made up 25 percent and 11 percent of energy production, respectively. Natural gas plant liquids were about 7 percent, with renewable energy comprising 12 percent and nuclear energy the remaining 9 percent.[37]

Figure 2-7 **U.S. Primary Energy Production by Major Sources, 2020**



The energy sources consumed in the United States reflected a similar pattern, with petroleum (35 percent) and natural gas (34 percent) making up the majority of energy use, followed by renewable energy (12 percent), coal (10 percent), and nuclear energy (9 percent) in 2020. In recent years the share of renewable energy sources, which includes solar, wind, biomass, hydropower, and geothermal, has increased substantially.

Figure 2-8 **U.S. Primary Energy Consumption by Energy Source, 2020**

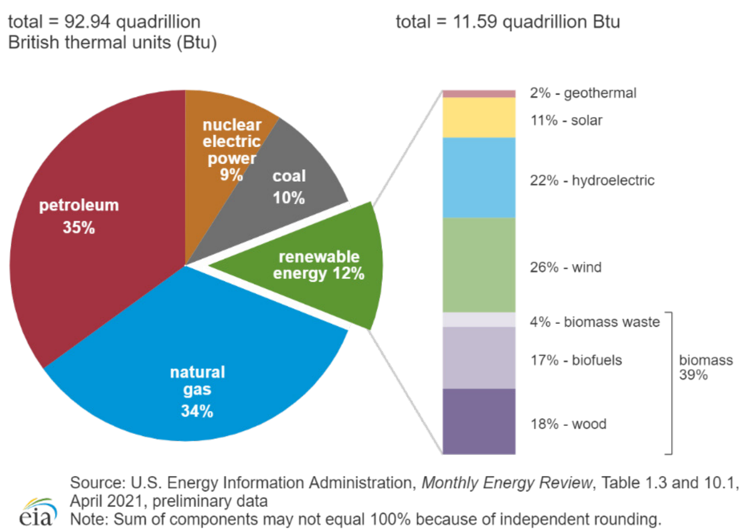
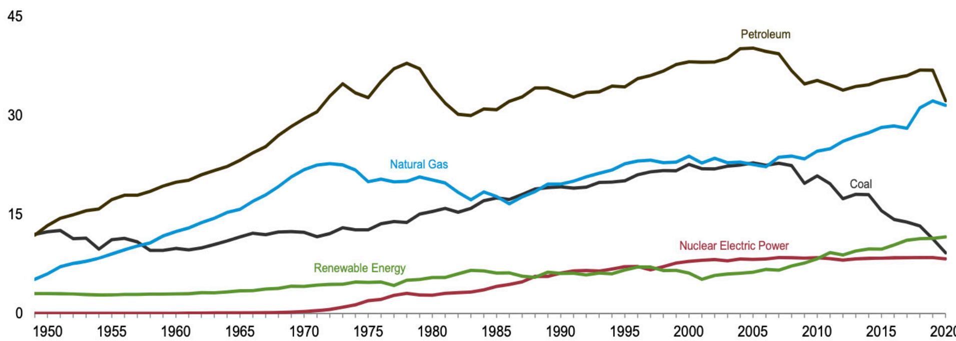


Figure 2-9 **Primary Energy Consumption**[38]



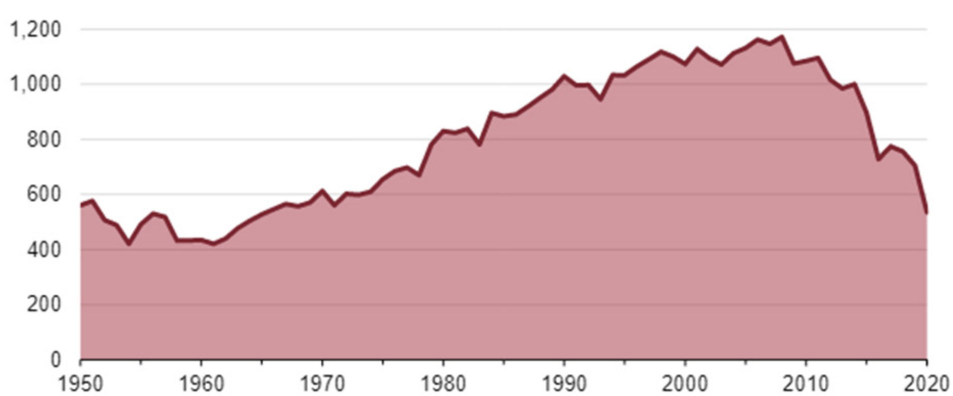
Fossil Fuels

Fossil fuels – petroleum, natural gas, and coal – accounted for the majority of total U.S. primary energy production and consumption in 2020. While they have dominated the U.S. energy mix for more than a century, the fossil fuel mix has shifted significantly over time toward less carbon-intensive sources.

Coal

Electric power generation has been the largest consumer of coal since the 1960s, while industrial sector use of coal has slowly declined since the 1970s. Coal consumption in the United States peaked in 2007 at about 1.13 billion short tonnes, and coal production peaked in 2008 at about 1.17 billion short tonnes. Due to weakening demand from the electricity sector, both have declined nearly every year since. In 2020, coal consumption was about 477 million short tons, equal to about 9.18 quadrillion BTU and the lowest percentage share of total U.S. energy consumption since at least 1949. Coal production in 2020 was 534 million short tons – the lowest amount since 1965 – and equal to about 10.69 quadrillion BTU.

Figure 2-10 **Annual U.S. Coal Production (1950-2020) Million short tons (>>st)**



Source: U.S. EIA[39]

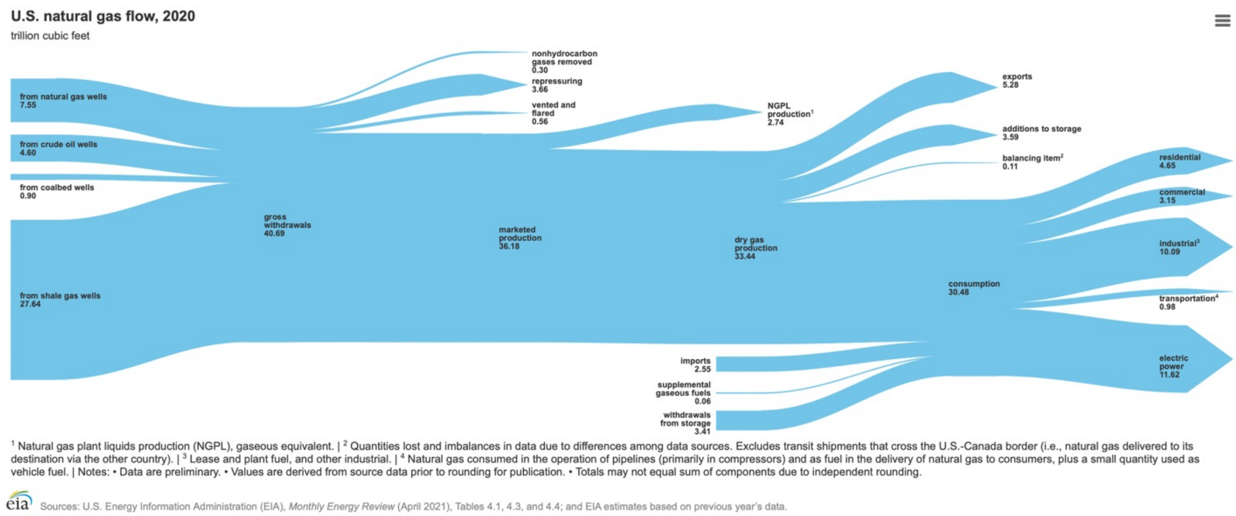
Petroleum

Following a general decline between 1970 and 2008, annual U.S. crude oil production began to rise in 2009. It reached a high of 12.29 million barrels per day in 2019,[40] largely driven by increasingly cost-effective drilling and production technologies. However, production declined to about 11.28 million barrels per day in 2020 – falling by over 8 percent, its largest decrease on record[41] – due to a large drop in demand resulting from the COVID-19 pandemic.

Natural Gas

Natural gas production in the United States has generally increased over the past decade, as widespread adoption of horizontal drilling and hydraulic fracturing techniques has allowed operators to more economically produce natural gas from shale formations. These production increases have contributed to a decline in natural gas prices, which in turn has contributed to increases in natural gas use by the electric power and industrial sectors. In 2020, both natural gas consumption by the U.S. electric power sector and natural gas exports reached record highs. Natural gas has been the primary source of electricity generation in the United States since surpassing coal in 2016, and more than 100 coal plants have been replaced with or converted to natural gas since 2011.[42] This displacement of more carbon-intensive fossil fuels has had a significant impact on overall emissions from the energy sector.

Figure 2-11 **U.S. Natural Gas Flows, 2020**



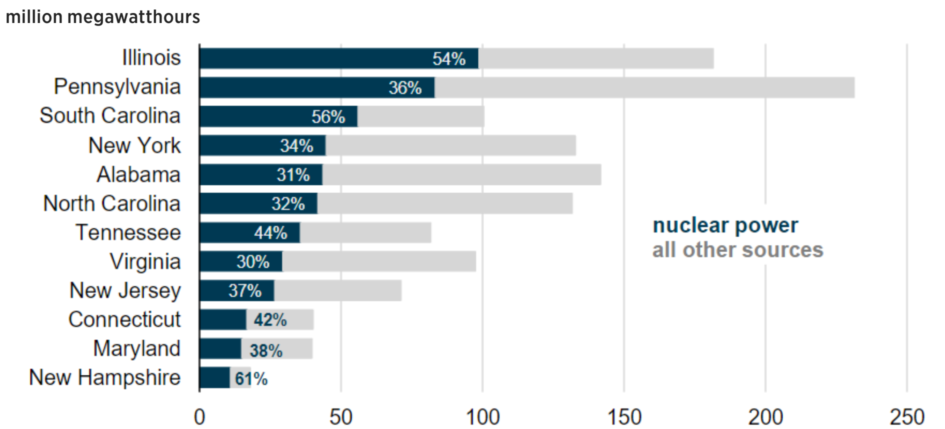
Source: U.S. EIA Monthly Energy Review [43]

Nuclear

Nuclear energy production in commercial nuclear power plants in the United States began in 1957, grew each year through 1990, and slightly from 1990-2000, and generally leveled off after 2000.[44] Even though there were fewer operating nuclear reactors in 2020 than in 2000, the amount of nuclear energy production in 2020 was 790 billion kilowatthours (kWh). A combination of increased capacity from power plant increased capacity factors have helped to compensate for reductions in the numbers of nuclear reactors and maintain a relatively consistent level of annual U.S. nuclear electricity generation for the past 20 years.

Nuclear power plants have consistently provided about 20 percent of total U.S. electricity generation since the 1990s.[45] Of the 28 U.S. states with operating commercial nuclear power plants, 12 states generated more than 30 percent of their electricity from nuclear power, and three states (New Hampshire, South Carolina, and Illinois) generated more than 50 percent of their in-state electricity from nuclear power in 2019.[46]

Figure 2-12 **Nuclear Eletricity Generation in Selected States (2019)**



Source: U.S. EIA[47]

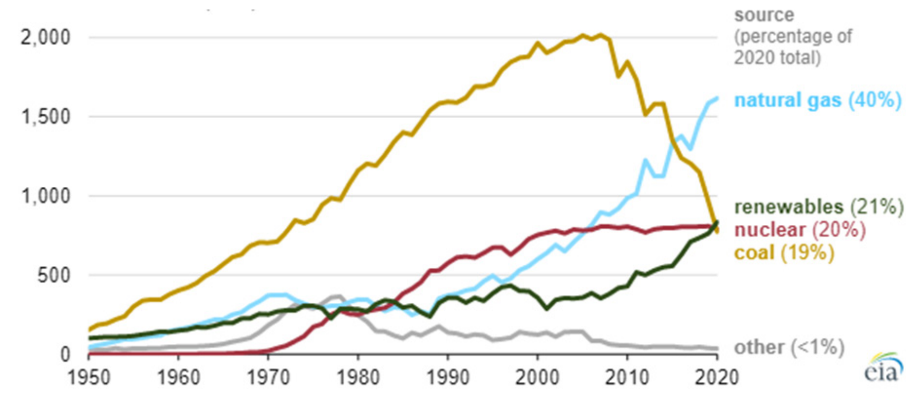
Renewables

In 2020, renewable energy production and consumption both reached record highs of about 11.77 and 11.59 quadrillion BTU respectively, driven mainly by record-high solar and wind energy production. Total biomass production and consumption in 2020 were both 10 percent lower than their highest levels recorded in 2018, in part due to the decreased use of biofuels for transportation given the COVID-19 pandemic. Geothermal energy use in 2020 was nearly the same as the highest annual level of geothermal energy production and consumption recorded in 2014.

Renewables (including wind, hydroelectric, solar, biomass, and geothermal energy) became the second-most prevalent U.S. electricity source, producing a record 834 billion kilowatt-hours (kWh), or about 21 percent of all electricity generated in the United States.[48] This was nearly double the renewable generation in 2010, with more than 90 percent of the increase in renewables over the past decade coming from wind and solar generation. Total clean energy generation in 2020 represented approximately 40 percent of total United States electricity generation.[49]

Figure 2-13 **Annual U.S. Electricity Generation from All Sectors (1950-2020)**

billion kilowatthours (kWh)

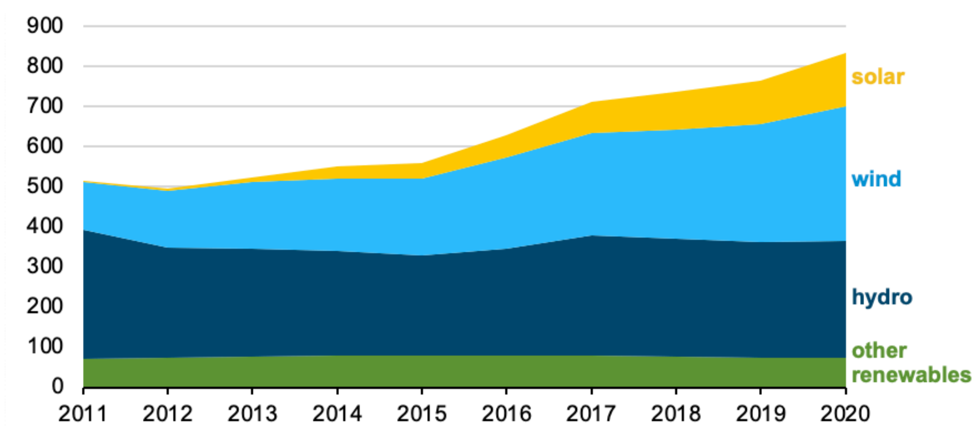


Source: U.S. EIA[50]

Wind, currently the most prevalent source of renewable electricity in the United States, grew 14 percent in 2020 from 2019. Utility-scale solar generation (from projects greater than 1 megawatt) increased 26 percent, and small-scale solar, such as grid-connected rooftop solar panels, increased 19 percent.[51]

Figure 2-14 **Title: U.S. Annual Electricity Generation From Renewables, By Source (2010-2020)**

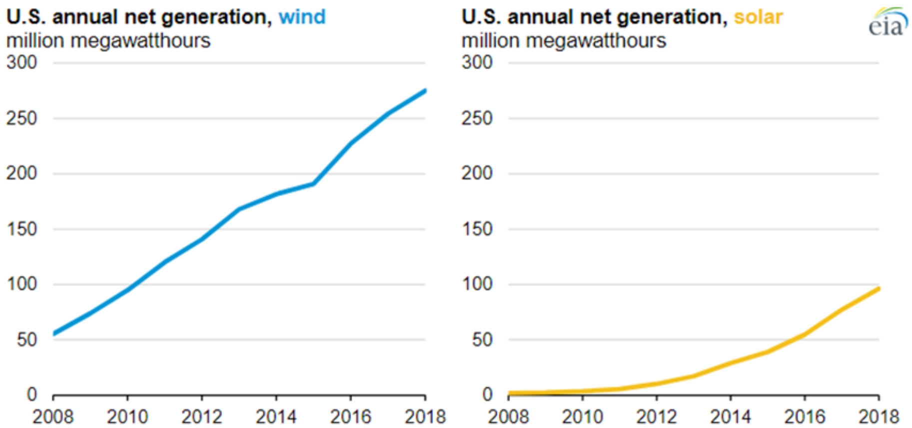
million megawatthours



Source: U.S. EIA[52]

Over the past decade, wind generation has seen a five-fold increase (55 million MWh in 2008 to 275 million MWh in 2018), while solar generation has increased by nearly a factor of 50 (2 million MWh in 2008 to 96 million MWh in 2018).[53]

Figure 2-14 **Title: U.S. Annual Electricity Generation From Renewables, By Source (2010-2020)**



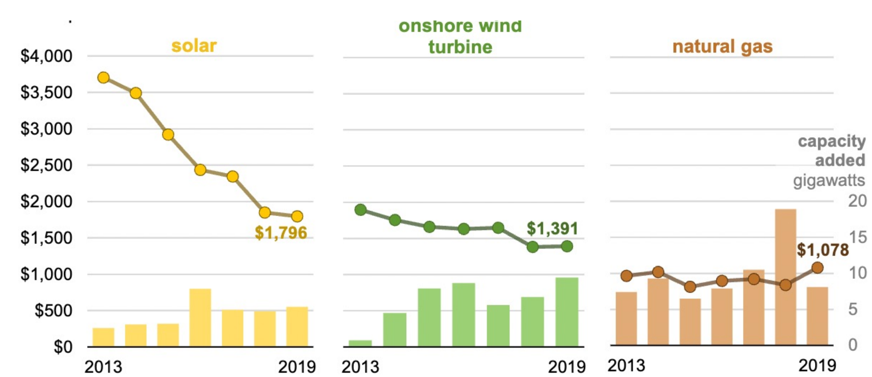
Source: U.S EIA[54]

Renewables are also expected to comprise most new U.S. electricity generating capacity in 2021, with solar accounting for the largest share of new capacity at 39 percent, followed by wind at 31 percent. Developers and plant owners anticipate the addition of utility-scale solar capacity to set a new record of 15.4 GW of capacity added to the grid in 2021, surpassing a nearly 12 GW increase in 2020. Another 12.2 GW of wind capacity is also scheduled to come online in 2021, following the addition of 21 GW in 2020.[55]

Average U.S. construction costs for renewable generation continue to fall, with costs for solar and wind dropping 50 percent and 27 percent, respectively, from 2013 to 2018.[56]

Figure 2-15 **Capacity-weighted Average Construction Costs, by Technology**

dollars per kilowatt



Source: U.S. Energy Information Administration, *Electric Generator Construction Costs*

The annual capacity-weighted average construction costs for solar photovoltaic systems in the United States continued to decrease in 2019, dropping by a little less than 3%, according to our latest data on newly constructed utility-scale electric generators. The average costs for wind turbines remained relatively stable in 2019, increasing $9 per kilowatt (kW), or a little less than 1% from the 2018 average. Costs for natural gas-fired generators had the largest change from 2018 to 2019, increasing $241/kW, or almost 29%.

Together, these technologies accounted for over 98% of the total capacity added to the U.S. electric grid in 2019. U.S. investment in all forms of new electric-generating capacity in 2019 decreased by 4.9% compared with 2018.

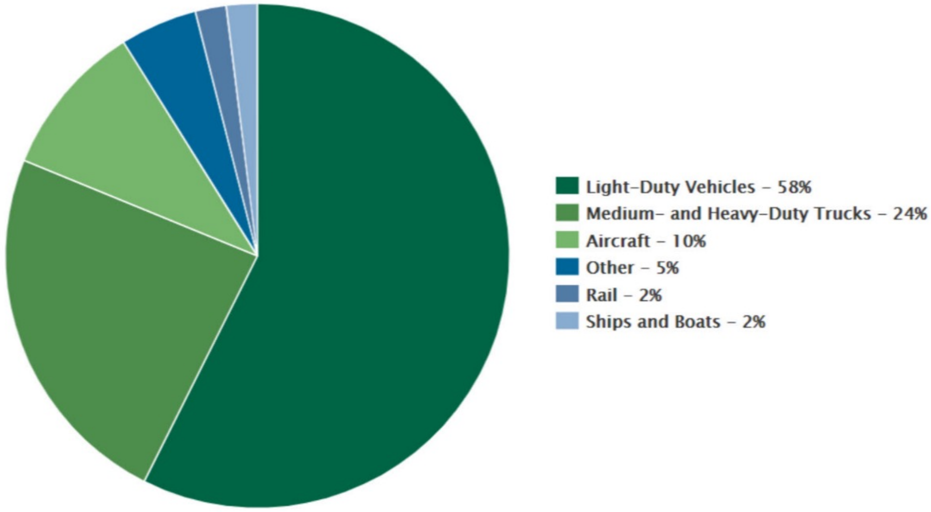
Source: U.S. EIA[57]

G. TRANSPORTATION

In 2016, the U.S. transportation sector overtook the power sector as the leading source of greenhouse gas emissions for the first time since the late 1970s and represented 29 percent of 2019 gross United States greenhouse gas emissions. Transportation emissions have grown significantly since 1990, in large part due to increased demand for travel. Growth in air travel and freight transportation including trucking was particularly pronounced in recent years, with an over 10 percent increase in for-hire freight shipments[58] and U.S. airline traffic[59] between 2015 and 2018.

In 2019, the majority of U.S. transportation sector greenhouse gas emissions (58 percent) came from light-duty vehicles, with the remainder from medium – and heavy-duty trucks (24 percent), aircraft (10 percent), rail (2 percent), ships and boats (2 percent), and other sources such as buses and motorcycles (5 percent).

Figure 2-16 **2019 U.S. Transportation Sector GHG Emissions by Source**



Source: U.S. EPA[60]

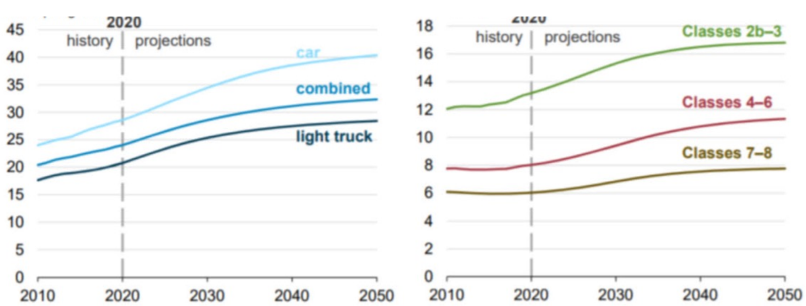
Since 2020, the Covid-19 pandemic has had dramatic impacts on U.S. transportation sector trends. Energy-related CO_2 emissions fell by 15 percent in the transportation sector in 2020 compared to the previous year, largely because of reduced travel. Because of pandemic restrictions, working from home and online meetings frequently replaced commuting and in-person meetings, and both domestic and international air travel fell as well.[61] The durability of these decreases, however, appears so far to be varied. As of March 2021, for example, most forms of passenger travel remained at reduced levels, while the demand for freight had shown a strong rebound.[62]

Since 2004, CO2 emissions from light-duty vehicles have decreased 23 percent, or 105 g/mi, and fuel economy has increased 29 percent, or 5.6 mpg. Over that time, CO_2 emissions and fuel economy have improved in twelve out of fifteen years.[63]

However, the overall new vehicle market continues to move away from the sedan/wagon vehicle type towards a combination of truck SUVs, car SUVs, and pickups. Sedans and wagons fell to 33 percent of the market, well below the 50 percent market share they held as recently as model year 2013, and far below the 80 percent market share they held in 1975. Conversely, truck SUVs reached a record 37 percent of the market in model year 2019, car SUVs reached a record 12 percent of the market, and pickups have increased in recent years to 16 percent of the market. The trend away from sedans/wagons, which remain the vehicle type with the highest fuel economy and lowest CO2 emissions, and towards vehicle types with lower fuel economy and higher CO2 emissions has offset some of the fleetwide benefits that otherwise would have resulted from the improvements within each vehicle type.

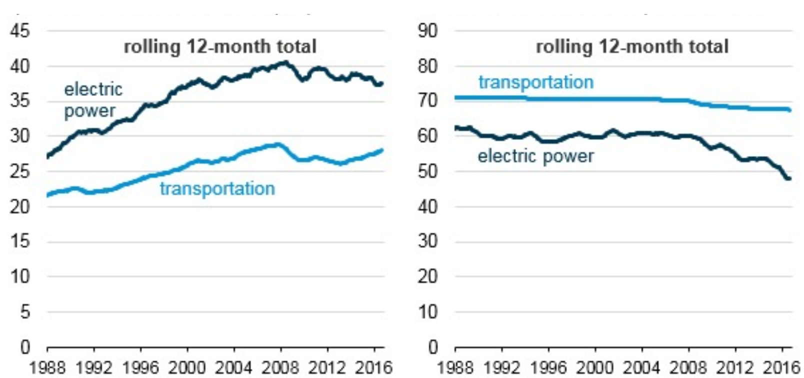
Among heavy duty vehicles, fuel economy has not improved significantly since 2010 but is projected to increase over the next decade across all vehicle classes (see figure 2-17)[64] – including with the projected uptake of zero-emission HDVs.

Figure 2-17 **On-Road Fuel Economy**



Overall, carbon intensity of the transport sector has fallen only slightly over the past decade, and relatively less than the power sector.[65]

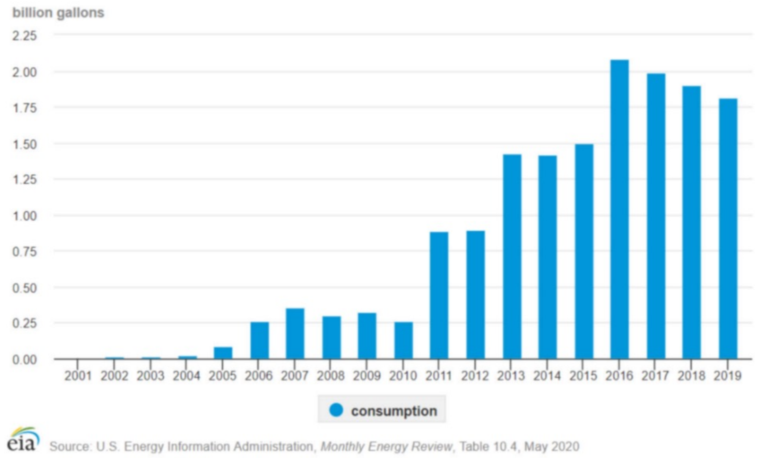
Figure 2-18 **Evolution of Energy Consumption and Carbon Intensity**



Source: U.S. Energy Information Administration[66]

While fossil fuels continue to dominate U.S. transportation sector energy use, alternative sources have been gaining ground. Due in part to the availability of federal and state financial and other incentives, and the federal Renewable Fuels Standard (RFS) Program, biodiesel consumption grew dramatically from about 10 million gallons in 2001 to about 2 billion gallons in 2016, with some decline since 2017 mainly due to the imposition of tariffs on imports.[67]

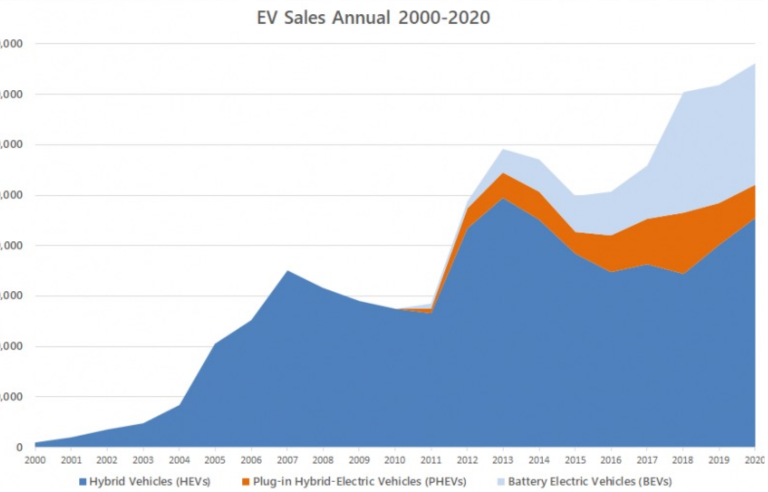
Figure 2-19 **U.S. Biodiesel Consumption, 2001-2019**



Source: U.S. EIA[68]

Moreover, the sale of electric vehicles (EVs) is growing quickly in the United States as a result of an ever-expanding supply of new models, improved infrastructure, tax incentives, and declining costs. The numbers of hybrid, plug-in hybrid, and battery-powered EVs sold have increased steadily since 2018. This trend continues, as 2021 saw monthly record highs for combined sales of electric-drive vehicles.

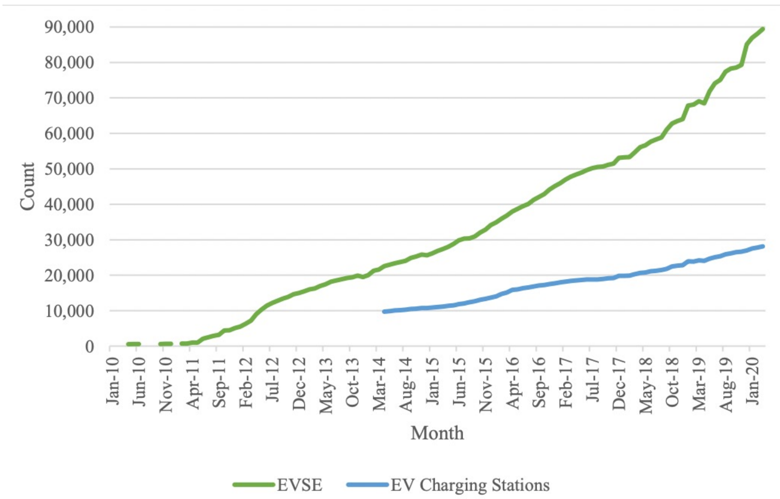
Figure 2-20[69][70] **EV Sales Annual 2000-2020**



Source: U.S. Bureau of Transportation Statistics

Infrastructure to support an EV fleet shows similar strong growth. Between December of 2015 and 2019 alone, for example, the number of EV charging stations in the United States doubled.[71] The expected continued growth in the EV fleet (including models like pick-up trucks and SUVs) will continue to drive increases in average fuel efficiency over the fleet and drive down emissions from transportation over time–especially when combined with an ever-cleaner electricity profile.

Figure 2-21 **Total Number of EV Supply Equipment[72] and EV Charging Stations (2010-2020)**



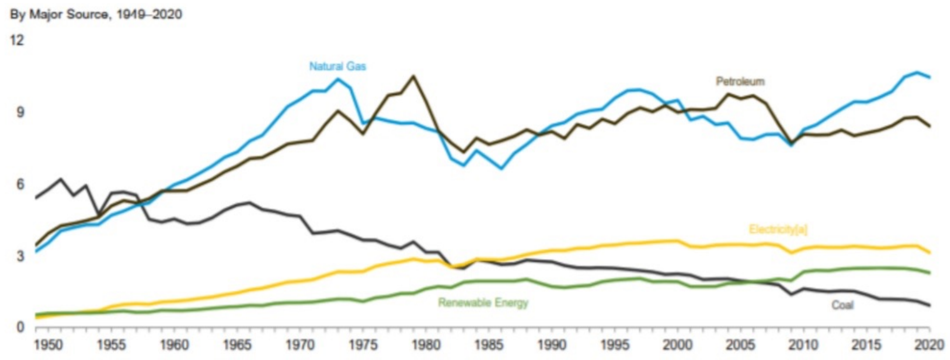
H. INDUSTRY

The industrial sector as a whole, including emissions from industrial processes and energy used on-site but excluding emissions from electricity used by industry but generated offsite, represented 23 percent of total gross greenhouse gases in 2019. The carbon intensity of the industrial sector has fallen over the past fifteen years, declining nearly 7 percent between 2005 and 2019. As a result of energy efficiency improvements and other structural factors – including shifts in industrial output away from energy-intensive manufacturing products to less energy-intensive products (e.g., from steel to computer equipment) – primary industrial energy consumption was only about 8 percent higher in 2019 than in 2005,[73] despite the sector's substantial growth in economic value over the same period.

As figure 2-23 shows, industrial sector energy consumption has shifted toward cleaner sources over time, with significant growth in the use of renewables and natural gas – the least carbon-intensive of the fossil fuels used in electricity generation and industrial process heat – and a steady decline in the use of coal.[74]

Figure 2-22 **Industrial Sector Energy Consumption**

Quadrillion BTUs



Source: U.S. EIA[75]

I. WASTE

In 2018, the United States generated approximately 292.4 million US short tons of municipal solid waste (MSW) – an increase from the 268.7 million tons generated in 2017 and the 208.3 million tons in 1990. Paper and paperboard products made up the largest component of MSW (about 23 percent), and food waste comprised the second-largest material component (22 percent). Yard trimmings and plastics constituted about 12 percent each, and the remaining amount of MSW generated was comprised of rubber, leather, and textiles, metals, wood, glass and other materials.

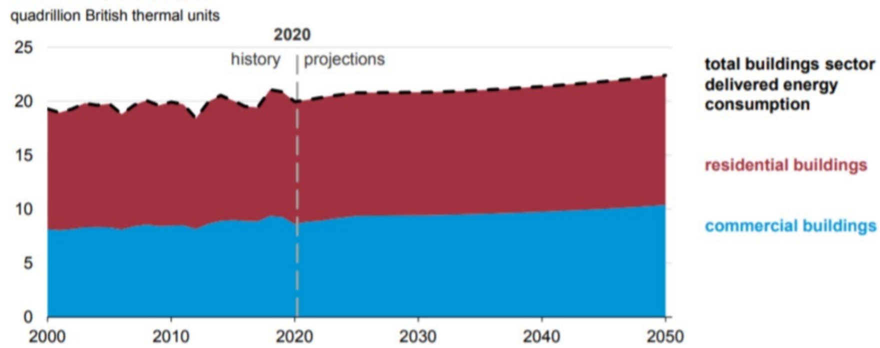
Recycling and composting have been the most significant change in waste management from a greenhouse gas perspective. In 2018, Americans composted or recycled over 94 million tons of MSW, an average of 1.6 pounds per person per day. In 2018, the recycling and composting rate (32 percent) was approximately double what it was in 1990, and the recycling, composting, combustion with energy recovery and landfilling of MSW saved over 193 million metric tons of carbon dioxide equivalent (MMtCO2e) – comparable to the emissions that could be reduced from taking almost 42 million cars off the road in 2018.[76]

J. BUILDING STOCK AND URBAN STRUCTURE

Energy use for buildings accounted for about 29 percent (approximately 20 quadrillion BTU) of total U.S. end-use energy consumption in 2020.[77] Their number, size, and distribution and the appliances and heating and cooling systems that go into buildings influence energy consumption and greenhouse gas emissions.

U.S. building sector energy use has remained relatively constant since 2000 and is expected to increase only slightly through 2050, with flat estimated growth in residential energy consumption and projected growth in commercial energy consumption of about 0.4 percent per year. While residential and commercial floorspace are both expected to expand by over 30 percent over the next three decades,[78] standards and incentives are expected to lead to further energy efficiency improvements, and growth in distributed electricity generation – including on-site solar – will largely offset the effects of this increase.[79]

Figure 2-23 **Buildings Sector Delivered Energy Consumption**



Source: EIA Annual energy Outlook, 2021[80]

Residential Buildings

After hitting a historic low during the Great Recession, the pace of new U.S. residential construction has generally continued to increase since the period covered by the 2014 National Communication. As shown in figure 2-24, new home starts dipped dramatically in the first half of 2020 with the onset of the COVID-19 pandemic but rebounded and continued to climb during the second half of the year.

Figure 2-24 **New Privately-Owned Housing Units Started**

Source: Fred Economic Data[81]

While the average U.S. household tODAy uses more air conditioning, appliances, and consumer electronics than ever before, annual site energy use per home has declined due to a variety of factors, including improvements in building insulation and materials; improved efficiencies of heating and cooling equipment, water heaters, refrigerators, lighting, and other appliances; and population migration to regions with lower heating needs.

Residential sector energy consumption has remained relatively flat since the mid-1990s, as this declining average energy consumption per household has offset an increasing number of homes overall (see figures 2-25 and 2-26).[82]

Figure 2-25 **New Privately-Owned Housing Units Started**

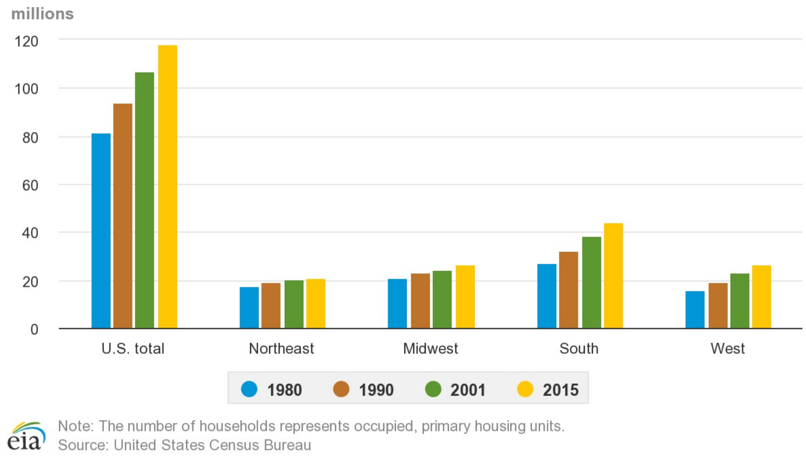
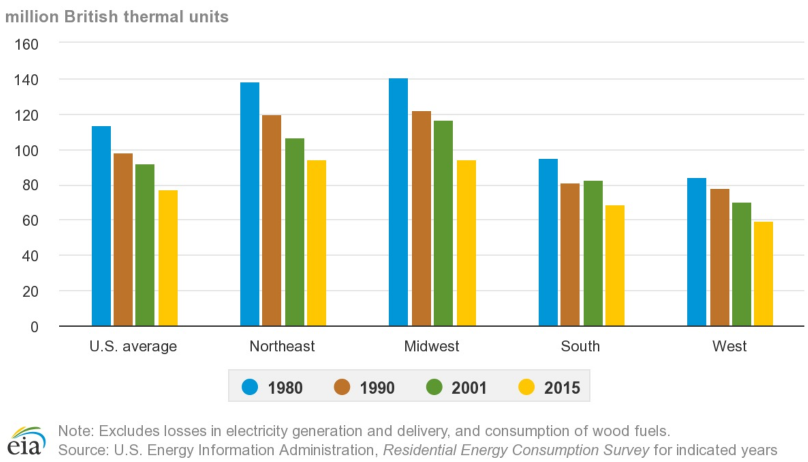


Figure 2-26 **Energy Consumption per household, U.S. Average and by Census Region in Selected Years**



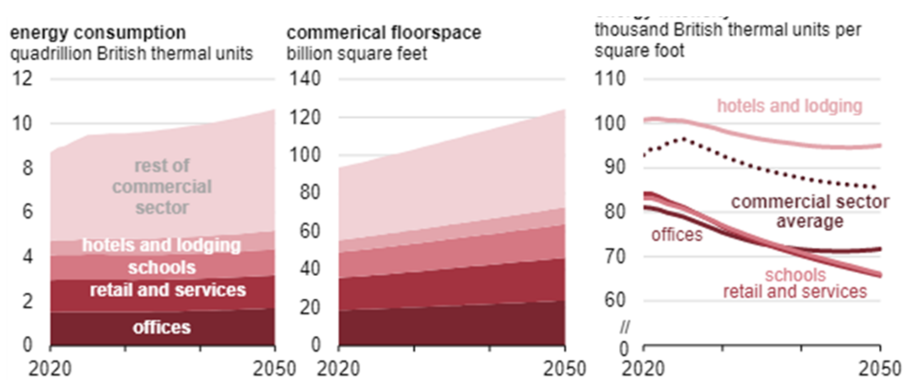
Source: EIA[83]

Commercial Buildings

Commercial buildings include a variety of building types – offices, hospitals, schools, police stations, places of worship, warehouses, hotels, and shopping malls. From 1979 to 2018, the total number of commercial buildings in the U.S. is estimated to have increased approximately 55 percent (up 6 percent since 2012) to 5.9 million, and total commercial floorspace approximately 90 percent (up 11 percent since 2012) to 97 billion square feet.[84]

While commercial floorspace is projected to continue to grow significantly over the next 30 years, total energy use is expected to increase at a much slower space. Wider adoption of commercial building sensors and controls over time – and other factors, including energy efficiency gains and warmer weather – are expected to contribute to declines in commercial energy consumption to meet heating, ventilation, and lighting needs.[85]

Figure 2-27 **Energy Consumption, Commercial Floorspace, and Energy Intensity fpr Selected Commercial Building Types (2020-2050)**



Source: EIA Annual Energy Outlook 2021[86]

K. AGRICULTURE

Agriculture has long been a key industry in the United States. U.S. farmers and ranchers produce a vast array of food and fiber crops, feed grains, oil seeds, fruits and vegetables, and other agricultural commodities for both domestic consumption and export. Investments in advanced production techniques, efficiencies, and cultivars and livestock varieties over the decades have made U.S. agriculture highly productive. While the area under harvest tODAy is roughly the same area as was harvested in 1910, U.S. agriculture now feeds a population three times larger and still exports additional product.[87] Agricultural exports in 2018 totaled more than $140 billion dollars. The sector is a major source of employment, with more than 902,000 people working on farms and ranches in 2019.[88]

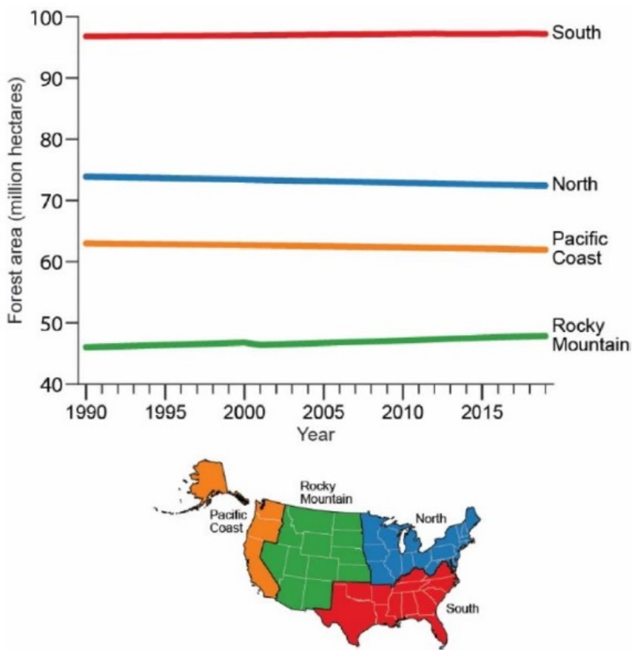
In 2020, there were approximately 2.02 million farms and ranches in the United States. Together they covered approximately 363 million hectares (897 million acres). The size of these operations varies greatly, with approximately 82 percent of farms showing sales of less than $100,000 in 2020, and approximately 4 percent with sales of $1 million or more. The average farm size is 180 hectares (444 acres). In recent years there has been a small but notable decline in the overall number of farms, but a small upward trend in average farm size.[89 90]

Emissions from agriculture come from a number of sources, including cultivation, organic soils, nitrogen fertilizer use, enteric fermentation, manure, and rice production.[91] Agricultural soil management activities, such as fertilizer application and other cropping practices, were the largest source of U.S. N2O emissions in 2019, accounting for 75 percent of emissions of this gas. However, soils also have the potential to sequester and store large quantities of carbon, reducing atmospheric CO2 concentrations. Additional opportunities to reduce emissions lie in improving the efficiency of fertilizer use, reducing methane emissions from livestock and rice production, and reducing the draining and disturbance of organic soils.

L. LAND USE, LAND USE CHANGE, AND FORESTS

Forests play a key role in the economy, ecology, and culture of the United States, whose approximately 310 million hectares (766 million acres) of forest[92] comprise the fourth largest forest area of any country in the world. This area has remained fairly stable since the beginning of the 20th century, even as the population of the country tripled. In recent decades, the area of forest land has even increased slightly. The dynamics vary from region to region. In the eastern part of the country, active farmland is decreasing and returning to a forested state. In 2019, total net sequestration from land use, land use change, and forests was 813 million tonnes (MMT) of CO2e, which offset approximately 12 percent of total United States greenhouse gas emissions (EPA 2021). Sequestration was primarily the result of carbon uptake by standing United States forests, forest management, increased tree cover in urban areas, storage in harvested wood products, and the management of agricultural soils. This volume was down from 900 MMT in 1990 but represented an increase from 2015.

Figure 2-28 **Changes in Forest Area by Region for Forest Land Remaining Forest Land in the Contiguous United States and Alaska 1990-2019**



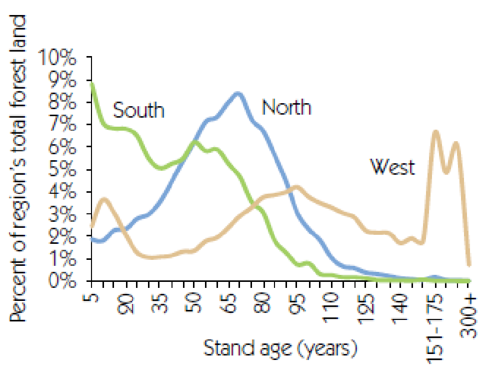
Source: 1990-2019 U.S. Inventory, pg. 6-26[93]

Private ownership accounts for 60 percent of forest land nationally.[94] Forest ownership patterns vary greatly from region to region though, with public lands predominating in the West. Forests provide a range of economic benefits to the U.S. economy. The U.S. supplies 10 per cent of the world's timber; and 96 percent of U.S. consumption of industrial wood comes from domestic sources.[95] The forest products industry accounts for approximately five percent of U.S. manufacturing GDP.[96] Visitor spending in U.S. forests generates more than $13 billion in revenue every year.[97] The value of the ecosystem services provided by these forests is vast. For example, 53 percent of the water in the contiguous United States originates on forest land.[98]

Forest land remaining forest land (including vegetation, soils, and harvested wood) account for the vast majority of total CO_2 removals each year. Other lands converted to forest land and settlements remaining settlements also contributed to substantial net sequestration. Croplands remaining croplands, wetlands remaining wetlands, other lands converted to wetlands, and settlements remaining settlements. All contributed to the total net removals. Estimates of land use, land use change, and forestry (LULUCF) emissions and removals, with the exception of CO_2 fluxes from wood products and urban trees, are calculated annually based on activity data collected through forest and land-use surveys conducted at multiple-year intervals ranging from 1 to 10 years. The latest *Inventory of U.S. Greenhouse Gas Emissions and Sinks*[99] describes the full methodology.

While forest cover in the United States has increased in recent decades, the age of our forests is also increasing. As more mature trees sequester relatively less carbon over time, this may affect overall rate of sequestration in the long term. Natural disturbances such as wildfires, drought, pest outbreaks, and wind throw may also increase over time, further affecting the rate of net sequestration. These disturbances may lead to increased tree mortality, which releases stored carbon over a period of years. However, regrowth after a disturbance also increases carbon sequestration, especially in the early years after a disturbance. The net impact on emissions over time depends on the specific event, and on subsequent policy responses. Forest management practices are in place to help ameliorate potential increases in future natural disturbances to the degree possible.

Figure 2-29[100] **Distribution of Forest Land by Region and Stand Age (2012)**



Forests are not the only ecosystem of note in the United States. Grassland, or prairie, ecosystems comprise approximately 363.5 million hectares (898.2 million acres). Many of these grasslands are used for livestock grazing or have been converted to cropland or settlements, but others remain in their natural state and serve as habitat for numerous native and migratory species while also preserving soil resources and storing carbon in soils and perennial biomass.

Coastal and inland wetlands cover approximately 43.3[101] million hectares (107 million acres) of the surface area of the United States. Wetlands play a fundamental role in important economic sectors such as fisheries; they also increase the resilience of coastal communities and businesses to extreme weather events. In the past, inland wetlands were occasionally drained for conversion to cropland; tODAy limited conversion of wetlands to settlements may occur along the coasts.[102] Wetlands, waterways, woodlands and shrublands, deserts and mountain and Arctic ecosystems also provide ecological services on which we depend, as well as economic values from a host of related activities.

4 https://www.cia.gov/library/publications/the-world-factbook/rankorder/2147rank.html

5 https://www.census.gov/newsroom/press-releases/2021/2020-census-apportionment-results.html

6 https://www.census.gov/quickfacts/fact/table/US/PST045217

7 https://www.census.gov/newsroom/press-releases/2018/estimates-national-state.html

8 https://census.gov/data/tables/2017/demo/popproj/2017-summary-tables.html

9 https://www.census.gov/library/publications/2015/demo/p25-1143.html

10 https://www.census.gov/library/visualizations/2021/dec/2020-resident-population-map.html

11 https://www.census.gov/library/visualizations/2021/dec/2020-resident-population-map.html

12 https://www.bea.gov/news/2021/gross-domestic-product-second-quarter-2021-advance-estimate-and-annual-update

13 https://www.bea.gov/news/2021/gross-domestic-product-4th-quarter-and-year-2020-advance-estimate

14 Ibid.

15 https://www.bls.gov/opub/ted/2020/unemployment-rate-rises-to-record-high-14-point-7-percent-in-april-2020.htm?view_full

16 https://www.bea.gov/news/2021/gross-domestic-product-second-quarter-2021-advance-estimate-and-annual-update

17 https://www.eia.gov/tODAyinenergy/detail.php?id=48856

18 https://www.eia.gov/tODAyinenergy/detail.php?id=46537

19 https://www.ers.usda.gov/publications/pub-details/?pubid=84879

20 From NOAA data

21 NCA4 Figure 7.1: Annual and seasonal changes in precipitation over the United States. Changes are the average for present-day (1986–2015) minus the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i) divided by the average for the first half of the century. (Figure source: [top

panel] adapted from Peterson et al. 2013,78 © American Meteorological Society. Used with permission; [bottom four panels] NOAA NCEI, data source: nCLIMDiv]. https://science2017.globalchange.gov/downloads/CSSR2017_FullReport.pdf , page 209.

22 https://nca2018.globalchange.gov/downloads/NCA4_Report-in-Brief.pdf

23 https://www.ncdc.noaa.gov/sotc/national/202013

24 https://www.climate.gov/news-features/understanding-climate/climate-change-and-1991-2020-us-climate-normals

25 https://www.climate.gov/news-features/understanding-climate/climate-change-and-1991-2020-us-climate-normals

26 https://nca2018.globalchange.gov/downloads/NCA4_Report-in-Brief.pdf

27 https://www.ncdc.noaa.gov/sotc/national/202013

28 https://www.climate.gov/news-features/blogs/beyond-data/2020-us-billion-dollar-weather-and-climate-disasters-historical

29 https://www.climate.gov/news-features/blogs/beyond-data/2020-us-billion-dollar-weather-and-climate-disasters-historical

30 https://www.eia.gov/environment/emissions/carbon/

31 https://www.eia.gov/environment/emissions/carbon/

32 https://www.eia.gov/outlooks/aeo/consumption/sub-topic-03.php

33 https://www.eia.gov/tODAyinenergy/detail.php?id=48896

34 https://www.eia.gov/tODAyinenergy/detail.php?id=48896

35 From EIA data. https://www.eia.gov/environment/emissions/carbon/

36 Material for rest of this section from https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T01.02#/?f=A unless otherwise noted.

37 https://www.eia.gov/totalenergy/data/monthly/pdf/sec1_4.pdf

38 https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T01.03#/?f=A, https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T10.01#/?f=A&start=1949&end=2020&charted=6-7-8-9-15

39 https://www.eia.gov/tODAyinenergy/detail.php?id=48696

40 https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T03.01#/?f=A&start=1949&end=2020&charted=4

41 https://www.eia.gov/tODAyinenergy/detail.php?id=47056

42 https://www.eia.gov/tODAyinenergy/detail.php?id=48256, https://www.eia.gov/tODAyinenergy/detail.php?id=44636

43 https://www.eia.gov/tODAyinenergy/detail.php?id=48256, https://www.eia.gov/totalenergy/data/flow-graphs/natural-gas.php

44 https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T08.01#/?f=A&start=1957&end=2020&charted=2

45 https://www.eia.gov/totalenergy/data/monthly/

46 https://www.eia.gov/tODAyinenergy/detail.php?id=43256

47 https://www.eia.gov/tODAyinenergy/detail.php?id=43256

48 https://www.eia.gov/tODAyinenergy/detail.php?id=48896

49 https://www.eia.gov/totalenergy/data/monthly/, https://www.eia.gov/tODAyinenergy/detail.php?id=48896

50 https://www.eia.gov/tODAyinenergy/detail.php?id=48896

51 https://www.eia.gov/tODAyinenergy/detail.php?id=48896

52 From EIA data

53 https://www.eia.gov/tODAyinenergy/detail.php?id=38752

54 https://www.eia.gov/tODAyinenergy/detail.php?id=38752

55 https://www.eia.gov/tODAyinenergy/detail.php?id=46416

56 https://www.eia.gov/tODAyinenergy/detail.php?id=45136

57 https://www.eia.gov/tODAyinenergy/detail.php?id=48736

58 https://www.bts.dot.gov/newsroom/january-2019-freight-transportation-services-index-tsi

59 https://www.bts.gov/newsroom/estimated-october-2018-us-airline-traffic-data

60 https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

61 https://www.eia.gov/tODAyinenergy/detail.php?id=47496

62 https://www.bts.gov/data-spotlight/after-year-covid-19-view-bts

63 2020 EPA Automotive Trends Report. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010UBX.pdf, pg. 3.

64 US EIA, AEO 2021.

65 https://www.eia.gov/tODAyinenergy/detail.php?id=29612

66 https://www.eia.gov/todayinenergy/detail.php?id=29612

67

68

69 Source: Bureau of Transportation Statistics, using data from Argonne National Laboratory https://www.bts.gov/data-spotlight/electric-vehicle-use-grows

70 https://www.bts.gov/data-spotlight/electric-vehicle-use-grows

71 https://www.nrel.gov/docs/fy20osti/77508.pdf

72 Electric Vehicle Supply Equipment are charging points; there may be multiple EVSE at a single charging station

73 https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T02.04#/?f=A&start=2005&end=2019&charted=16

74 https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T02.04#/?f=A

75 https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T02.04#/?f=A

76 https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#NationalPicture

77 https://www.eia.gov/tools/faqs/faq.php?id=86&t=1

78 https://www.eia.gov/outlooks/aeo/pdf/06%20AEO2021%20Buildings.pdf

79 EIA projects U.S. energy intensity to continue declining, but at a slower rate - TODAy in Energy - U.S. Energy Information Administration (EIA) Also: https://www.eia.gov/tODAyinenergy/detail.php?id=42635

80 https://www.eia.gov/outlooks/aeo/pdf/06%20AEO2021%20Buildings.pdf

81 https://fred.stlouisfed.org/series/HOUST

82 https://www.eia.gov/energyexplained/use-of-energy/homes.php

83 https://www.eia.gov/energyexplained/use-of-energy/homes.php

84 https://www.eia.gov/energyexplained/use-of-energy/commercial-buildings.php

85 https://www.eia.gov/tODAyinenergy/detail.php?id=47736

86 https://www.eia.gov/tODAyinenergy/detail.php?id=47736

87 https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=58268, https://www.census.gov/data/tables/time-series/dec/popchange-data-text.html

88 https://www.bls.gov/ooh/farming-fishing-and-forestry/agricultural-workers.htm

89 Farms and Land in Farms, USDA, February 2021. https://downloads.usda.library.cornell.edu/usda-esmis/files/5712m6524/tq57pj927/rx914h75j/fnlo0221.pdf

90 https://downloads.usda.library.cornell.edu/usda-esmis/files/5712m6524/3j333500g/ht24wn24x/FarmLandIn-02-16-2018.pdf

91 Sources of Greenhouse Gas Emissions | US EPA

92 Oswalt, Sonja N.; Smith, W. Brad; Miles, Patrick D.; Pugh, Scott A., coords. 2019. Forest Resources of the United States, 2017: a technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. WO-97. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 223 p. https://doi.org/10.2737/WO-GTR-97; based on USDA Forest Service Forest Inventory & Analysis

93 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

94 https://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs199.pdf

95 https://www.fs.fed.us/about-agency/newsroom/by-the-numbers

96 https://www.energy.gov/eere/amo/forest-products-industry-profile

97 https://www.fs.fed.us/about-agency/newsroom/by-the-numbers

98 https://www.fs.fed.us/about-agency/newsroom/by-the-numbers

99 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

100 https://www.fia.fs.fed.us/library/brochures/docs/2012/ForestFacts_1952-2012_English.pdf

101 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019. Pg. 481.

102 https://www.fws.gov/wetlands/documents/Wetlands-Status-and-Trends-Reports-Fact-Sheet.pdf

3 GREENHOUSE GAS INVENTORY SUMMARY

The United States is committed to providing regular, transparent reporting on current and historical greenhouse gas emissions. Estimates of emissions and removals are reported annually, via the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. As a Party to the U.N. Framework Convention on Climate Change (UNFCCC), consistent with its Article 4[103] of the Convention and decisions at the First, Second, Fifth, and Nineteenth Conference of Parties,[104] the United States is committed to submitting a national inventory of anthropogenic sources and sinks of greenhouse gases to the UNFCCC by April 15 of each year. The United States views the *Inventory*, in conjunction with accompanying Common Reporting Format (CRF) reporting tables, as an opportunity to fulfill this annual commitment under the UNFCCC. The complete CRF reporting tables, including the CO_2 equivalent emission trend tables, are available online at https://unfccc.int/documents/272414.

This chapter summarizes the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 2019, consistent with information submitted to the UNFCCC secretariat in April 2021 and available online at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019 (EPA 2021). To ensure that the U.S. emissions inventory is comparable with those of other UNFCCC Parties, the Inventory emissions and removals estimates presented in this report and this chapter are organized by source and sink categories and calculated using methodologies consistent with those recommended in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and UNFCCC guidelines for annual inventory reporting (UNFCCC 2014). Additionally, the U.S. emissions inventory has continued to incorporate new methodologies and data from the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* and the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. As with each inventory submission, the "Recalculations and Improvements" chapter of the April 2021 *Inventory* submission includes a description on improvements and recalculations relative to the previous *Inventory*, consistent with the principle of continuous improvement.

BACKGROUND INFORMATION

Greenhouse gases trap heat and make the planet warmer. The most important greenhouse gases directly emitted as a result of human activities include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several fluorinated gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. From the pre-industrial era (i.e., ending about 1750)[105] to 2019, concentrations of CO_2, CH_4, and N_2O have increased globally by 47, 167, and 23 percent, respectively (IPCC 2013 and

NOAA/ESRL 2021a, b, c). The 1990–2019 Inventory estimates the total greenhouse gas emissions and removals associated with human activities across the United States.

RECENT TRENDS IN U.S. GREENHOUSE GAS EMISSIONS AND SINKS

In 2019, total gross U.S. greenhouse gas emissions were 6,558.3 MMT CO_2e.[106] Total U.S. emissions have increased by 1.8 percent from 1990 to 2019, down from a high of 15.6 percent above 1990 levels in 2007. Total gross emissions decreased from 2018 to 2019 by 1.7 percent (113.1 MMT CO_2e). Net emissions (i.e., including sinks) were 5,769.1 MMT CO_2e. Overall, net emissions decreased 1.7 percent from 2018 to 2019 and decreased 13.0 percent from 2005 levels, as shown in Table 3-1. The decline reflects the combined impacts of many long-term trends, including population, economic growth, energy market trends, technological changes including energy efficiency, and carbon intensity of energy fuel choices. Between 2018 and 2019, the decrease in total greenhouse gas emissions was driven largely by a decrease in CO_2 emissions from fossil fuel combustion. As described in the previous chapter, the decrease in CO_2 emissions from fossil fuel combustion was a result of a 1 percent decrease in total energy use and reflects a continued market shift from coal to less carbon intensive natural gas and renewables in the electric power sector.

Figures 3-1 and 3-2 illustrate the overall trends in both total U.S. greenhouse gas emissions by gas and annual changes in net emissions since 1990. Table 3-1 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2019. Overall, from 1990 to 2019, total emissions of CO_2 increased by 142.4 MMT CO_2e. (2.8 percent), while total emissions of methane (CH_4) decreased by 117.2 MMT CO_2e. (15.1 percent), and total emissions of nitrous oxide (N_2O) remained constant overall despite fluctuations throughout the time series across specific categories. During the same period, aggregate weighted emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) rose by 86.0 MMT CO_2e. (86.3 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, SF_6, and NF_3 are significant because many of them have both extremely high global warming potentials (GWPs) and, in the cases of PFCs, SF_6, and NF_3, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon (C) sequestration in managed forests, trees in urban areas, agricultural soils, landfilled yard trimmings, and coastal wetlands. These were estimated to offset 12.4 percent (812.7 MMT CO_2e.) of total emissions in 2019. The following sections describe each gas's contribution to total U.S. greenhouse gas emissions in more detail.

Figure 3-1 **U.S Greenhouse Gas Emissions by Gas**

Between 2005 and 2019, net U.S. emissions from all greenhouse gases declined by a total of 865.9 MMT CO_2e, or 13 percent. Total U.S. emissions increased by 4.1 percent from 1990 to 2019.

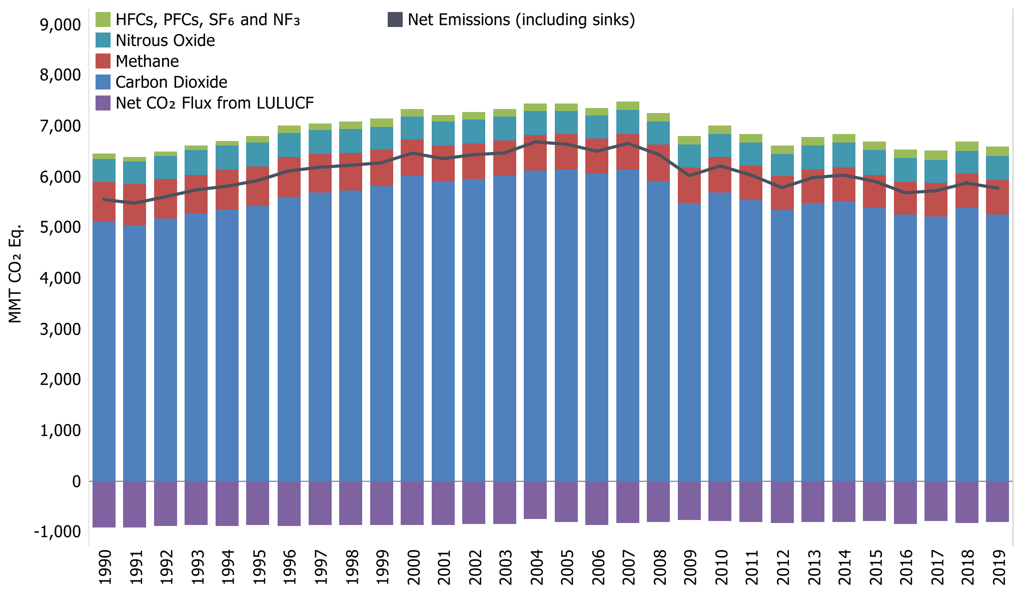


Figure 3-2 **Annual Percent Change in Gross U.S. Greenhouse Gas Emissions Relative to the Previous Year**

Between 2005 and 2019, net U.S. greenhouse gas emissions fell by 13.0 percent and average annual rate of decrease over that time period was 0.9 percent.

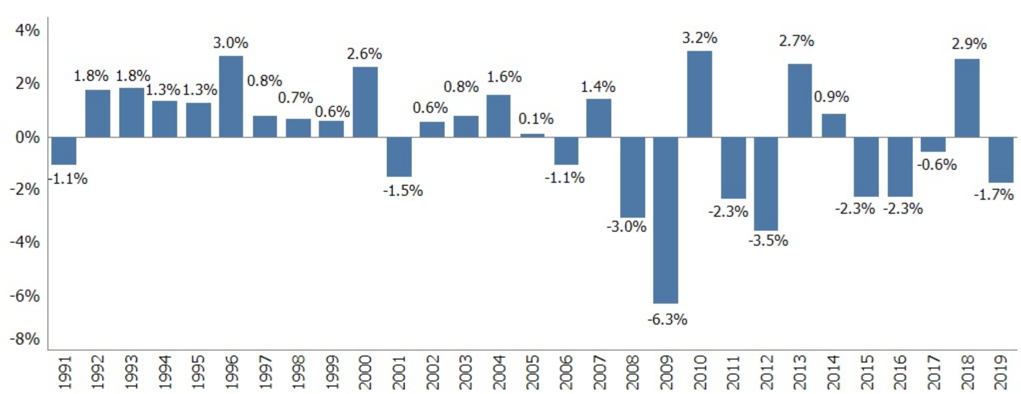


Figure 3-3 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 2019. Table 3-1 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2019. The primary greenhouse gas emitted by human activities in the United States was CO_2, representing approximately 80.1 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, was fossil fuel combustion, primarily from transportation and power generation. Methane emissions (CH_4) account for approximately 10.1 percent of emissions. The major sources of methane include enteric fermentation associated with domestic livestock, natural gas systems, and decomposition of wastes in landfills. Nitrous oxide emissions accounts for 7 percent of 2019 emissions and major sources include agricultural soil management, wastewater treatment, stationary sources of fuel combustion, and manure management. Ozone depleting substance substitute emissions, and emissions of HFC-23 during the production of HCFC-22, were the primary contributors to aggregate hydrofluorocarbon (HFC) emissions. Perfluorocarbon (PFC) emissions were primarily attributable to electronics manufacturing and primary aluminum production. Electrical transmission and distribution systems accounted for most sulfur emissions. The electronics industry is the only source of nitrogen trifluoride (NF_3) emissions. Collectively, fluorinated emissions account for nearly 3 percent of 2019 emissions.

Figure 3-3 **2019 U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2e)**
The primary greenhouse gases emitted by human activities in the United States was CO_2, representing approximately 80.1 percent of total greenhouse gas emissions.

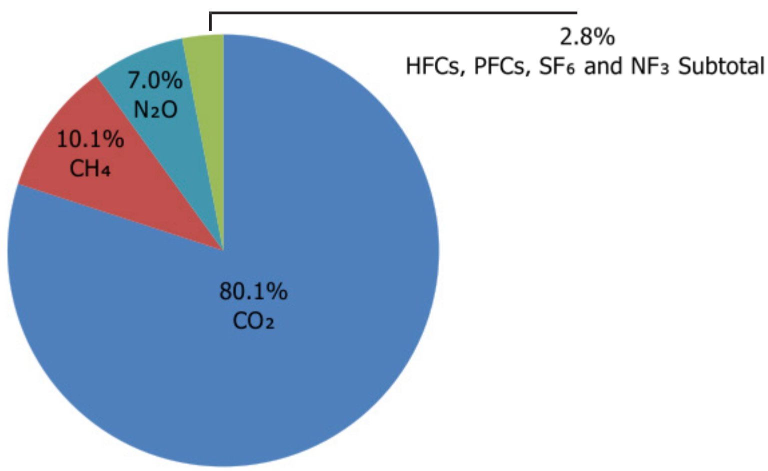


Table 3-1 **Recent Trends in U.S. Greenhouse Gas Emission and Sinks (MMT CO_2e)**
In 2019, net U.S. greenhouse gas emissions were 5,769.1 MMT CO_2e., representing a 4.1 percent increase since 1990 but a 13 percent decrease since 2005.

Gas/Source	1990	2005	2015	2016	2017	2018	2019
Carbon Dioxide (CO_2)	**5,113.5**	**6,134.5**	**5,371.8**	**5,248.0**	**5,207.8**	**5,375.5**	**5,255.8**
Fossil Fuel Combustion	4,731.5	5,753.5	5,008.3	4,911.5	4,854.5	4,991.4	4,856.7
Transportation	1,469.1	1,858.6	1,719.2	1,759.9	1,782.4	1,816.6	1,817.2
Electric Power	1,820.0	2,400.1	1,900.6	1,808.9	1,732.0	1,752.9	1,606.0
Industrial	853.8	852.9	797.3	792.5	790.1	813.6	822.5
Residential	338.6	358.9	317.3	292.8	293.4	338.1	336.8
Commercial	228.3	227.1	244.6	231.6	232.0	245.7	249.7
U.S. Territories	21.7	55.9	29.2	26.0	24.6	24.6	24.6
Non-Energy Use of Fuels	112.8	129.1	108.5	99.8	113.5	129.7	128.8
Petroleum Systems	9.7	12.1	32.4	21.8	25.0	37.1	47.3
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	47.9	43.6	40.6	42.6	41.3
Cement Production	33.5	46.2	39.9	39.4	40.3	39.0	40.9
Natural Gas Systems	32.0	25.2	29.1	30.1	31.2	33.9	37.2
Petrochemical Production	21.6	27.4	28.1	28.3	28.9	29.3	30.8
Ammonia Production	13.0	9.2	10.6	10.2	11.1	12.2	12.3
Lime Production	11.7	14.6	13.3	12.6	12.9	13.1	12.1
Incineration of Waste	8.1	12.7	11.5	11.5	11.5	11.5	11.5
Other Process Uses of Carbonates	6.3	7.6	12.2	11.0	9.9	7.5	7.5
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	4.6	5.1	5.0	5.9	6.2
Urea Fertilization	2.4	3.5	4.7	4.9	5.1	5.2	5.3
Carbon Dioxide Consumption	1.5	1.4	4.9	4.6	4.6	4.1	4.9
Liming	4.7	4.3	3.7	3.1	3.1	2.2	2.4
Aluminum Production	6.8	4.1	2.8	1.3	1.2	1.5	1.9
SODA Ash Production	1.4	1.7	1.7	1.7	1.8	1.7	1.8
Ferroalloy Production	2.2	1.4	2.0	1.8	2.0	2.1	1.6
Titanium Dioxide Production	1.2	1.8	1.6	1.7	1.7	1.5	1.5
Glass Production	1.5	1.9	1.3	1.2	1.3	1.3	1.3
Zinc Production	0.6	1.0	0.9	0.8	0.9	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	0.9	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+
Wood Biomass, Ethanol, and Biodiesel Consumption[a]	*219.4*	*230.7*	*317.7*	*316.6*	*312.3*	*319.6*	*316.2*
International Bunker Fuels[b]	*103.5*	*113.2*	*110.9*	*116.6*	*120.1*	*122.1*	*116.1*

Gas/Source	1990	2005	2015	2016	2017	2018	2019
Methane (CH_4)[c]	**776.9**	**686.1**	**651.5**	**642.4**	**648.4**	**655.9**	**659.7**
Enteric Fermentation	164.7	169.3	166.9	172.2	175.8	178.0	178.6
Natural Gas Systems	186.9	164.2	149.8	147.3	148.7	152.5	157.6
Landfills	176.6	131.4	111.4	108.0	109.4	112.1	114.5
Manure Management	37.1	51.6	57.9	59.6	59.9	61.7	62.4
Coal Mining	96.5	64.1	61.2	53.8	54.8	52.7	47.4
Petroleum Systems	48.9	39.5	41.5	39.2	39.3	37.3	39.1
Wastewater Treatment	20.2	20.1	18.8	18.7	18.5	18.4	18.4
Rice Cultivation	16.0	18.0	16.2	15.8	14.9	15.6	15.1
Stationary Combustion	8.6	7.8	8.5	7.9	7.6	8.5	8.7
Abandoned Oil and Gas Wells	6.8	7.2	7.4	7.4	7.2	7.3	6.6
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.7	6.4	6.2	5.9
Mobile Combustion	6.4	4.0	2.6	2.5	2.5	2.4	2.4
Composting	0.4	1.9	2.1	2.3	2.4	2.3	2.3
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Petrochemical Production	0.2	0.1	0.2	0.2	0.3	0.3	0.3
Anaerobic Digestion at Biogas Facilities	+	0.1	0.2	0.2	0.2	0.2	0.2
Ferroalloy Production	+	+	+	+	+	+	+
Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Nitrous Oxide (N_2O)[c]	**452.7**	**455.8**	**468.2**	**450.8**	**446.3**	**459.2**	**457.1**
Agricultural Soil Management	315.9	313.4	348.5	330.1	327.6	338.2	344.6
Wastewater Treatment	18.7	23.0	25.4	25.9	26.4	26.1	26.4
Stationary Combustion	25.1	34.4	30.5	30.0	28.4	28.2	24.9
Manure Management	14.0	16.4	17.5	18.1	18.7	19.4	19.6
Mobile Combustion	44.7	41.6	21.7	20.8	19.8	18.8	18.0
Nitric Acid Production	12.1	11.3	11.6	10.1	9.3	9.6	10.0
Adipic Acid Production	15.2	7.1	4.3	7.0	7.4	10.3	5.3
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Composting	0.3	1.7	1.9	2.0	2.2	2.0	2.0
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	1.9	1.7	1.5	1.4	1.4
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Electronics Industry	+	0.1	0.2	0.2	0.3	0.3	0.2
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+

Gas/Source	1990	2005	2015	2016	2017	2018	2019
International Bunker Fuels[b]	0.9	1.0	1.0	1.0	1.1	1.1	1.0
Hydrofluorocarbons (HFCs)	**46.5**	**127.5**	**168.3**	**168.1**	**170.3**	**169.8**	**174.6**
Substitution of Ozone Depleting Substances[d]	0.2	107.3	163.6	164.9	164.7	166.0	170.5
HCFC-22 Production	46.1	20.0	4.3	2.8	5.2	3.3	3.7
Electronics Industry	0.2	0.2	0.3	0.3	0.4	0.4	0.3
Magnesium Production and Processing	+	+	0.1	0.1	0.1	0.1	0.1
Perfluorocarbons (PFCs)	**24.3**	**6.7**	**5.2**	**4.4**	**4.1**	**4.7**	**4.5**
Electronics Industry	2.8	3.3	3.1	2.9	2.9	3.0	2.7
Aluminum Production	21.5	3.4	2.1	1.4	1.1	1.6	1.8
Substitution of Ozone Depleting Substances	+	+	+	+	+	0.1	0.1
Sulfur Hexafluoride (SF_6)	28.8	11.8	5.5	6.0	5.9	5.7	5.9
Electrical Transmission and Distribution	23.2	8.4	3.8	4.1	4.2	3.9	4.2
Magnesium Production and Processing	5.2	2.7	1.0	1.1	1.0	1.0	0.9
Electronics Industry	0.5	0.7	0.7	0.8	0.7	0.8	0.8
Nitrogen Trifluoride (NF_3)	**+**	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
Electronics Industry	+	0.5	0.6	0.6	0.6	0.6	0.6
Unspecified Mix of HFCs, PFCs, SF_6, and NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Total Emissions (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Emissions[c]	7.9	16.8	27.8	13.2	26.0	23.4	23.5
LULUCF CH_4 Emissions	5.0	9.3	16.6	7.7	15.3	13.8	13.8
LULUCF N_2O Emissions	3.0	7.5	11.3	5.5	10.6	9.7	9.7
LULUCF Carbon Stock Change[e]	(908.7)	(804.8)	(791.7)	(856.0)	(792.0)	(824.9)	(812.7)
LULUCF Sector Net Total[f]	(900.8)	(788.1)	(763.8)	(842.8)	(766.1)	(801.4)	(789.2)
Net Emissions (Sources and Sinks)	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

+ Does not exceed 0.05 MMT CO_2e.

[a] Emissions from Wood Biomass, Ethanol, and Biodiesel Consumption are not included specifically in summing Energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry.

[b] Emissions from International Bunker Fuels are not included in totals.

[c] LULUCF emissions of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for Peatlands Remaining Peatlands, Forest Fires, Drained Organic Soils, Grassland Fires, and Coastal Wetlands Remaining Coastal Wetlands; CH_4 emissions from Land Converted to Coastal Wetlands; and N_2O emissions from Forest Soils and Settlement Soils.

[d] Small amounts of PFC emissions also result from this source.

[e] LULUCF Carbon Stock Change is the net C stock change from the following categories: Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements, and Land Converted to Settlements.

f The LULUCF Sector Net Total is the net sum of all LULUCF CH4 and N2O emissions to the atmosphere plus net C stock changes.

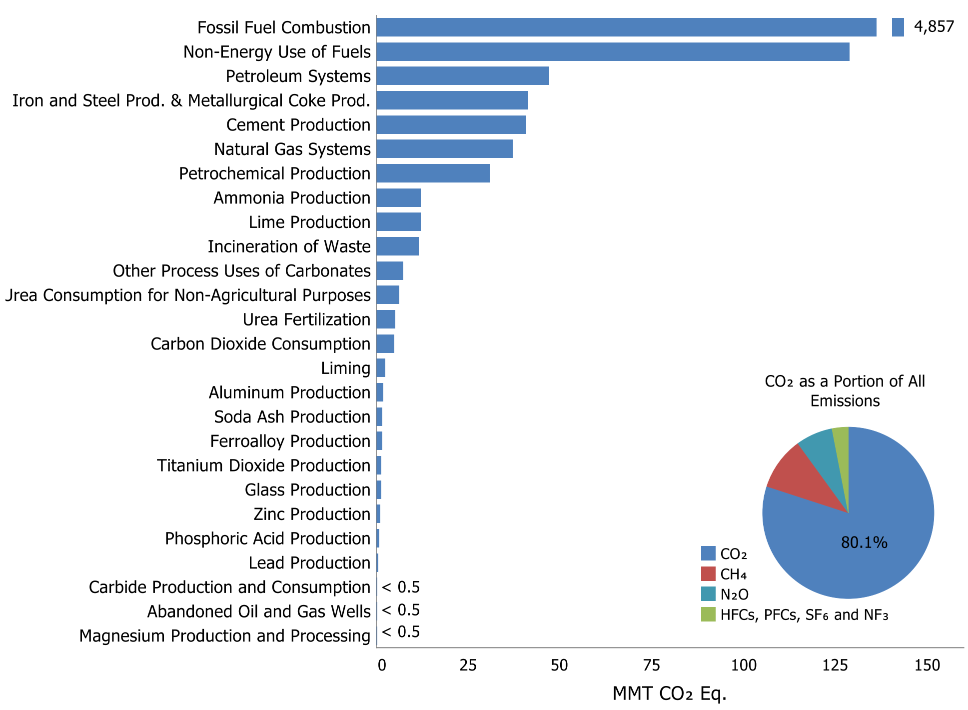
Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Billions of tonnes of carbon in the form of CO_2 are absorbed by oceans and living biomass (i.e., sinks) and are emitted to the atmosphere annually through natural processes (i.e., sources). When in equilibrium, global carbon fluxes among these various reservoirs are roughly balanced.[107]

Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO_2 have risen approximately 47 percent (IPCC 2013; NOAA/ESRL 2021a), principally due to the combustion of fossil fuels for energy. Globally, an estimated 33,513 MMT of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2018, of which the United States accounted for approximately 15 percent.[108] Within the United States, fossil fuel combustion accounted for 92.4 percent of CO_2 emissions in 2019. Transportation was the largest emitter of CO_2 in 2019, followed by electric power generation. There are 25 additional sources of CO_2 emissions included in the *Inventory* (see Figure 3-4). Although not illustrated in the Figure 3-4, changes in land use and forestry practices can also lead to net CO_2 emissions (e.g., through conversion of forest land to agricultural or urban use) or to a net sink for CO_2 (e.g., through net additions to forest biomass). See more on these emissions and removals in Table 3-5.

Figure 3-4 **2019 Sources of CO_2 Emissions**

In 2019, CO_2 accounted for 79.9 percent of U.S. greenhouse gas emissions, with fossil fuel combustion accounting for 92 percent of CO_2 emissions.



As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 76 percent of GWP-weighted total U.S. gross emissions across the time series. Between 1990 and 2019, CO_2 emissions from fossil fuel combustion increased from 4,731.5 MMT CO_2e. to 4,856.7 MMT CO_2e., a 2.6 percent total increase. In 2019, CO_2 emissions from fossil fuel combustion were 15.6 per cent (896.8 MMT CO_2e.) below 2005 levels. From 2018 to 2019, these emissions decreased by 134.7 MMT CO_2e. (2.7 percent).

Box 3-1 **Global Warming Potentials–**

UNFCCC reporting guidelines for national inventories require the use of GWP values from the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007).[109] All estimates are provided throughout the report in both CO_2 equivalents and unweighted units. A comparison of emission values using the AR4 GWP values versus the *IPCC Second Assessment Report* (SAR) (IPCC 1996), and the *IPCC Fifth Assessment Report* (AR5) (IPCC 2013) GWP values can be found in Annex 6 of the Inventory.[110] The 100-year GWP values used in this report are listed below in Table 3-2.

Table 3-2 **Global Warming Potentials (100-Year Time Horizon) Used in this Report**

Gas	GWP
CO_2	1
CH_4[a]	25
N_2O	298
HFC-23	14,800
HFC-32	675
HFC-41	92
HFC-125	3,500
HFC-134a	1,430
HFC-143a	4,470
HFC-152a	124
HFC-227ea	3,220
HFC-236fa	9,810
HFC-43-10mee	1,640
HFC-245fa	1,030
HFC-365mfc	794
CF_4	7,390
C_2F_6	12,200
C_3F_8	8,830
c-C_5F_8	1.97
C_4F_{10}	8,860
c-C_4F_8	10,300
C_5F_{12}	9,160
C_6F_{14}	9,300
SF_6	22,800
NF_3	17,200
Other Fluorinated Gases	See Annex 6 to the *Inventory*

[a] The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to production of CO_2 is not included. See Annex 6 of the *Inventory* for additional information.

Source: IPCC (2007), EPA (2021).

Historically, changes in emissions from fossil fuel combustion have been the driving factor affecting U.S. emissions trends. Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors. Important drivers include: (1) changes in demand for energy; and (2) a general decline in recent years in the carbon intensity of fuels combusted for energy by non-transport sectors of the economy. Long-term factors affecting energy demand include population and economic trends, technological changes including energy efficiency, shifting energy fuel choices, and various policies at the national, state, and local level. In the short term, the overall consumption and mix of fossil fuels in the United States fluctuates primarily in response to changes in general economic conditions, overall energy prices, the relative price of different fuels, weather, and the availability of non-fossil alternatives. For example, coal consumption for electric power is influenced by a number of factors, including the relative price of coal and alternative sources, the ability of electricity producers to switch fuels, and longer-term trends in coal markets. Likewise, warmer winters lead to a decrease in heating degree days and result in a decreased demand for heating fuel and electricity for heat in the residential and commercial sectors, which leads to a decrease in emissions from reduced fuel consumption.

The five fuel-consuming economic sectors are transportation, electric power, industrial, residential, and commercial. Carbon dioxide emissions are produced by the electric power sector as fossil fuel is consumed to provide electricity to one of the other four "end use" sectors see Figure 3-5. Note that this Figure reports emissions from U.S. Territories as their own end-use sector due to incomplete data for their individual end-use sectors. Fossil fuel combustion for electric power also includes emissions of less than 0.5 MMT CO_2e. from geothermal-based generation. Figure 3-5 further describes direct and indirect CO_2 emissions from fossil fuel combustion, separated by end-use sector.

Figure 3-5 **2019 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type**
In 2019, U.S. transportation sector emissions were primarily from petroleum consumption, while electricity generation emissions were primarily from natural gas and coal consumption.

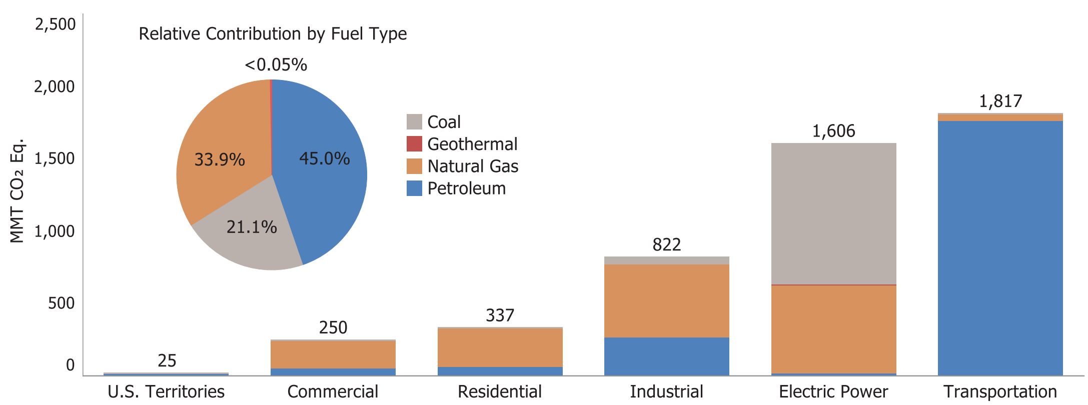


Figure 3-6 **2019 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion**

In 2019, direct fossil fuel combustion accounted for the vast majority of fossil fuel-related CO_2 emissions from the transportation sector (mostly petroleum combustion) and industrial sectors (mostly natural gas combustion). Electricity consumption indirectly accounted for most of the fossil fuel-related CO_2 emissions from the commercial and residential sectors.

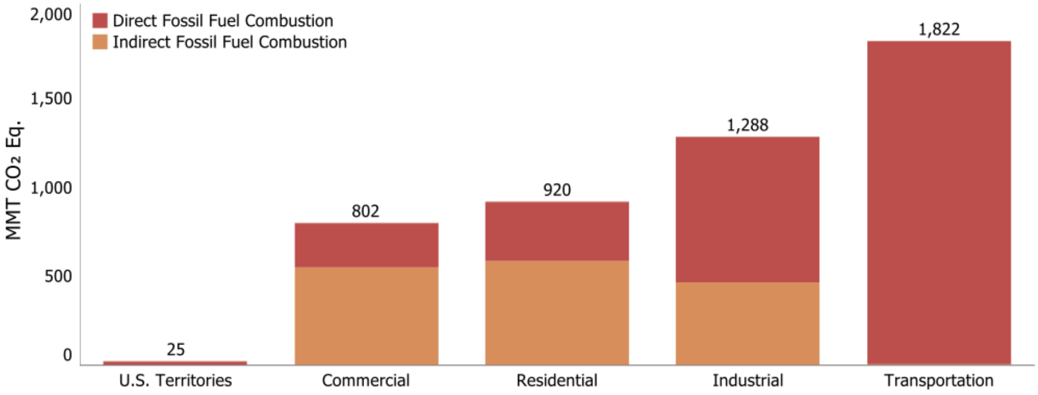


Table 3-3 **CO2 Emissions from Fossil Fuel Combustion by End-Use Sector (MMT CO2e.)**

The figures below reflect the distribution of electricity generation emissions to each of the four end-use sectors on the basis of each sector's share of aggregate electricity consumption. Between 2005 and 2019, CO_2 emissions from fossil fuel combustion declined by 896.8 MMT CO_2e., or 16 percent.

End-Use Sector	1990	2005	2015	2016	2017	2018	2019
Transportation	**1,472.2**	**1,863.4**	**1,723.5**	**1,764.1**	**1,786.8**	**1,821.2**	**1,821.9**
Combustion	1,469.1	1,858.6	1,719.2	1,759.9	1,782.4	1,816.6	1,817.2
Electricity	3.0	4.7	4.3	4.2	4.3	4.7	4.7
Industrial	**1,540.2**	**1,589.2**	**1,346.8**	**1,310.1**	**1,294.5**	**1,314.9**	**1,287.8**
Combustion	853.8	852.9	797.3	792.5	790.1	813.6	822.5
Electricity	686.4	736.3	549.5	517.6	504.4	501.3	465.3
Residential	**931.3**	**1,214.9**	**1,001.1**	**946.2**	**910.5**	**980.2**	**920.3**
Combustion	338.6	358.9	317.3	292.8	293.4	338.1	336.8
Electricity	592.7	856.0	683.8	653.5	617.1	642.1	583.5
Commercial	**766.0**	**1,030.1**	**907.6**	**865.2**	**838.2**	**850.6**	**802.1**
Combustion	228.3	227.1	244.6	231.6	232.0	245.7	249.7
Electricity	537.7	803.0	663.0	633.6	606.2	604.8	552.4
U.S. Territories[a]	**21.7**	**55.9**	**29.2**	**26.0**	**24.6**	**24.6**	**24.6**
Total	**4,731.5**	**5,753.5**	**5,008.3**	**4,911.5**	**4,854.5**	**4,991.4**	**4,856.7**
Electric Power	**1,820.0**	**2,400.1**	**1,900.6**	**1,808.9**	**1,732.0**	**1,752.9**	**1,606.0**

End-Use Sector	1990	2005	2015	2016	2017	2018	2019

Notes: Combustion-related emissions from electric power are allocated based on aggregate national electricity use by each end-use sector and represent indirect fossil fuel combustion for each end-use sector. Totals may not sum due to independent rounding.

[a] Fuel consumption by U.S. Territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands) is included in this report.

Transportation End-Use Sector.

Transportation activities accounted for 37.5 percent of U.S. CO_2 emissions from fossil fuel combustion in 2019. The largest sources of transportation CO_2 emissions in 2019 were passenger cars (40.5 percent); freight trucks (23.6 percent); light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.2 percent); commercial aircraft (7.2 percent); pipelines (2.9 percent); other aircraft (2.4 percent); rail (2.2 percent); and ships and boats (2.1 percent). Annex 3.2 presents the total emissions from all transportation and mobile sources, including CO_2, CH_4, N_2O, and HFCs.

In terms of the overall trend, from 1990 to 2019, total transportation CO_2 emissions increased due, in large part, to increased demand for travel. The number of vehicle miles traveled (VMT) by light-duty motor vehicles (i.e., passenger cars and light-duty trucks) increased 47.5 percent from 1990 to 2019[111] as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices during the beginning of this period. As noted in Chapter 2, while an increased demand for travel has led to increasing CO_2 emissions since 1990, improvements in average new vehicle fuel economy since 2005 has slowed the rate of increase of CO_2 emissions. Petroleum-based products supplied 95 percent of the energy used for transportation, with 60 percent from gasoline consumption in automobiles and other highway vehicles. Diesel fuel for freight trucks and jet fuel for aircraft accounted for 25 and 10 percent of fuel consumption, respectively. The remaining 5 percent of petroleum-based energy used for transportation was supplied by natural gas, residual fuel, aviation gasoline, and liquefied petroleum gases.

Industrial End-Use Sector.

Industrial emissions accounted for 27 percent of CO_2 emissions from fossil fuel combustion in 2019. These industrial emissions resulted both directly from the combustion of fossil fuels and indirectly from the generation of electricity that is used by industry. Approximately 64 percent of these emissions resulted from direct fossil fuel combustion to produce steam and/or heat for industrial processes. The remaining emissions resulted from the use of electricity for motors, electric furnaces, ovens, lighting, and other applications. Total direct and indirect emissions from the industrial sector have declined by 16.4 percent since 1990. This decline is due to structural changes in the U.S. economy (i.e., shifts from a manufacturing-based to a service-based economy), fuel switching, and efficiency improvements.

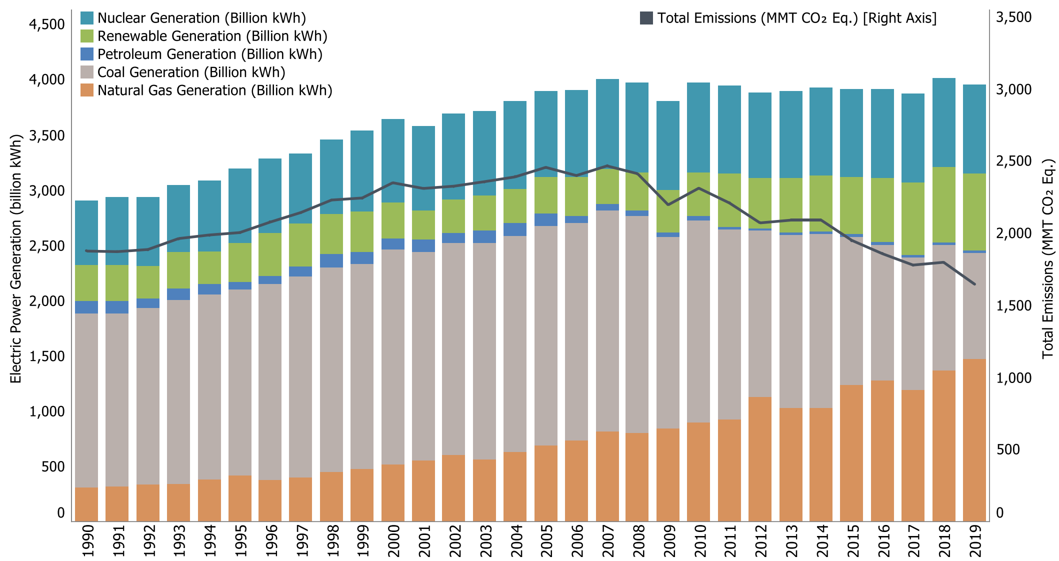
Residential and Commercial End-Use Sectors.
The residential and commercial end-use sectors accounted for 19 and 17 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2019. The residential and commercial sectors relied heavily on electricity for meeting energy demands, with 63 and 69 percent, respectively, of their emissions attributable to electricity use for lighting, heating, cooling, and operating appliances. The remaining emissions were due to the consumption of natural gas and petroleum for heating and cooking. Total direct and indirect emissions from the residential sector have decreased by 1 percent since 1990. Total direct and indirect emissions from the commercial sector have increased by 4.7 percent since 1990.

Electric Power.
The United States relies on electricity to meet a significant portion of its energy demands. Electricity generators used 31 percent of U.S. energy from fossil fuels and emitted 33 percent of the CO_2 from fossil fuel combustion in 2019. The type of energy source used to generate electricity is the main factor influencing emissions.[112] For example, some electricity is generated through non-fossil fuel options such as nuclear, hydroelectric, wind, solar, or geothermal energy. The mix of fossil fuels used also impacts emissions. The electric power sector is the largest consumer of coal in the United States. The coal used by electricity generators accounted for 93 percent of all coal consumed for energy in the United States in 2019. [113]However, the amount of coal and the percentage of total electricity generation from coal has been decreasing over time. Coal-fired electric generation (in kilowatt-hours [kWh]) decreased from 54 percent of generation in 1990 to 28 percent in 2019.[114] This corresponded with an increase in natural gas generation and renewable energy generation, largely from wind and solar energy. Natural gas generation (in kWh) represented 11 percent of electric power generation in 1990 and increased over the subsequent thirty-year period to represent 34 percent of electric power generation in 2019. Wind and solar generation (in kWh) represented 0.1 percent of electric power generation in 1990 and increased over the subsequent thirty-year period to represent 9 percent of electric power generation in 2019.

Overall U.S. demand for electricity has been relatively flat since 2005, due in part to a shift toward energy efficient products and more stringent energy efficiency standards for household equipment and building energy code adoption (EIA 2020a). Across the time series, changes in electricity generation and the carbon intensity of fuels used for electric power had a significant impact on CO_2 emissions. While CO_2 emissions from the electric power sector have decreased by approximately 12 percent since 1990, the carbon intensity of the electric power sector, in terms of CO_2e. per quadrillion BTU (QBtu) input, has significantly decreased–(27 percent) during that same timeframe. This decoupling of the level of electric power generation and the resulting CO_2 emissions is shown in Figure 3-7.

Figure 3-7 **2019 Electric Power Generation and Emissions**

Changes in electricity demand and the carbon intensity of fuels used for electric power generation have a significant impact on CO2 emissions. Carbon dioxide emissions from the electric power sector have decreased by approximately 12 percent since 1990, and the carbon intensity of the electric power sector, in terms of CO_2e. per QBtu input, has significantly decreased by 16 percent during that same timeframe.



Other CO_2 Trends

Other significant CO_2 trends over this time series include the following:

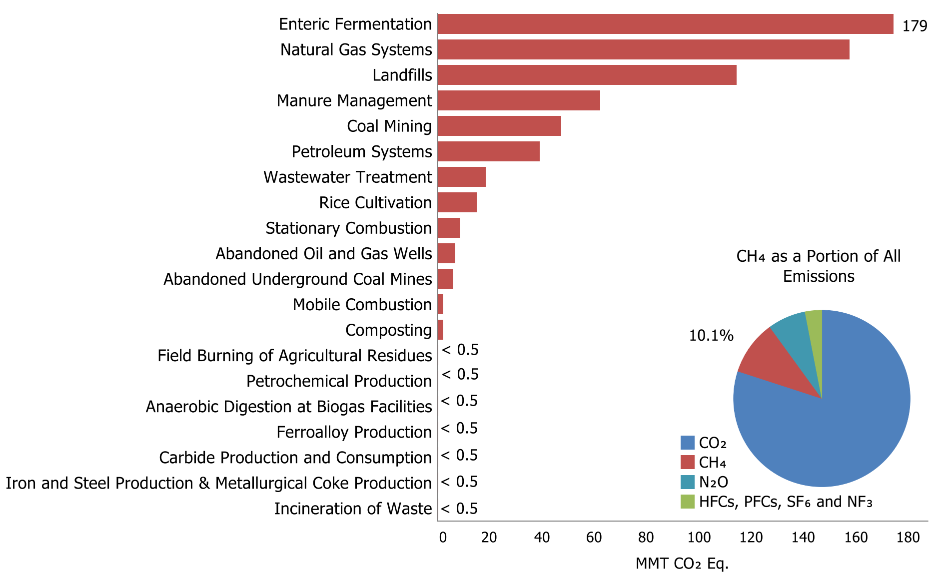
- CO_2 emissions from natural gas and petroleum systems increased by 42.8 MMT CO_2e. (102.4 percent) from 1990 to 2019. This increase is due primarily to increases in the production segment, where flaring emissions from associated gas flaring, tanks, and miscellaneous production flaring have increased over time.
- CO_2 emissions from iron and steel production and metallurgical coke production have decreased by 63.4 MMT CO_2e. (60.6 percent) from 1990 through 2019, due to restructuring of the industry, technological improvements, and increased scrap steel utilization.
- Total carbon stock change (i.e., net CO_2 removals) in the LULUCF sector decreased by approximately 10.6 percent between 1990 and 2019. This decrease was primarily due to a decrease in the rate of net C accumulation in forest C stocks and *Cropland Remaining Cropland,* as well as an increase in emissions from *Land Converted to Settlements*. See additional information on trends from land use, land use change, and forestry below.

Methane Emissions

Methane (CH_4) is significantly more potent than CO_2 at trapping heat in the atmosphere—by a factor of 25 over a 100-year time frame, based on the *IPCC Fourth Assessment Report* estimate (IPCC 2007). Over the last 250 years, the concentration of CH_4 in the atmosphere increased by 167 percent (IPCC 2013; NOAA/ESRL 2021b). Within the United States, the main anthropogenic sources of CH_4 include enteric fermentation from domestic livestock, natural gas systems, landfills, domestic livestock manure management, coal mining, and petroleum systems (see Figure 3-8).

Figure 3-8 **2019 Sources of CH_4 Emissions**

In 2019, CH_4 accounted for 10.1 percent of U.S. greenhouse gas emissions on a 100-year GWP-weighted basis. Enteric Fermentation is the largest source of CH_4 emissions contributing 178.6 MMT CO_2e., accounting for 27.1 percent of total CH_4 emissions. Natural Gas Systems followed close behind, contributing 157.6 MMT CO_2e. or 23.9 percent.



Note: Emissions of CH_4 from LULUCF (e.g., from forest fires) are reported separately from gross emissions totals and are not included in Figure 3-9. Refer to Table 3-5 for a breakout of LULUCF emissions by gas.

Significant trends for the largest sources of U.S. CH_4 emissions include the following:

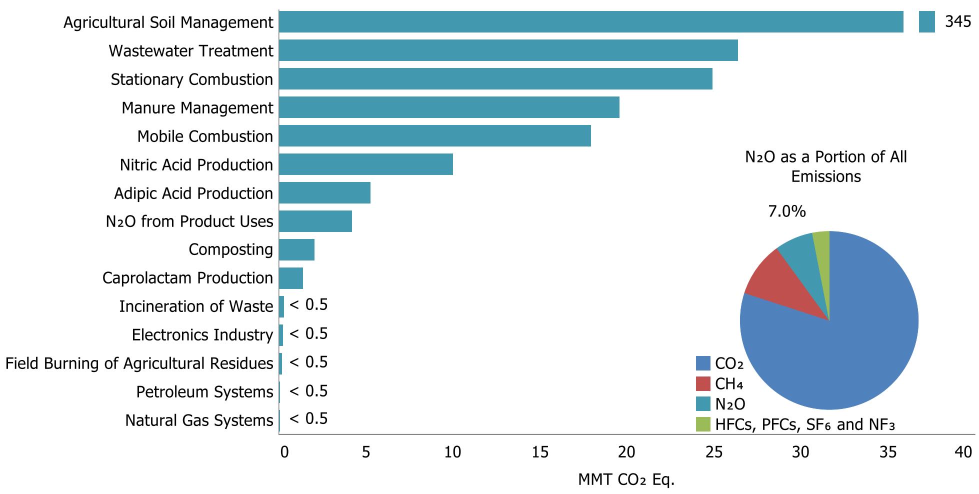
- Enteric fermentation was the largest anthropogenic source of CH_4 emissions in the United States. In 2019, enteric fermentation CH_4 emissions were 178.6 MMT CO_2e (27.1 percent of total CH_4 emissions), an increase of 13.9 MMT CO_2e (8.4 percent) since 1990. This increase in emissions from 1990 to 2019 generally follows the increase in cattle populations.
- Natural gas systems were the second largest anthropogenic source category of CH_4 emissions in the United States in 2019, emitting 157.6 MMT CO_2e of CH_4 into the atmosphere. Those emissions have decreased by 29.3 MMT CO_2e (15.7 percent) since 1990. The decrease in CH_4 emissions is largely due to decreases in emissions from distribution, transmission, and storage of natural gas. The decrease in distribution emissions is due to decreased emissions from pipelines and distribution station leaks, and the decrease in transmission and storage emissions is largely due to reduced compressor station emissions (including emissions from compressors and equipment leaks).
- Landfills were the third largest anthropogenic source of CH_4 emissions in the United States (114.5 MMT CO_2e), accounting for 17.4 percent of total CH_4 emissions in 2019. From 1990 to 2019, CH_4 emissions from landfills decreased by 62.1 MMT CO_2e (35.2 percent), with small year-to-year increases. This downward trend in emissions coincided with both increased landfill gas collection and control systems and a reduction of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings) discarded in municipal solid waste (MSW) landfills over the time series.[115] While the amount of landfill gas collected and combusted continues to increase, the rate of increase in collection and combustion no longer exceeds the rate of additional CH_4 generation from the amount of organic MSW landfilled as the U.S. population grows.

Nitrous Oxide Emissions

Nitrous oxide (N_2O) is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy, industrial, and waste management fields. While total N_2O emissions are much lower than CO_2 emissions, N_2O is nearly 300 times more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time frame (IPCC 2007). Since 1750, the global atmospheric concentration of N_2O has risen by approximately 23 percent (IPCC 2013; NOAA/ESRL 2021c). The main anthropogenic activities producing N_2O in the United States are agricultural soil management, wastewater treatment, stationary fuel combustion, manure management, fuel combustion in motor vehicles, and nitric acid production (see Figure 3-9).

Figure 3-9 **2019 Sources of N_2O Emissions**

In 2019, N_2O accounted for 7 percent of U.S. greenhouse gas emissions on a 100-year GWP-weighted basis. Agricultural Soil was the largest source, accounting for 345 MMT CO_2e (75.4 percent) of N_2O emissions.



Note: Emissions of N_2O from LULUCF are reported separately from gross emissions totals and are not included in Figure 3-10. Refer to Table 3-5 for a breakout of LULUCF emissions by gas.

Significant trends for the largest sources of U.S. emissions of N_2O include the following:

- Agricultural soils accounted for 75.4 percent of N_2O emissions and 5.3 percent of total greenhouse gas emissions in the United States in 2019. Estimated emissions from this source in 2019 were 344.6 MMT CO_2e. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2019, although overall emissions were 9.1 percent higher in 2019 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.
- Wastewater treatment, both domestic and industrial, accounted for 5.8 percent of N_2O emissions and 0.4 percent of total greenhouse gas emissions in the United States in 2019. Emissions from wastewater treatment increased by 41.0 percent (7.7 MMT CO_2e) since 1990. Nitrous oxide emissions from wastewater treatment processes gradually increased across the time series as a result of growing U.S. population and protein consumption.
- Nitrous oxide emissions from industrial wastewater treatment sources, included for the first time in the current (i.e., 1990 to 2019) Inventory, fluctuated throughout the time series, with production changes associated with the treatment of wastewater from the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, petroleum refining, and brewery industries.
- Nitrous oxide emissions from manure management accounted for 4.3 percent of N_2O emissions in 2019 and increased by 40.2 percent (5.6 MMT CO_2e) from 1990 to 2019. While the industry trend has been a shift toward liquid systems, driving down the emissions per unit of nitrogen excreted (dry manure handling systems have greater aerobic conditions that promote N_2O

emissions), increases in specific animal populations have driven an increase in overall manure management N_2O emissions over the time series.

- Nitrous oxide emissions from mobile combustion decreased by 26.8 MMT CO_2e. (59.8 percent) from 1990 to 2019, primarily as a result of national vehicle emissions standards and emission control technologies for on-road vehicles.

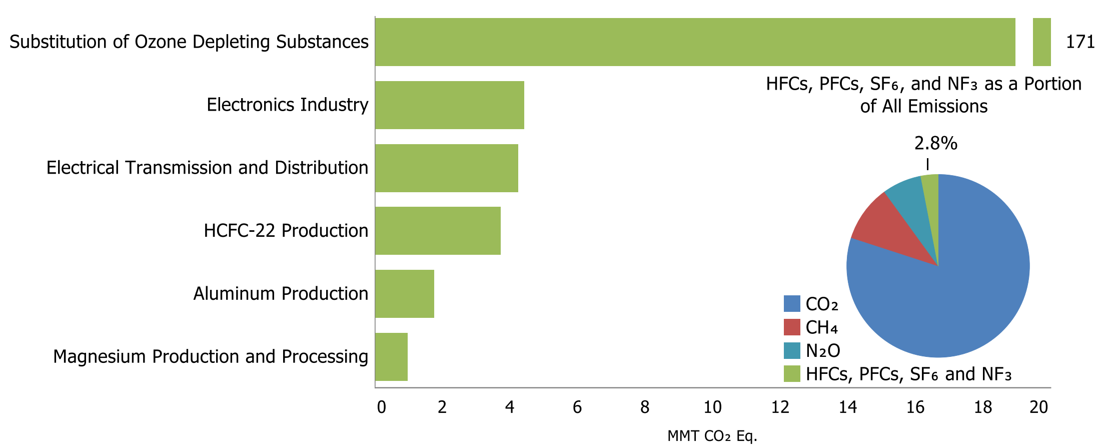
HFC, PFC, SF_6, and NF_3 Emissions

HFCs, PFCs, SF_6, and NF_3 are potent greenhouse gases. In addition to having very high global warming potentials, SF_6 and PFCs have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere once emitted. Sulfur hexafluoride is the most potent greenhouse gas the IPCC has evaluated (IPCC 2013).

Hydrofluorocarbons (HFCs) are synthetic chemicals that are used as alternatives to ozone depleting substances (ODS), which are being phased out under the Montreal Protocol on Substances that Deplete the Ozone Layer, and the Clean Air Act Amendments of 1990. HFCs have been used as alternatives to ODS under the Montreal Protocol. While their impact is small compared to their predecessors, recent research has shown that the use of HFCs is associated with a weak depletion of stratospheric ozone.[116] (Under the 2016 Kigali Amendment to the Montreal Protocol, there is now a global effort to phase down HFCs as well.) Perfluorocarbons (PFCs) are emitted from the production of electronics and aluminum and also (in smaller quantities) from their use as alternatives to ozone depleting substances. Sulfur hexafluoride (SF_6) is emitted from the production of electronics and magnesium, as well as from the manufacturing and use of electrical transmission and distribution equipment. NF_3 is also emitted from electronics production. One HFC, HFC-23, is emitted during production of HCFC-22 and electronics (see Figure 3-10).

Figure 3-10 **2019 Sources of HFCs, PFCs, SF_6, and NF_3 Emissions**

In 2019, HFCs, PFCs, SF6, and NF_3 accounted for 2.8 percent of U.S. greenhouse gas emissions on a GWP-weighted basis. Emissions from the substitution of ozone-depleting substances (e.g., chlorofluorocarbons) have been consistently increasing, from 0.2 MMT CO_2e. in 1990 to 170.6 MMT CO_2e. in 2019.



Some significant trends for the largest sources of U.S. HFC, PFC, SF_6, and NF_3 emissions include the following:

- Hydrofluorocarbon and perfluorocarbon emissions resulting from their use as substitutes for ozone-depleting substances (ODS) (e.g., chlorofluorocarbons [CFCs]) are the largest share of fluorinated emissions (92 percent) and have been consistently increasing, from small amounts in 1990 to 170.6 MMT CO_2e in 2019. This increase was in large part the result of efforts to phase out CFCs and other ODS in the United States.
- Emissions from HCFC-22 production were 3.7 MMT CO_2e in 2019, a 92 percent decrease from 1990 emissions. The decrease from 1990 emissions was caused primarily by a reduction in the HFC-23 emission rate (kg HFC-23 emitted/kg HCFC-22 produced). The emission rate was lowered by optimizing the production process and capturing much of the remaining HFC-23 for use or destruction.
- GWP-weighted PFC, HFC, SF_6, and NF_3 emissions from the electronics industry have increased by 23.7 percent from 1990 to 2019, reflecting the competing influences of industrial growth and the adoption of emission reduction technologies. Within that time span, emissions peaked at 9.0 MMT CO_2e in 1999, the initial year of EPA's PFC Reduction/Climate Partnership for the Semiconductor Industry, but have since declined to 4.4 MMT CO_2e in 2019 (a 51.3 percent decrease relative to 1999).
- Sulfur hexafluoride emissions from electric power transmission and distribution systems decreased by 81.7 percent (18.9 MMT CO_2e) from 1990 to 2019. There are two factors contributing to this decrease: (1) a sharp increase in the price of SF_6 during the 1990s; and (2) a growing awareness of the environmental impact of SF_6 emissions through programs such as EPA's SF_6 Emission Reduction Partnership for Electric Power Systems.

OVERVIEW OF IPCC SECTOR EMISSIONS AND TRENDS

Figure 3-11 and Table 3-4 show aggregate emissions and sinks, using the sectors defined by the IPCC methodological guidance and UNFCCC reporting guidelines to promote comparability across countries. Over the thirty-year period of 1990 to 2019, total emissions from the Energy, Industrial Processes and Product Use, and Agriculture sectors grew by 66.7 MMT CO_2e (1.3 percent), 28.2 MMT CO_2e (8.1 percent), and 73.3 MMT CO_2e (13.2 percent), respectively. Emissions from the Waste sector decreased by 52.4 MMT CO_2e (24.2 percent). Over the same period, net carbon (C) sequestration in the LULUCF sector decreased by 96.0 MMT CO_2 (10.6 percent decrease in total net C sequestration), while emissions from the LULUCF sector (i.e., CH_4 and N_2O) increased by 15.5 MMT CO_2e (196.1 percent).

Figure 3-11 **U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector**

Along with Table 3-4, this figure aggregates emissions and sinks by sectors, as defined by the Intergovernmental Panel on Climate Change and also presents net emissions including sinks.

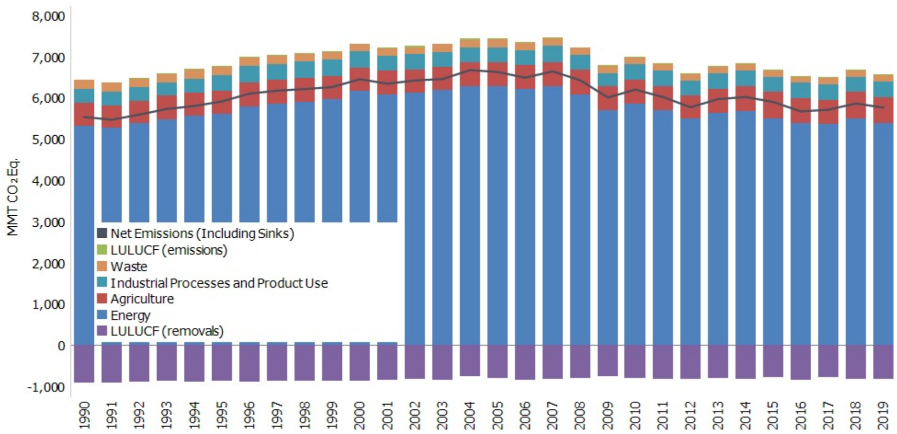


Table 3-4 **Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector**

From 1990 to 2019, total emissions in the energy, industrial processes and product use, and agriculture sectors increased, while emissions in the waste sector decreased. Net sequestration in the land-use change and forestry sector decreased by 96.0 MMT CO_2 (10.6 percent).

IPCC Sector	1990	2005	2015	2016	2017	2018	2019
Energy	**5,325.6**	**6,302.3**	**5,519.8**	**5,390.9**	**5,351.0**	**5,518.1**	**5,392.3**
Industrial Processes and Product Use	**345.6**	**365.7**	**375.4**	**368.0**	**367.7**	**371.3**	**373.7**
Agriculture	**555.3**	**577.1**	**616.1**	**604.4**	**605.5**	**621.0**	**628.6**
Waste	**216.2**	**178.0**	**159.8**	**157.1**	**159.0**	**161.1**	**163.7**
Total Emissions[a] (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Sector Net Total[b]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Net Emission (Sources and Sinks)[c]	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[a] Total emissions without LULUCF.

[b] The LULUCF Sector Net Total is the sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of MMT CO_2e.

[c] Net emissions with LULUCF.

Energy

The Energy sector contains emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions, and the use of fossil fuels for non-energy purposes. As noted above, energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2019. Energy-related activities are also responsible for CH_4 and N_2O emissions (40.6 percent and 9.5 percent of total U.S. emissions of each gas, respectively). Overall, emission sources in the Energy sector account for a combined 82.2 percent of total U.S. greenhouse gas emissions in 2019.

Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) sector includes greenhouse gas emissions generated and emitted as the byproducts of non-energy-related industrial processes, which involve the chemical or physical transformation of raw materials and can release waste gases such as CO_2, CH_4, N_2O, and fluorinated gases (e.g., HFC-23). These processes include iron and steel production and metallurgical coke production, cement production, petrochemical production, lime production, ammonia production, nitric acid production, other process uses of carbonates (e.g., flue gas desulfurization), urea consumption for non-agricultural purposes, adipic acid production, HCFC-22 production, aluminum production, sODA ash production and use, ferroalloy production, titanium dioxide production, caprolactam production, glass production, zinc production, phosphoric acid production, lead production, and silicon carbide production and consumption. Most of these industries also emit CO_2 from fossil fuel combustion which, in line with IPCC sectoral definitions, is included in the Energy Sector.

This sector also includes the release of HFCs, PFCs, SF6, and NF3 and other fluorinated compounds used in industrial manufacturing processes and by end-consumers (e.g., residential and mobile air conditioning). These industries include electronics industry, electric power transmission and distribution, and magnesium metal production and processing. In addition, N2O is used in and emitted by electronics industry and anesthetic and aerosol applications, and CO2 is consumed and emitted through various end-use applications. In 2019, emissions resulting from use of the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) by end-consumers was the largest source of IPPU emissions and accounted for 170.6 MMT CO2e (45.6 percent) of total IPPU emissions.

IPPU activities are responsible for 3.2, 0.1, and 4.6 percent of total U.S. CO2, CH4, and N2O emissions respectively, as well as for all U.S. emissions of fluorinated gases such as HFCs, PFCs, SF6 and NF3. Overall, emission sources in the IPPU sector accounted for 5.7 percent of U.S. greenhouse gas emissions in 2019.

Agriculture

The Agriculture sector includes anthropogenic emissions from agricultural activities (except fuel combustion, which per IPCC guidance is addressed in the Energy sector, and some agricultural CO_2, CH_4, and N_2O fluxes, which are addressed in the Land Use, Land-Use Change, and Forestry sector). Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes, including the following source categories: agricultural soil management, enteric fermentation in domestic livestock, livestock manure management, rice cultivation, urea fertilization, liming, and field burning of agricultural residues.

In 2019, agricultural activities were responsible for emissions of 628.6 MMT CO_2e, or 9.6 percent of total U.S. greenhouse gas emissions. Methane, N_2O, and CO_2 are greenhouse gases emitted by agricultural activities. Methane emissions from enteric fermentation and manure management represented approximately 27.1 percent and 9.5 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2019. Agricultural soil management activities, such as application of synthetic and organic fertilizers, deposition of livestock manure, and growing N-fixing plants, were the largest contributors to U.S. N_2O emissions in 2019, accounting for 75.4 percent of total N_2O emissions. Carbon dioxide emissions from the application of crushed limestone and dolomite (i.e., soil liming) and urea fertilization represented 0.1 percent of total CO_2 emissions from anthropogenic activities.

Land Use, Land-Use Change, and Forestry

The LULUCF sector contains emissions and removals of CO_2 and emissions of CH_4 and N_2O from managed lands in the United States. Consistent with the *2006 IPCC Guidelines*, emissions and removals from managed lands are considered to be anthropogenic, while emissions and removals from unmanaged lands are considered to be natural.[117] The share of managed land in the United States is approximately 95 percent of total land included in the *Inventory*. More information on the definition of managed land used in the *Inventory* is provided in Chapter 6 of the *Inventory*.[118]

Overall, the Inventory results show that U.S. managed land is a net sink for CO_2 (i.e. provides net carbon sequestration). The primary drivers of fluxes on managed lands include forest management practices, tree planting in urban areas, the management of agricultural soils, and land use change. The main drivers for forest carbon sequestration include forest growth and increasing forest area (i.e., afforestation), as well as a net accumulation of carbon stocks in harvested wood pools. The net sequestration in *Settlements Remaining Settlements,* which occurs predominantly from urban forests (i.e., Settlement Trees) and landfilled yard trimmings and food scraps, is a result of net tree growth and increased urban forest area, as well as long-term accumulation of yard trimmings and food scraps carbon in landfills.

The LULUCF sector in 2019 resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 812.7 MMT CO_2e. (Table 3-5). [119]This represents an offset of 12.3 percent of total (i.e., gross) U.S. greenhouse gas emissions in 2019. Emissions of CH_4 and N_2O from LULUCF activities in 2019 were 23.5 MMT CO_2e., representing 0.4 percent of total greenhouse gas emissions.[120] Between 1990 and 2019, total carbon sequestration in the LULUCF sector decreased by 10.6 percent, primarily due to a decrease in the rate of net carbon accumulation in forests and *Cropland Remaining Cropland,* as well as an increase in CO_2 emissions from *Land Converted to Settlements*. The overall net flux from LULUCF (i.e., net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of MMT CO_2e.) resulted in a removal of 789.2 MMT CO_2e in 2019.

Forest fires were the largest source of CH_4 emissions from the LULUCF sector in 2019, totaling 9.5 MMT CO_2e. *Coastal Wetlands Remaining Coastal Wetlands* resulted in CH_4 emissions of 3.8 MMT CO_2e. Grassland fires resulted in CH_4 emissions of 0.3 MMT CO_2e. *Land Converted to Wetlands* resulted in CH_4 emissions of 0.2 MMT CO_2e. *Drained Organic Soils* and *Peatlands Remaining Peatlands* resulted in CH_4 emissions of less than 0.05 MMT CO_2e. each.

Forest fires were also the largest source of N_2O emissions from the LULUCF sector in 2019, totaling 6.2 MMT CO_2e. Nitrous oxide emissions from fertilizer application to settlement soils in 2019 totaled to 2.4 MMT CO_2e. Additionally, the application of synthetic fertilizers to forest soils in 2019 resulted in N_2O emissions of 0.5 MMT CO_2e. Grassland fires resulted in N_2O emissions of 0.3 MMT CO_2e. *Coastal Wetlands Remaining Coastal Wetlands* and *Drained Organic Soils* resulted in N_2O emissions of 0.1 MMT CO_2e. each. *Peatlands Remaining Peatlands* resulted in N_2O emissions of less than 0.05 MMT CO_2e. Carbon dioxide removals from C stock changes are presented in Table 3-5 along with CH_4 and N_2O emissions for LULUCF source categories.

Table 3-5 **U.S. Greenhouse Gas Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2e)**

Land-Use Category	1990	2005	2015	2016	2017	2018	2019
Forest Land Remaining Forest Land	**(785.9)**	**(652.8)**	**(650.6)**	**(715.7)**	**(640.9)**	**(682.4)**	**(675.5)**
Land Converted to Forest Land	**(98.2)**	**(98.7)**	**(98.9)**	**(99.0)**	**(99.1)**	**(99.1)**	**(99.1)**
Cropland Remaining Cropland	**(23.2)**	**(29.0)**	**(12.8)**	**(22.7)**	**(22.3)**	**(16.6)**	**(14.5)**
Land Converted to Cropland	**51.8**	**52.2**	**56.1**	**54.4**	**54.6**	**54.3**	**54.2**
Grassland Remaining Grassland	**8.5**	**10.7**	**13.8**	**10.4**	**11.9**	**12.3**	**15.1**
Land Converted to Grassland	**(6.2)**	**(40.1)**	**(23.9)**	**(24.0)**	**(24.4)**	**(24.1)**	**(23.2)**
Wetlands Remaining Wetlands	**(3.5)**	**(2.6)**	**(4.1)**	**(4.1)**	**(4.0)**	**(4.0)**	**(4.0)**
Land Converted to Wetlands	**0.7**	**0.7**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Settlements Remaining Settlements	**(107.6)**	**(113.5)**	**(123.7)**	**(121.5)**	**(121.4)**	**(121.2)**	**(121.7)**
Land Converted to Settlements	**62.9**	**85.0**	**80.1**	**79.4**	**79.3**	**79.3**	**79.2**
LULUCF Carbon Stock Change[i]	**(908.7)**	**(804.8)**	**(791.7)**	**(856.0)**	**(792.0)**	**(824.9)**	**(812.7)**
LULUCF Emissions[j]	**7.9**	**16.8**	**27.8**	**13.2**	**26.0**	**23.4**	**23.5**
LULUCF CH_4 Emissions	5.0	9.3	16.6	7.7	15.3	13.8	13.8
LULUCF N_2O Emissions	3.0	7.5	11.3	5.5	10.6	9.7	9.7
LULUCF Sector Net Total[k]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

+ Absolute value does not exceed 0.05 MMT CO_2e.

[i] LULUCF Carbon Stock Change includes any C stock gains and losses from all land use and land use conversion categories.

[j] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[k] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of MMT CO_2e.

Waste

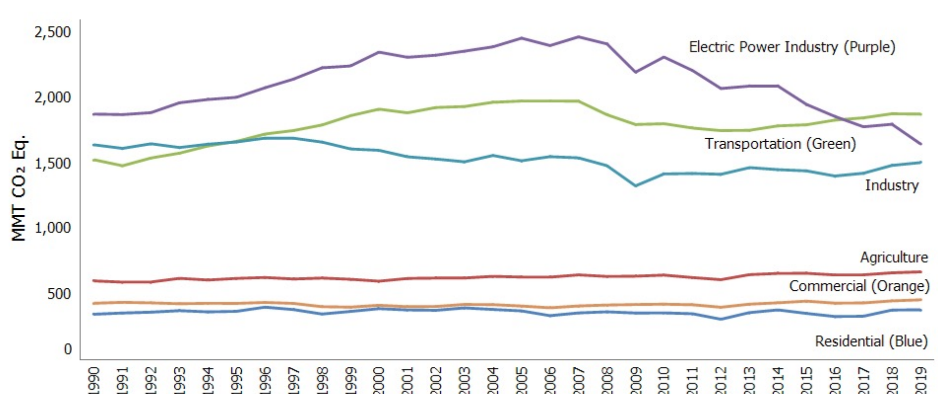
The Waste sector includes emissions from waste management activities (except incineration of waste, which is addressed in the Energy sector). Landfills were the largest source of anthropogenic greenhouse gas emissions from waste management activities, generating 114.5 MMT CO_2e. and accounting for 69.9 percent of total greenhouse gas emissions from waste management activities and 17.4 percent of total U.S. CH_4 emissions.[121] Additionally, wastewater treatment generated emissions of 44.8 MMT CO_2e. and accounted for 27.3 percent of total Waste sector greenhouse gas emissions, 2.8 percent of U.S. CH_4 emissions, and 5.8 percent of U.S. N_2O emissions in 2019. Emissions of CH_4 and N_2O from composting are also accounted for in this sector, generating emissions of 2.3 MMT CO_2e and 2.0 MMT CO_2e, respectively. Anaerobic digestion at biogas facilities generated CH_4 emissions of 0.2 MMT CO_2e., accounting for 0.1 percent of emissions from the waste sector. Overall, emission sources accounted for in the Waste sector generated 163.7 MMT CO_2e., or 2.5 percent of total U.S. greenhouse gas emissions in 2019.

EMISSIONS BY ECONOMIC SECTOR

Throughout the Inventory of U.S. Greenhouse Gas Emissions and Sinks report, emission estimates are grouped into five sectors defined by the IPCC: Energy; IPPU; Agriculture; LULUCF; and Waste. It is also useful to characterize emissions according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture. Emissions from U.S. Territories are reported as their own end-use sector due to a lack of specific consumption data for the individual end-use sectors within U.S. Territories. For more information on trends in the Land Use, Land Use Change and Forestry sector, see discussion above on LULUCF sector emission and removal trends.

Figure 3-12 **2019 U.S. Greenhouse Gas Emissions Allocated to Economic Sectors**

In 2019, transportation accounted for the largest portion (28.6 percent) of U.S. greenhouse gas emissions, electricity generation activities accounted for 25.1 percent, and industry accounted for 22.9 percent. In contrast to transportation and industry, emissions from electricity generation emissions have generally declined over the past decade.



Note: Emissions and removals from Land Use, Land Use Change, and Forestry are excluded from figure above. Excludes U.S. Territories.

Table 3-6 **U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2e)**

U.S. greenhouse gas emissions from major economic sectors decreased for the Electric Power. The long-term decline in these emissions has been due to structural changes in the U.S. economy, fuel switching, and energy efficiency improvements

Economic Sectors	1990	2005	2015	2016	2017	2018	2019
Transportation	1,526.6	1,975.6	1,794.1	1,830.0	1,847.3	1,878.2	1,875.7
Electric Power Industry	1,875.7	2,456.3	1,950.0	1,857.6	1,778.9	1,798.0	1,648.1
Industry	1,640.7	1,518.8	1,441.6	1,402.2	1,423.4	1,483.3	1,504.8
Agriculture	600.2	629.7	658.5	645.8	646.6	662.0	669.5
Commercial	429.2	407.9	445.4	430.1	431.9	447.3	455.3
Residential	345.1	371.0	351.5	327.8	329.9	377.3	379.5
U.S. Territories	25.2	63.7	30.0	26.8	25.4	25.4	25.4
Total Emissions (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Sector Net Total[a]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Net Emissions (Sources and Sinks)	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Total emissions presented without LULUCF. Total net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[a] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Using this categorization, emissions from transportation activities, in aggregate, accounted for the largest portion (28.6 percent) of total U.S. greenhouse gas emissions in 2019. Electric power accounted for the second largest portion (25.1 percent) of U.S. greenhouse gas emissions in 2019, while emissions from industry accounted for the third largest portion (22.9 percent). Emissions from industry have in general declined over the past decade due to a number of factors, including structural changes in the U.S. economy (i.e., shifts from a manufacturing-based to a service-based economy), fuel switching, and energy efficiency improvements.

The remaining 23.3 percent of U.S. greenhouse gas emissions were contributed by, in order of magnitude, the agriculture, commercial, and residential sectors, plus emissions from U.S. Territories. Activities related to agriculture accounted for 10.2 percent of U.S. emissions; unlike other economic sectors, agricultural sector emissions, as previously noted, were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation. An increasing amount of carbon is stored in agricultural soils each year, but per reporting guidelines this CO_2 sequestration is assigned to the LULUCF sector rather than the agriculture economic sector and is reflected in the LULUCF sector Net Total. The commercial and residential sectors accounted for 6.9 percent and 5.8 percent of emissions, respectively, and U.S. Territories accounted for 0.4 percent of emissions; emissions from these sectors primarily consisted of CO_2 emissions from fossil fuel combustion. As described above, carbon dioxide was also emitted and sequestered by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, landfilling of yard trimmings, and changes in carbon stocks in coastal wetlands.

Electricity is ultimately used in the economic sectors described above. Table 3-7 presents greenhouse gas emissions from economic sectors with emissions related to electric power distributed into end-use categories (i.e., emissions from electric power are allocated to the economic sectors in which the electricity is used). To distribute electricity emissions among end-use sectors, emissions from the source categories assigned to electric power were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity for each end-use sector (EIA 2020a and Duffield 2006).[122] These source categories include CO_2 from fossil fuel combustion and the use of limestone and dolomite for flue gas desulfurization, CO_2 and N_2O from incineration of waste, CH_4 and N_2O from stationary sources, and SF_6 from electrical transmission and distribution systems.

When emissions from electricity use are distributed among these end-use sectors, industrial activities and transportation account for the largest shares of U.S. greenhouse gas emissions (29.7 percent and 28.7 percent, respectively) in 2019. The commercial and residential sectors contributed the next largest shares of total U.S. greenhouse gas emissions in 2019 (15.6 and 14.9 percent, respectively). Emissions from the commercial and residential sectors increase substantially when emissions from electricity use are included, due to their relatively large share of electricity use for energy (e.g., lighting, cooling, appliances). In all sectors except agriculture, CO_2 accounts for more than 79.0 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels.

Table 3-7 **U.S. Greenhouse Gas Emissions by Economic Sector with Electricity-Related Emissions Distributed (MMT CO_2e)**

In 2019, after distributing emissions from electricity generation to end-use sectors, industry accounted for 29.7 percent of total U.S. greenhouse gas emissions, and the transportation sector accounted for 28.7 percent.

Economic Sectors	1990	2005	2015	2016	2017	2018	2019
Industry	2,313.1	2,234.1	1,964.2	1,894.6	1,902.7	1,958.3	1,947.2
Transportation	1,529.8	1,980.4	1,798.4	1,834.3	1,851.8	1,883.0	1,880.6
Commercial	983.4	1,229.8	1,125.7	1,080.8	1,054.5	1,067.8	1,022.3
Residential	956.0	1,247.1	1,053.1	998.9	963.7	1,035.9	978.3
Agriculture	635.3	668.0	699.7	684.9	685.3	701.1	704.6
U.S. Territories	25.2	63.7	30.0	26.8	25.4	25.4	25.4
Total Emissions (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Sector Net Totala	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Net Emissions (Sources and Sinks)	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Emissions from electric power are allocated based on aggregate electricity use in each end-use sector. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[a] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Box 3-2 **Trends in U.S. Greenhouse Gas Emissions and Other Key Indices**

Total greenhouse gas emissions can be compared to other economic and social indices to highlight changes over time. These comparisons include: (1) emissions per unit of aggregate energy use, because energy-related activities are the largest sources of emissions; (2) emissions per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; (3) emissions per unit of total gross domestic product as a measure of national economic activity; and (4) emissions per capita.

Table 3-8 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have grown at an average annual rate of 0.1 percent since 1990, although changes from year to year have been significantly larger. This growth rate is slightly slower than that for total energy use and fossil fuel consumption, overall gross domestic product (GDP), and national population (see Figure 3-15). The direction of these trends started to change after 2005, when greenhouse gas emissions, total energy use and fossil fuel consumption began to peak. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.8 percent since 2005. Fossil fuel consumption has also decreased at a slower rate than emissions since 2005, while total energy use, GDP, and national population continued to increase.

Table 3-8 **Recent Trends in U.S. Greenhouse Gas Emissions and Other Key Indices (Index 1990 = 100)**

Variable	1990	2005	2015	2016	2017	2018	2019	Avg. Annual Growth Rate Since 1990[a]	Avg. Annual Growth Rate Since 2005[a]
Greenhouse Gas Emissionsb	100	115	104	101	101	104	102	0.1percent	-0.8percent
Energy Use[c]	100	119	116	116	116	120	119	0.6percent	0.0percent
GDP[d]	100	159	186	189	194	200	204	2.5percent	1.8percent
Population[e]	100	118	128	129	130	131	132	1.0percent	0.8percent

[a] Average annual growth rate.

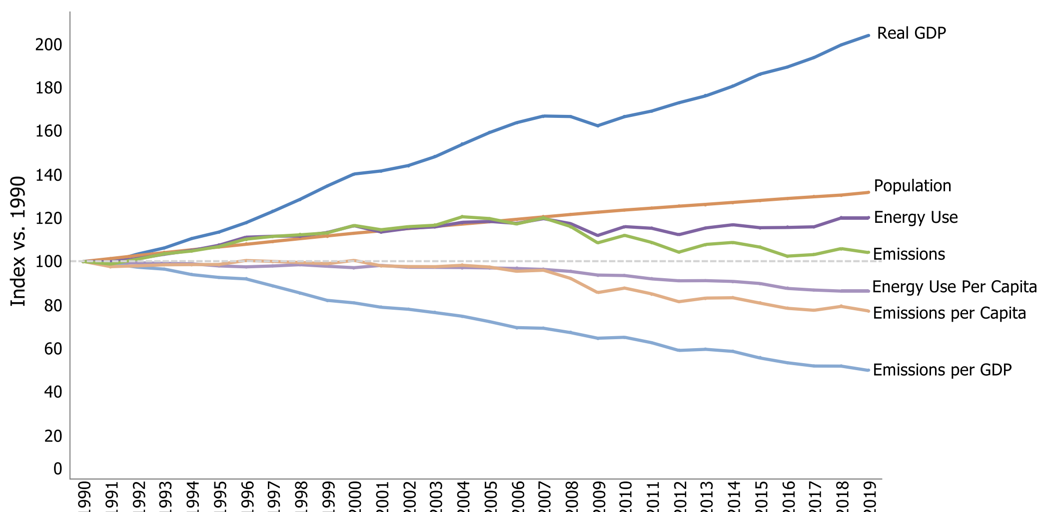
[b] GWP-weighted values.

[c] Energy content-weighted values (EIA 2020a).

[d] GDP in chained 2009 dollars (BEA 2020).

[e] U.S. Census Bureau (2020).

Figure 3-15 **U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product (GDP)**



Source: BEA (2019), U.S. Census Bureau (2020), and emission estimates in this report.

PRECURSOR GREENHOUSE GAS EMISSIONS

The reporting requirements of the UNFCCC[123] request that information be provided on precursor greenhouse gases, which include carbon monoxide (CO), nitrogen oxides (NOx), non-CH_4 volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2). These gases are not direct greenhouse gases, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases. Carbon monoxide is produced when carbon-containing fuels are combusted incompletely. Nitrogen oxides (i.e., NO and NO_2) are created by lightning, fires, fossil fuel combustion, and in the stratosphere from N_2O. Non-methane volatile organic compounds—which include hundreds of organic compounds that participate in atmospheric chemical reactions (i.e., propane, butane, xylene, toluene, ethane, and many others)—are emitted primarily from transportation, industrial processes, and non-industrial consumption of organic solvents. In the United States, SO_2 is primarily emitted from coal combustion for electric power generation and the metals industry. Sulfur-containing compounds emitted into the atmosphere tend to exert a negative radiative forcing (i.e., cooling) and therefore are discussed separately.

One important indirect climate change effect of NMVOCs and NOx is their role as precursors for tropospheric ozone formation. They can also alter the atmospheric lifetimes of other greenhouse gases. Additional compound such as NO_x, NMVOCs, and CO also have indirect effects on Earth's radiative balance and climate change. For example, chemical reactions involving these compounds will directly impact the atmospheric concentrations of CH_4, CO_2, and O_3.

Since 1970, the United States has published estimates of emissions of CO, NOx, NMVOCs, and SO_2 (EPA 2020b),[124] which are regulated under the Clean Air Act. Table 3-9 shows that fuel combustion accounts for the majority of emissions of these indirect greenhouse gases. Industrial processes—such as the manufacture of chemical and allied products, metals processing, and industrial uses of solvents—are also significant sources of CO, NOx, and NMVOCs. As Table 3-9 shows, emissions of each of these precursor greenhouse gas has decreased significantly since 1990 as a result of the implementation of Clean Air Act programs, as well as technological improvements.[125]

Table 3-9 **Emissions of NOx, CO, NMVOCs, and SO_2 (kt)**

Gas/Activity	1990	2005	2015	2016	2017	2018	2019
NOx	**21,739**	**17,339**	**10,187**	**8,792**	**8,642**	**8,145**	**7,754**
Mobile Fossil Fuel Combustion	10,862	10,295	5,634	4,739	4,563	4,123	3,862
Stationary Fossil Fuel Combustion	10,023	5,858	3,084	2,856	2,728	2,711	2,581
Oil and Gas Activities	139	321	622	594	565	565	565
Industrial Processes and Product Use	592	572	408	402	397	397	397
Forest Fires	22	126	312	87	281	242	242
Waste Combustion	82	128	88	80	71	71	71
Grassland Fires	5	21	21	19	21	20	20
Agricultural Burning	13	15	14	14	14	14	14
Waste	+	2	2	1	1	1	1
CO	**130,969**	**71,781**	**51,525**	**39,287**	**45,314**	**42,355**	**41,524**
Mobile Fossil Fuel Combustion	119,360	58,615	32,635	28,789	28,124	26,590	25,749
Forest Fires	800	4,511	11,136	3,080	10,036	8,626	8,626
Stationary Fossil Fuel Combustion	5,000	4,648	3,688	3,690	3,692	3,692	3,692
Waste Combustion	978	1,403	1,576	1,375	1,175	1,175	1,175
Industrial Processes and Product Use	4,129	1,557	1,163	1,075	1,006	1,006	1,006
Oil and Gas Activities	302	318	622	607	592	592	592
Grassland Fires	84	358	356	324	345	331	341
Agricultural Burning	315	363	342	340	339	338	337
Waste	1	7	7	6	5	5	5
NMVOCs	**20,930**	**13,154**	**10,596**	**9,774**	**9,444**	**9,228**	**9,123**
Industrial Processes and Product Use	7,638	5,849	3,796	3,776	3,767	3,767	3,767
Mobile Fossil Fuel Combustion	10,932	5,724	3,458	2,873	2,758	2,543	2,437
Oil and Gas Activities	554	510	2,656	2,459	2,262	2,262	2,262
Stationary Fossil Fuel Combustion	912	716	493	489	496	496	496
Waste Combustion	222	241	132	121	109	109	109
Waste	673	114	63	57	52	52	52
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA
SO2	**20,935**	**13,196**	**3,578**	**2,906**	**2,313**	**2,233**	**1,966**
Stationary Fossil Fuel Combustion	18,407	11,541	2,901	2,269	1,638	1,569	1,304
Industrial Processes and Product Use	1,307	831	482	466	509	509	509
Oil and Gas Activities	390	180	92	89	86	86	86
Mobile Fossil Fuel Combustion	793	619	78	57	58	47	45
Waste Combustion	38	25	26	24	22	22	22
Waste	+	1	1	1	1	1	1
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.5 kt.

NA (Not Available)

Source: (EPA 2020b) except for estimates from Forest Fires, Grassland Fires, and Field Burning of Agricultural Residues.

INSTITUTIONAL ARRANGEMENTS

The institutional arrangements for measuring progress toward the target are explained in more detail in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2019*, in Section 1.2 on National Inventory Arrangements (U.S. EPA 2021). The institutional arrangements for development of the national greenhouse gas Inventory have not changed since the *Second Biennial Report of the United States of America* (U.S. DOS 2016). The U.S. Environmental Protection Agency (EPA), in cooperation with other U.S. government agencies, prepares the annual greenhouse gas inventory. Within EPA, the Office of Atmospheric Programs (OAP) is the lead office responsible for the emission calculations provided in the national greenhouse gas inventory, as well as the completion of the National Inventory Report and the Common Reporting Format (CRF) tables. EPA's Office of Transportation and Air Quality is also involved in calculating transportation and mobile combustion emissions for the inventory. While the U.S. Department of State (DOS) is the UNFCCC focal point, EPA's OAP serves as the inventory focal point for technical questions and comments on the U.S. inventory.

Other federal and state government authorities, research and academic institutions, industry associations, and private consultants are involved in supplying data to, reviewing, or preparing portions of the inventory. The U.S. Department of Agriculture's U.S. Forest Service and Agricultural Service, National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), and Department of Defense (DoD) contribute both to the collection of data, but also support compilation of the estimates and supporting analysis. Other U.S. agencies provide official data for use in the Inventory. For example, the U.S. Department of Energy's Energy Information Administration provides national fuel consumption data, and the U.S. Department of Defense provides data on military fuel consumption and use of bunker fuels.

Endnotes

103 Article 4(1)(a) of the United Nations Framework Convention on Climate Change (also identified in Article 12) and subsequent decisions by the Conference of the Parties elaborated the role of Annex I Parties in preparing national inventories. Article 4 states "Parties to the Convention, by ratifying, shall develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…" See <http://unfccc.int> for more information.

104 See UNFCCC decisions 3/CP.1, 9/CP.2, 3/CP.5, and 24/CP.19 at <https://unfccc.int/documents>.

105 The pre-industrial period is considered as the time preceding the year 1750 (IPCC 2013).

106 The gross emissions total presented in this report for the United States excludes emissions and sinks from

removals from Land Use, Land-Use Change, and Forestry (LULUCF). The net emissions total presented in this report for the United States includes emissions and sinks from removals from LULUCF.

107 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."

108 Global CO_2 emissions from fossil fuel combustion were taken from International Energy Agency CO_2 Emissions from Fossil Fuels Combustion Overview. See <https://webstore.iea.org/co2-emissions-from-fuel-combustion-2020-highlights> (IEA 2020). The publication has not yet been updated to include complete global 2019 data.

109 See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

110 See Table A-241, pp. A-499 of Annex 6 of the latest Inventory available online at <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019>

111 VMT estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2019). In 2007 and 2008 light-duty VMT decreased 3.0 percent and 2.3 percent, respectively. Note that the decline in light-duty VMT from 2006 to 2007 is due at least in part to a change in FHWA's methods for estimating VMT. In 2011, FHWA changed its methods for estimating VMT by vehicle class, which led to a shift in VMT and emissions among on-road vehicle classes in the 2007 to 2019 time period. In absence of these method changes, light-duty VMT growth between 2006 and 2007 would likely have been higher.

112 In line with the reporting requirements for inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not included in the electricity sector totals and trends discussed in this section. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry.

113 See Table 6.2 Coal Consumption by Sector of EIA (2020a).

114 Values represent electricity net generation from the electric power sector. See Table 7.2b Electricity Net Generation: Electric Power

Sector of EIA (2020a).

115 Carbon dioxide emissions from landfills are not included specifically in summing waste sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs and decay of disposed wood products are accounted for in the estimates for LULUCF.

116 Hurwitz, M. M., Fleming, E. L., Newman, P. A., Li, F., Mlawer, E., Cady-Pereira, K., and Bailey, R. (2015), Ozone depletion by hydrofluorocarbons, Geophys. Res. Lett., 42, 8686– 8692, doi:10.1002/2015GL065856

117 See <http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_01_Ch1_Introduction.pdf>.

118 The current land representation does not include land in U.S. Territories, but there are planned improvements to include these regions in future Inventories. U.S. Territories represent approximately 0.1 percent of the total land base for the United States.

119 LULUCF Carbon Stock Change is the net C stock change from the following categories: Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining

120 LULUCF emissions include the CH_4 and N_2O emissions reported for Peatlands Remaining Peatlands, Forest Fires, Drained Organic Soils, Grassland Fires, and Coastal Wetlands Remaining Coastal Wetlands; CH_4 emissions from Land Converted to Coastal Wetlands; and N_2O emissions from Forest Soils and Settlement Soils.

121 Landfills also store carbon, due to incomplete degradation of organic materials such as harvest wood products, yard trimmings, and food scraps, as described in the Land-Use, Land-Use Change, and Forestry chapter of the Inventory report.

122 U.S. Territories consumption data that are obtained from EIA are only available at the aggregate level and cannot be broken out by end-use sector. The distribution of emissions to each end-use sector for the 50 states does not apply to territories data.

123 See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

124 See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

125 More information is available online at: https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health and https://gispub.epa.gov/neireport/2017/.

REFERENCES

BEA (2020) *2020 Comprehensive Revision of the National Income and Product Accounts: Current-dollar and "real" GDP, 1929–2020*. Bureau of Economic Analysis (BEA), U.S. Department of Commerce, Washington, D.C. Available online at: <http://www.bea.gov/national/index.htm#gdp>.

Duffield, J. (2006) Personal communication. Jim Duffield, Office of Energy Policy and New Uses, U.S. Department of Agriculture, and Lauren Flinn, ICF International. December 2006.

EIA (2020a) *Electricity Generation*. *Monthly Energy Review, November 2020*. Energy Information Administration, U.S. Department of Energy, Washington, D.C. DOE/EIA-0035(2019/11).

EIA (2020b) *Electricity in the United States*. *Electricity Explained*. Energy Information Administration, U.S. Department of Energy, Washington, D.C. Available online at: <https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states>.

EIA (2019) *International Energy Statistics 1980-2019*. Energy Information Administration, U.S. Department of Energy. Washington, D.C. Available online at: <https://www.eia.gov/beta/international/>.

EPA (2021). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*. U.S. Environmental Protection Agency, Washington, D.C. EPA. EPA Publication No. EPA 430-R-21-005.

EPA (2020a) Acid Rain Program Dataset 1996-2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, D.C.

EPA (2020b) 1970–2019 Average annual emissions, all criteria pollutants in MS Excel. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data. Office of Air Quality Planning and Standards, May 2020. Available online at: <https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data>.

EPA (1997) Compilation of Air Pollutant Emission Factors, AP-42. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Research Triangle Park, NC. October 1997.

FHWA (1996 through 2019) *Highway Statistics*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Report FHWA-PL-96-023-annual. Available online at: <http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm>.

IPCC (2013) *Climate Change 2013: The Physical Science Basis*. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Stocker, T.F., D. Qin, G.-K., Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2007) *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press. Cambridge, United Kingdom 996 pp.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. [H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.)]. Hayama, Kanagawa, Japan.

IPCC (1996) *Climate Change 1995: The Science of Climate Change*. Intergovernmental Panel on Climate Change. [J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press. Cambridge, United Kingdom.

NOAA/ESRL (2021a) Trends in Atmospheric Carbon Dioxide. Available online at: <http://www.esrl.noaa.gov/gmd/ccgg/trends/>. January 12, 2021.

NOAA/ESRL (2021b) Trends in Atmospheric Methane. Available online at:

<https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/>. January 5, 2021.

NOAA/ESRL (2021c) Nitrous Oxide (N_2O) hemispheric and global monthly means from the NOAA/ESRL Chromatograph for Atmospheric Trace Species data from baseline observatories (Barrow, Alaska; Summit, Greenland; Niwot Ridge, Colorado; Mauna Loa, Hawaii; American Samoa; South Pole). Available online at: < https://www.esrl.noaa.gov/gmd/ccgg/trends_n2o/>. January 5, 2021.

UNFCCC (2014) *Report of the Conference of the Parties on its Nineteenth Session, Held in Warsaw from 11 to 23 November 2013*. (FCCC/CP/2013/10/Add.3). January 31, 2014. Available online at: <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

U.S. DOS (2014) US Climate Action Report: Available online at: <https://unfccc.int/documents/198424>.

U.S. DOS (2016) Second Biennial Report of the United States of America: Available online at: <https://unfccc.int/documents/198949>.

U.S. Census Bureau (2020) U.S. Census Bureau International Database (IDB). Available online at: <https://www.census.gov/programs-surveys/international-programs.html>.

4
POLICIES AND MEASURES

INTRODUCTION

The United States has made continual progress toward its greenhouse gas emissions reduction targets. As described in Chapter 3 of this National Communication and Chapter 3 of the Biennial Reports contained in the annex, the United States in 2019 achieved a 13 percent reduction in net emissions below 2005 levels. Preliminary data shows the United States on track to achieve its target of net emissions reductions, in the range of 17 percent below 2005 levels in 2020, as communicated in 2010. [126]

The success of these emission reductions can be attributed to, in part, market transformations and energy use changes driven by both federal and nonfederal policy and measures, primarily across the electricity and transportation sectors. In the United States, the prices of utility-scale solar and wind turbine generation have dropped 80 and 55 percent, respectively, over the past decade.[127][128] Related, the share of coal-fired generation has dropped 50 percent over that time. Vehicle fuel economy has improved 25 percent over 10 years, and the price of electric vehicle battery packs have dropped 90 percent, contributing to lower fossil fuel use in transportation.

Since that 2020 goal was set, the United States has increased its ambition and put into place new policies and measure to drive down emissions and put the country on a path to achieve these goals. The policies and measure help modify long-term trends by locking in clean infrastructure, avoiding new fossil infrastructure buildout and either retiring or transitioning existing infrastructure to address GHG emissions, speeding the turnover of fossil fuel vehicle and appliance stock, and shifting behaviors and culture in support of a clean energy future.

This chapter describes the federal and nonfederal policies through 2020 that contribute to the United States meeting its emission reduction targets. The United States has also developed a National Climate Strategy that lays out priority policies and measures to take this decade to ensure the country continues on a path toward net-zero emissions no later than 2050, and to keep a limit of 1.5 C of global warming within reach.

POLICY MAKING PROCESS

Federal Government

The U.S. federal government utilizes various types of policies and measure to promote the mitigation of greenhouse gas emissions, including laws, investments, regulations, voluntary programs, and partnerships with nonfederal governments and the private sector. The federal government has jurisdiction over important mechanisms to mitigate greenhouse gas emissions, including the regulation of pollution from power plants and vehicles, the advancement of fuel economy in vehicles and energy efficiency of appliances, the advancement of building energy codes, the regulation of interstate and international trade, and the ability to invest in technology research, innovation, and deployment–including within federally-owned and occupied properties.

The United States operates a whole-of-government approach through numerous interagency processes to ensure the efficient coordination of programs and funding. Many federal processes require a consideration of the impact proposed federal actions on greenhouse gas emissions, as well as the cost and benefit of actions to mitigate those impacts. Additionally, progress made with policies and measure intended to mitigate greenhouse gas emissions is monitored and evaluated over time. Assessments often happen during and after implementation to understand the impact–as was the case with the historic investments in clean energy in the 2009 American Recovery and Reinvestment Act–as well as the assessment of economy-wide progress on emissions through the annual *U.S. Inventory of Greenhouse Gas Emissions and Sinks*.

Lastly, because of the multi-branch system of government in the United States, many federal policies and measures can continue through multiple changes in leadership within the executive and legislative branches.

Nonfederal Governments

In addition to federal actions, the nonfederal governments–primarily from states, territories, tribal areas, counties and cities–have legal jurisdiction in many sectors to advance policies and measure that can mitigate greenhouse gas emissions. These policies and measures can have a substantial impact on emissions,[129] and the vast majority of them have continued or strengthened since the Sixth National Communication.

In particular, U.S. states often have the ability to set more stringent pollution standards than federal standards and to establish renewable electricity portfolio standards. States and cities can establish building energy and performance standards. In fact, as noted in Chapter 2, 38 states and territorial jurisdictions have renewable or clean energy portfolio standards or goals for electric power–nearly all of which are statutory and binding–including sixteen that will achieve 100 percent clean electricity by 2050 or sooner.[130]Fourteen states have adopted low – and zero-emission standards for light-duty vehicles.[131] In addition, 24 states and the District of Columbia have established economy-wide greenhouse gas targets, the majority in statute and some extending to 2050.[132]

National Targets

As detailed in its *Fifth National Communication,* and as part of its commitment under the Copenhagen Accord, the United States communicated a target of achieving economy-wide emissions reductions in the range of 17 percent below 2005 levels in 2020, which has remained in place since that communication.

In April 2021 the United States communicated its nationally determined contribution (NDC) under the Paris Agreement: to achieve an economy-wide target of reducing its net greenhouse gas emissions by 50-52 percent below 2005 levels in 2030. This 2030 NDC represents increased ambition compared to the NDC communicated in 2015, which set a target of reducing net greenhouse gas emissions by 26-28 percent below 2005 levels in 2025.

More information on these targets is presented in Chapters 2 and 3 of the annexed Biennial Reports.

KEY POLICIES AND MEASURES

The United States continues to advance many effective and complementary policies and measures across sectors to meet its targets. Discussed here are a subset of policies and measures that provide a significant contribution to greenhouse gas mitigation–or have the potential to over time. While this section mentions policies and measure that have continued since the last National Communication, the goal is to emphasize new or expanded policies and measures–and progress–since then.

Energy: Supply

Federally-Led Investment in Clean and Renewable Energy

The federal government deploys a number of policies to accelerate clean and renewable sources of energy, including supporting research, development, and deployment. One of the most effective policies over the past decade has been the Energy Investment Tax Credit and the Energy Production Tax Credit for renewable forms of energy. First established in 1978 and 1992, respectively, and extended multiple times, they are currently set to expire in 2023 and 2021, respectively. The tax incentives remain one of the biggest investments in renewable energy in U.S. history and help provide long-term certainty for investment in wind turbine, solar, and other renewable generation. Between 2010 and 2020, renewable electricity grew from 10 percent of generation, or 425 billion kWh, to 21 percent, or 834 billion kWh. Renewables also surpassed coal generation for the first time in 2020, and are anticipated to account for 84 percent of capacity additions in 2021–when including storage.[133]

Multiple agencies advance a whole-of-government approach to accelerate clean energy deployment through the following subset of key programs:

- **Financing Clean Energy:** DOE's Loan Program Office (LPO) plays a large role in advancing renewable energy through loan guarantees in new renewable generation projects, energy efficiency, nuclear energy, transmission infrastructure, and critical materials. At the end of 2020, LPO managed a portfolio of over $30 billion in loans, loan guarantees, and conditional commitments–17 percent in support of solar. LPO has over $40 billion in available authority, more than half of which is available for advanced nuclear, advanced fossil, and renewable and efficient energy. Included in that available authority is $2 billion for the Tribal Energy Loan Guarantee Program, first launched in 2018, that helps grow economic opportunities on Tribal lands through energy development.[134]
- **Growing Community Green Power:** EPA's Green Power Partnership (GPP) encourages U.S. organizations to voluntarily purchase green power, offers recommended minimum levels of purchasing, and provides partners with information and recognition for their purchases and on-site renewable power systems. At the end of 2020, the program included over 700 partners who have committed to purchasing about 70 billion kilowatt-hours of green power,–or 40 percent of the voluntary green power market.[135] In addition, the program recognizes over 100

Green Power Communities–towns, villages, cities, counties, and tribal governments that collectively buy green power in amounts that meet or exceed EPA's GPP community purchase requirements.

- **Expanding Rural Access to Clean Energy:** The Rural Energy for America Program (REAP) provides grants and loan guarantees to agricultural producers and rural small businesses to reduce energy costs through energy efficiency and renewable energy systems. REAP invests over $600 million per year in rural renewable energy and electric infrastructure in all 50 states and Puerto Rico. [136]Between 2007 and 2017–per the latest Census of Agriculture produced by USDA–the number of farms using a renewable energy-producing system has more than quadrupled to 130,000 farms, or 6.5 percent of all farms.[137]

- **Leading on Federal Lands:** DOI and its Bureau of Land Management (BLM) are working with communities, state regulators, industry, and other federal agencies in building a clean energy future by providing sites for environmentally sound development of renewable energy and transmission facilities on public lands. At the end of December 2020, energy projects on BLM-managed lands included 71 solar and wind energy projects with a combined installed capacity of nearly 10,000 MW. There is an additional 2,500 MW of geothermal energy operating on BLM-managed lands. [138] The Bureau of Ocean Energy Management at DOI also works to advance offshore wind energy on the U.S. Outer Continental Shelf (OCS). This program began in 2009, when DOI announced the final regulations for the OCS Renewable Energy Program. Since then, BOEM has executed leases for potential wind energy developments offshore several states, including Delaware, Maryland, Massachusetts, New Jersey, New York, North Carolina, Rhode Island, and Virginia.[139]

Key Non-Federal Spotlight:

Leadership by nonfederal governments is also critical to achieving emissions reductions across the full economy, and the full geographic sweep of the United States. Examples of key subnational policies include:

- **Regional Emissions Trading–Regional Greenhouse Gas Initiative:** The Regional Greenhouse Gas Initiative (RGGI) is a cooperative, market-based effort among eleven Northeast and Mid-Atlantic states (as of the date of this report) to cap and reduce CO_2 emissions in the power sector. Since RGGI's inception in 2009, power plant CO_2 emissions in the region were reduced by 47 percent over its first 10 years of operation (47 percent below 2008 emissions in 2018), outpacing reductions in the rest of the country by 90 percent. The RGGI states recently set a new cap for 2030 that is 30 percent below the 2020 cap. Ninety percent of emission allowances are distributed through auctions. Proceeds from RGGI–totaling over $4.3 billion to date–are reinvested in programs to help electricity consumers including energy efficiency, clean and renewable energy, greenhouse gas abatement, and direct bill assistance.

- **State Renewable and Clean Energy Portfolio Standards:** Thirty-eight states and territorial jurisdictions have renewable or clean energy portfolio standards or goals for electric power that dictate a specific percentage of electricity sold in the state that must come from renewable or clean sources. In most states, these are statutory and binding standards–including sixteen that will achieve 100 percent clean electricity by 2050 or sooner. The designs of these programs vary across states, including components on performance-based standards, targets and timetables, geographic and resource eligibility, alternative compliance payments. In several other states, utilities have adopted programs with performance-based incentives, including feed-in tariffs, standard offer payments, and payments in exchange for renewable energy certificates. In fact, 20 of the largest investor-owned utilities committed to reducing emissions by 100 percent (net or absolute) or reaching 100 percent clean electricity by 2050, and some as early as 2035.[140] Financial mechanisms and incentives for clean energy exist in most states, with more than 500 incentives and funding offered by state and local governments across the nation, as well as utilities and nonprofit organizations.[141] States with portfolio standards have demonstrated higher levels of capacity for developing clean and renewable energy.

Energy: Residential, Commercial, and Industrial End Use

The United States pursues multiple approaches to reduce the emissions intensity of energy used by residential and commercial buildings, including through building and appliance energy efficiency codes and standards; voluntary energy efficiency and conservation programs; investments in rural energy efficiency; and investments in efficient public housing and housing for low-income households; innovation in grid-interactive technology for high-performance buildings of the future.

Multiple agencies advance a whole-of-government approach through the following subset of key programs:

- **Developing Strong Building Energy Codes:** DOE's Building Energy Codes Program (BECP) participates in the development and advancement of cost-saving building energy codes. It is the responsibility of the federal government to make determinations on the energy and cost savings of new commercial and residential model energy codes, and to help states review, adopt, and implement these codes through financial and technical assistance. DOE found that the adoption of recent model energy codes could result in $138 billion in energy cost savings and 900 MMT of avoided CO2 emissions between 2010 and 2040.[142]

- **Finalizing New Energy Efficiency Standards for Appliances and Equipment:** DOE establishes and regularly updates energy efficiency standards and text procedures for more than 60 home and office appliance and equipment types that account for about 90 percent of home energy use, 60 percent of commercial building energy use, and 30 percent of industrial energy use. These standards ensure that dishwashers, refrigerators, and many other products operate more cleanly and efficiently. The national standards completed through 2016 are estimated to save consumers 142 quadrillion British thermal units (QBtu) and $2 trillion in energy costs through 2030.[143]

- **Promoting Energy Efficiency:** EPA's ENERGY STAR labeling program makes it easy for consumers and businesses to purchase products that save them money and reduce greenhouse gases, thus increasing demand for highly efficient and clean products. In 2019 alone, consumers purchased 300 million ENERGY STAR certified products, as well as 300 million certified light bulbs–savings nearly 500 billion kWh of electricity, $39 billion in energy savings, and 390 MMT of avoided greenhouse gas emissions.[144]

- **Promoting Voluntary Leadership through Better Buildings:** DOE's Better Building Initiative continues to help American commercial, industrial, and multi-family buildings set and achieve ambitious energy and water efficiency goals. There have been over 950 private and public sector Better Building Partners across industry, commercial real estate, retail, health, hospitality, education, and government. They represent 14 percent of the U.S. manufacturing energy footprint and 13 percent of total commercial building space. These partners have collectively saved more than 2.5 QBtu of energy, savings of more than $14.6 billion and 150 MMT of CO2. In particular, the Better Plants Program for industry includes over 250 companies representing more than 3,500 facilities across all 50 states and has accomplished 1.9 QBtu in energy savings and more than $9 billion in cost savings to date.[145]

- **Investing in Rural Communities, Homes for Low-income Households, and Public Housing:** The Rural Energy Savings Program at USDA offered $82 million in zero-interest loan capital to eligible rural utilities and similar energy efficiency providers to relend to their customers for energy efficiency measures and customer-owned renewable systems. Loans awarded to the Orcas Power & Light Co-operative in Washington and Ouachita Electric Co-operative in Arkansas, for example, were used to set up successful on-bill financing programs that offered cost-effective energy efficiency and electrification upgrades to low – and moderate-income homeowners and renters.

  DOE's Weatherization Assistance Program (WAP) serves approximately 35,000 low-income families every year to permanently reduce their energy bills by making their homes more energy efficient, healthy, and safe. WAP provides around $300 million each year, primarily through formula grants, to all 50 states, the District of Columbia, U.S. overseas territories, and Indian tribal governments. The average home investment is $4,695 in mechanical, building shell, electric, water, health and safety measures, leveraging $3.48 in utility and state funding and returning $2.78 in benefits for each federal dollar invested. WAP is particularly important for low-income households that spend a disproportionately larger share of their income on energy costs–nearly 14 percent, compared to the average household of 3 percent.[146]

  Lastly, the U.S. Department of Housing and Urban Development (HUD) is also improving the energy efficiency of assisted and insured housing stock through a variety of programs, including energy performance contracts in public and other federally-assisted housing, Multi-family Better Buildings Challenge with DOE, and the Federal Housing Administration financing programs, such as PowerSaver and Energy Efficient Mortgages.

- **Leveraging Technology for the Future of Buildings:** DOE recently launched a Grid-Interactive Efficient Buildings (GEB) Initiative to advance clean and flexible energy resources in buildings by combining energy efficiency and demand flexibility with smart technologies and communication systems to inexpensively deliver greater affordability, comfort, productivity, and performance to U.S. homes and buildings. This initiative will help the United States leverage GEBs to realize the estimated $100-200 billion in possible energy savings and at least 80 MMT in avoided CO2 emissions per year by 2030.[147]

- **Investing in Utility Scale Renewable Energy and Efficiency:** Under the Rural Electrification Act, USDA's Rural Utilities Service (RUS) Electric Loan Program makes low interest loans available to electric utilities for distribution, transmission, generation, smart grid, security, and energy efficiency infrastructure investments serving rural communities. The program's portfolio of rural renewable power generation is growing rapidly. From 2015 through 2020, RUS approved 33 loans totaling $477 million to finance 45 solar projects and one microgrid serving rural communities. Solar financing has grown from $31 million per year to $150 million per year. Associated capacity has grown from 23 MW/year to 140 MW/year. The program has a significant pipeline of solar projects and has experienced a surge in interest and demand. The program has also financed wind, biomass, and hydroelectric projects providing power to rural consumers.

Key Non-Federal Spotlight:

- **Building Performance Standards:** In 2019, New York City became the first major U.S. city to establish building performance standards for greenhouse gas emissions. Starting in 2024, the new standard will set building emission intensity limits across 10 commercial and multi-family building categories, and will result in a 40 percent reduction in emissions below 2005 levels in 2030.[148]

Transport

The United States pursues multiple approaches to reduce emissions produced by transportation activities including from fossil-fuel powered on-road vehicles, rail equipment, aviation, and marine vessels. A subset of key efforts includes:

- **Advancing Low-Emission and Fuel-Efficient Cars, Trucks, and Heavy-Duty Vehicles:** Since 2009, the United States has been implementing a coordinated national program to dramatically increase the efficiency of American vehicles to reduce carbon pollution. The U.S. EPA and the National Highway Traffic Safety Administration issued standards for light-duty passenger vehicles, including passenger cars and light trucks for model years (MYs) 2012–2016, and a second set of final rules for MY2017-2025. At the time of the rulemaking, the combined standards were expected to cut per-mile greenhouse gas emissions of new vehicles by approximately 40 percent–resulting in approximately 2 billion tonnes of CO_2e emission reductions and approximately 4 billion barrels of oil savings over the lifetime of vehicles sold in model years 2017 through 2025.[149] These standards (currently under review) were revised in 2020 to increase stringency 1.5 percent per year for MY2021 through MY2026, which would result in nearly 1 billion tonnes of avoided CO2e emissions and 84 billion gallons of oil saved over the lifetime of the vehicles sold under this rule.[150] These standards continue to deliver results, as 2020 saw new vehicles achieve their highest fuel economy ever–25.7 miles per gallon.[151] Additionally, the national programs for heavy-duty vehicle and engine performance standards cover model years 2018-2027 for certain trailers and model years 2021-2027 for semi-trucks, large pickup trucks, vans, and buses. The final standards are expected to lower CO2 emissions by approximately 1.1 billion tonnes and avoid up to two billion barrels of oil over the lifetime of the vehicles sold under the program.[152]

- **Investing in Zero-emission Vehicle Infrastructure and Manufacturing:** To complement these vehicle standards, the United States also invests in critical vehicle infrastructure and manufacturing to accelerate the deployment of zero-emission technology. Under the Alternative Fuel Corridors Program at the U.S. Department of Transportation, the Federal Highway Administration has continued establishing a national network of alternative fueling and electric vehicle charging infrastructure along national highway system corridors, in collaboration with State and local partners. These designations help promote and facilitate the installation of alternative fuel infrastructure through consortia of state agencies, utilities, alternative fuel providers, and car manufacturers. Alternative fuel corridors currently include over 165,000 miles across 49 states and the District of Columbia.[153] The Advanced Technology Vehicle Manufacturing Loan Program, operated out of the Loan Program Office at DOE, commands $17.7 billion in lending authority to manufacturers of advanced technology vehicles that achieve a high fuel efficiency, or of vehicle components and related engineering projects. The program has supported the production of more than 4 million advanced technology vehicles through $8 billion in project loans.[154]

- **Tackling Emissions in Aviation:** In pursuit of abatement efforts in aviation, the U.S. EPA finalized rules for the control of air pollution from airplanes and airplane engines, including greenhouse gas emissions. These U.S. standards will align action with the international emissions standards set by the International Civil Aviation Organization (ICAO). The U.S. aircraft covered by the rule, including domestic and international flights originating from the United States, constitute about 10 percent of transport sector emissions and about three percent of total U.S. emissions. This rule ensures ensure that U.S. manufactured airplanes and airplane engines meet the same standards as the rest of the world.

Key Non-Federal Spotlight:

- **Regional Transportation and Climate Initiative (TCI):** The TCI is a regional collaboration of twelve Northeast, Mid-Atlantic, and Southeast jurisdictions working together to improve transportation, develop clean energy for transportation, and reduce carbon dioxide pollution from the sector, and improve air quality. A subset of these jurisdictions committed to developing and implementing a cap-and-invest program to reduce CO2 emission from the transportation sector by 30 percent below 2023 levels by 2032–or about 70 million mtCO2. In addition to up to $2 billion in annual clean transportation investments by 2032, other annual benefits that could be realized include up to $3.6 billion in health and safety improvements, thousands fewer childhood asthma cases and exacerbations, and 350 avoided deaths.

- **California Low Carbon Fuel Standard:** California implemented the first state-wide low-carbon fuel standard in 2011 and amended the regulation in 2018 with stronger carbon intensity benchmarks aligned with California's 2030 greenhouse gas emission reduction Challenge and the Natural Gas STAR Program–work with oil and natural gas companies to promote proven, cost-effective technologies and practices that improve operational efficiency and reduce methane emissions. Since starting in 2016, Methane Challenge partners have avoided over 7 million $mtCO_2$ e of methane from leaking from pipelines, and the Natural Gas Start program has eliminated a cumulative 1.6.8 trillion cubic feetof natural gas over the past 25 years.[155]

- **Advancing Alternatives to High-GWP Substances:** Through its Significant New Alternatives Policy (SNAP) Program, EPA evaluates and regulates substitutes for the ozone-depleting chemicals that are being phased out nationally under the CAA and globally under the Montreal Protocol on Substances That Deplete the Ozone Layer. EPA evaluates a number of criteria for listing as acceptable those alternatives that reduce overall risk to human health and the environment, while placing restrictions or bans on others, thereby allowing for a safe and smooth transition. The SNAP Program lists are continually being revised and consider the comparative risk of available and potentially available alternatives for a given use. SNAP has continued to identify climate-friendly and ozone-friendly alternatives for chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), and other ozone-depleting substances (ODS).[156]

In December 2020, new legislation (the "American Innovation and Manufacturing" Act, or "AIM" Act) provided EPA with new authorities to address HFCs by phasing down their production and consumption and facilitating the transition to next-generation alternatives and technologies. This law aligns with the intent of the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer to reduce the production and consumption of HFCs.

Agriculture

In 2019, greenhouse gas emissions from the Agriculture sector accounted for 10 percent of gross U.S. emissions, excluding emissions associated with electric power consumed in the sector.[157] The United States continues to undertake a set of key efforts to reduce emissions and enhance sequestration related to the use and management of agricultural lands and livestock:

- **Promoting Climate-Smart Practices on Agriculture Lands:** The Natural Resource Conservation Service (NRCS) at the U.S. Department of Agriculture administers a number of technical and financial assistance programs to help landowners implement practices or measures to address natural resource concerns, including the management of vegetation and soils to sequester carbon, nutrient and production management to reduce GHG emissions, and structural and non-structural practices to manage methane from animal agriculture. These programs provide various types of technical and financial assistance to a wide range of participants across the landscape. For example, the Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP) provide financial and technical assistance to agricultural producers and private forest landowners for the implementation of climate-smart conservation activities. These practices deliver important environmental benefits, including soil health for resilient and adaptive systems, improved nitrogen management to reduce GHG emissions and improve water quality, and carbon sequestration.

- **Reducing Methane Emissions from Agriculture:** Operating since 1993, AgSTAR is a voluntary effort run by EPA with support from USDA that encourages the use of biogas recovery systems and sustainable manure management practices, primarily through the use anaerobic digestors. AgSTAR provides technical and regulatory assistance and planning guidance to livestock managers who wish to pursue digestion projects. AgSTAR also works to identify and address barriers to biogas recovery projects and provides information and training to the state and local government agencies that permit these projects and the private-sector organizations that implement them. Digestion systems attributed to the AgSTAR program have resulted in nearly 20 million mtCO2e in emissions reductions since 2000.[158] Through its conservation programs, NRCS also provides technical and financial assistance to help private agricultural operations manage their livestock and improve rice production in ways that can reduce methane emissions. This includes supporting implementation of a range of identified practices and enhancements, providing tools and assistance to assess and address an operation's GHG impacts, and evaluating emerging technology and methods that can support methane reductions.

Land Use, Land-use Change and Forestry (LULUCF)

Land use, including land use change and forestry (LULUCF), practices contribute greenhouse gas emissions to the atmosphere, but they are much more important as the country's largest emissions sink, sequestering over 12 percent of emissions from other sectors each year. Thus, the United States is pursuing multiple approaches to reduce gross emissions from the land sector while also growing its capacity to sequester and store carbon from the atmosphere. A subset of key efforts includes:

- **Advancing the Conservation of Sensitive Lands:** Programs within the Farm Service Agency (FSA) and NRCS at the U.S. Department of Agriculture aim to reduce greenhouse gas emissions on high-carbon soils and sensitive lands. The Conservation Reserve Program (CRP) at the Farm Service Agency, in particular, provides financial incentives to farmers to voluntarily convert environmentally sensitive land to from agricultural production to native grasses, wildlife plantings, forested area, restored wetlands, filter strips, or riparian buffers. It is estimated that the CRP sequesters more carbon on private lands than any other federally administered program through greater sequestration by removing land from intensive agricultural production and avoiding the application of fertilizer. FSA estimates that the CRP currently protects more than 20 million acres of land and help mitigate more than 12 million $mtCO2_e$ annually.[159] NRCS also protects the long-term viability and conservation benefits of working lands and wetlands through its suite of Conservation Easement programs. The NRCS easement portfolio currently protects over 5 million acres, the majority of which have converted drained marginal cropland into wetland easements that increase carbon sequestration and improve water quality

- **Promoting the Stewardship of Public and Private Forests:** The United States is committed to promoting forest conservation, avoiding deforestation, and restoring and expanding forests that can offset greater carbon pollution. This work extends to both public and private lands. The U.S. Forest Service (USFS) oversees 193 million acres of federal forestland. One of the agency's largest areas of focus is reforesting areas damaged by wildfire, insects, or disease, and increasing forests' resilience to those disturbances. The Forest Legacy and Community Forest Programs work in partnerships with states and private landowners to conserve over 2.8 million acres of forest land and open spaces through easements, purchases, and support for community planning.[160] Additionally, the Urban and Community Forestry Program provides financial and technical assistance to state and local agencies to improve the management of urban tree cover and communities, which total 140 million acres across the United States. Tree planting in urban areas helps to reduce energy costs, stormwater runoff, and urban heat island effects, while increasing carbon sequestration and property values.

Waste

Emissions from waste account for only 2.5 percent of total greenhouse gas emissions, but make up over 20 percent of methane emissions, mostly from landfills.[161] Thus reducing emissions from landfills is a priority for the United States. In 2016, the EPA finalized new emissions standards and guidelines for new and existing municipal solid waste landfills. Under these rules, new, modified, and existing landfills need to collect and control landfill gas at emission levels nearly a third lower than current requirements. At the time these rules were finalized, they were estimated to reduce methane emissions by an combined 330,000 tonnes a year by 2025–equivalent to reducing 8.2 million tonnes CO2e–in addition to climate benefits totaling over $500 million in 2025.[162] To support landfills reduce methane emissions, EPA also operates the Landfill Methane Outreach Program, a voluntary initiative working in nearly all states and territories to support landfill operators with the recovery and beneficial use of landfill biogas for energy use.

Cross-cutting

The United States undertakes a number of additional actions that reduce emissions; advance low-carbon, renewable energy and efficiency technology across sectors; and compile and track emissions generated by a majority of emitters across every sector. These cross-cutting efforts include:

- **Cutting the cost of clean energy and energy efficiency through tax credits:** Several existing federal energy tax provisions and energy grants help incentivize low – and zero-carbon and clean energy technologies, reduce energy and fuel use, and lower greenhouse gas emissions. Combined, these provisions had estimated federal tax expenditures exceeding $10 billion annually.[163] Lowering the amount of tax owed provides an incentive and great return on investments into the deployment of clean energy technology, including clean electricity generation and fuels across transportation, power, and industrial sectors; energy efficiency upgrades to homes, businesses, and factories; the manufacturing of advanced clean energy technology; the installation of alternative fueling infrastructure; and the purchase of zero-pollution vehicles. Examples of incentives include:
    - Energy Production Tax Credit (for renewable and alternative energy only)
    - Energy Investment Tax Credit (for renewable energy only)
    - Residential Energy Efficient Property Credit (for renewable energy)
    - Qualified Plug-In Electric Drive Vehicle Tax Credit
    - Tax Deduction for Energy Efficient Commercial Buildings
    - Credit for Construction of New Energy Efficient Homes
    - Manufacturers' Energy Efficient Appliance Credit

- **Furthering Study of Carbon Capture and Carbon Removal Technologies:** Mitigating greenhouse gas emissions before they happen is paramount to achieving national targets. Yet it is understood that carbon capture, storage, and removal technologies will play a role in further avoiding emissions and removing gas already in the atmosphere. The U.S. Department of Energy houses several programs that support the research, development, and demonstration of technologies that can capture carbon from a wide array of sources, including power plants, cement and steel facilities, refineries, petrochemical facilities, or other sources. This includes research and demonstration of technological and natural carbon removal through direct air capture, mineralization, chemical and biological carbon utilization, and terrestrial and coastal sequestration through forest and wetland management and restoration. DOE, USDA, and other agencies support research, design and development (RD&D) on these technologies and approaches.[164]

- **Tracking emissions through Mandatory Greenhouse Gas Reporting:** Since 2011, EPA has required the reporting of greenhouse gas emissions from approximately 8,000 facilities across 41 U.S. industry groups that emit 25,000 mt or more of CO2e per year. The reporting program covers about 85 to 90 percent of total U.S. emissions sources and includes the gasses CO_2, CH_4, N_2O, HFCs, PFCs, SF6, and other fluorinated gases, including nitrogen trifluoride and hydrofluorinated ethers. In 2019, reported direct emissions totaled 2.85 billion mtCO2e. This program allows for the accurate and timely collection of emissions data to inform future policy decisions and the compilation of the *U.S. Inventory of Greenhouse Gas Emissions and Sinks*, which supports transparency.[165]

Key Non-Federal Spotlight

- **Non-federal Climate Ambition:** In 2017, a groundswell of state, local, and tribal governments, along with companies, investors, universities, faith groups, and other non-governmental organizations, coalesced in support of the United States' commitment under the Paris Agreement. Now named *America Is All In*, this diverse coalition includes nearly 2,000 governments, organizations, universities, and businesses of every size. Combined, this coalition represents 68 percent of U.S. GDP, 65 percent of U.S. population, and 51 percent of U.S. emissions.[166] These governments and organizations committed to act on climate change mitigation, resilience, and advocacy in their own communities and properties, including goals to eliminate net emissions entirely from the power the consume and across their operations. A recent analysis by the group found that ambitious action by the coalition can be a significant contribution to whole-of-society efforts that reduce U.S. greenhouse gas emissions by 50 percent below 2005 levels in 2030.[167] The United States supports robust subnational action that works in direct collaboration with federal action, investment, and other assistance.

Please see Annex 2 for a table summarizing policies and measures relevant to this reporting period.

126 2019 U.S. Inventory of Greenhouse Gas Emissions and Sinks, U.S. Environmental Protection Agency

127 National Renewable Energy Laboratory. https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html

128 U.S. Department of Energy. https://www.energy.gov/articles/doe-releases-new-reports-highlighting-record-growth-declining-costs-wind-power

129 See, for example, Accelerating America's Pledge: Going All In to Deliver a Prosperous, Low-Carbon Economy for the United States. https://www.americaisallin.com/wp-content/uploads/2021/02/accelerating-americas-pledge-1.pdf

130 U.S. Energy Information Administration. https://www.eia.gov/energyexplained/renewable-sources/portfolio-standards.php

131 California Air Resources Board. https://ww2.arb.ca.gov/resources/documents/states-have-adopted-californias-vehicle-standards-under-section-177-federal

132 C2ES. https://www.c2es.org/document/greenhouse-gas-emissions-targets/

133 U.S. Energy Information Administration.

134 U.S. Department of Energy, Loan Program Office. https://www.energy.gov/lpo/portfolio

135 U.S. Environmental Protection Agency. https://www.epa.gov/greenpower/green-power-partnership-program-success-metrics

136 U.S. Department of Agriculture. https://www.usda.gov/media/press-releases/2021/04/22/earth-day-usda-invests-487-million-rural-water-energy-and-biofuel

137 Census of Agriculture, U.S. Department of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

138 U.S. Department of the Interior. Bureau of Land Management. https://www.blm.gov/programs/energy-and-minerals/renewable-energy

139 https://www.boem.gov/renewable-energy/lease-and-grant-information

140 National Resource Defense Council. https://www.nrdc.org/resources/race-100-clean

141 Database of State Incentives for Renewables & Efficiency. https://programs.dsireusa.org/system/program

142 U.S. Department of Energy. Building Energy Codes Program. https://www.energycodes.gov/impact-analysis

143 U.S. Department of Energy. https://www.energy.gov/eere/buildings/downloads/appliance-and-equipment-standards-fact-sheet

144 U.S. Environmental Protection Agency. ENERGY STAR Program. https://www.energystar.gov/about?s=mega

145 U.S. Department of Energy. Better Buildings Solution Center. https://betterbuildingssolutioncenter.energy.gov/better-buildings-progress-reports

146 U.S. Department of Energy. https://www.energy.gov/sites/default/files/2021/01/f82/WAP-fact-sheet_2021_0.pdf

147 U.S. Department of Energy. Grid-Interactive Efficient Buildings Initiative https://www.energy.gov/eere/buildings/articles/bto-director-david-nemtzow-reflects-grid-interactive-efficient-buildings

148 New York City. Sustainable Buildings. https://www1.nyc.gov/site/sustainablebuildings/ll97/local-law-97.page

149 U.S. Environmental Protection Agency. https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-model-year-2017-and-later-light-duty-vehicle

150 U.S. Environmental Protection Agency. https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-final-rule

151 U.S. Department of Energy. Vehicle Technologies Office. https://www.energy.gov/eere/vehicles/articles/fotw-1177-march-15-2021-preliminary-data-show-average-fuel-economy-new-light

152 U.S. Environmental Protection Agency. https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-phase-2-greenhouse-gas-emissions-standards

153 U.S. Department of Transportation. Federal Highway Administration. https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/

154 U.S. Department of Energy. Loan Program Office. https://www.energy.gov/lpo/products-services/advanced-technology-vehicles-manufacturing-loan-program

155 U.S. Environmental Protection Agency. Voluntary Methane Programs. https://www.epa.gov/newsreleases/epa-methane-challenge-partners-lead-efficiency-and-emission-reductions, https://edap.epa.gov/public/extensions/NGS/Accomplishments.html

156 U.S. Environmental Protection Agency. SNAP Program. https://www.epa.gov/snap/snap-regulations

157 U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

158 U.S. Environmental Protection Agency. AgSTAR Accomplishments. https://www.epa.gov/agstar/agstar-accomplishments

159 U.S. Department of Agriculture. Conservation Reserve Program. https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/

160 https://www.fs.usda.gov/managing-land/private-land/forest-legacy

161 U.S. Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

162 U.S. Environmental Protection Agency. Municipal Solid Waste Landfills: New Source Performance Standards and Emission Guidelines. https://www.epa.gov/stationary-sources-air-pollution/municipal-solid-waste-landfills-new-source-performance-standards

163 Congressional Research Service.

164 See for example U.S. Department of Energy. Carbon Capture Program. https://netl.doe.gov/coal/carbon-capture

165 U.S. Environmental Protection Agency. GHGRP. https://www.epa.gov/ghgreporting/ghgrp-reported-data

166 America Is All In. Accelerating America's Pledge. https://www.americaisallin.com/wp-content/uploads/2021/02/accelerating-americas-pledge-1.pdf

167 America Is All In. An All-In Climate Strategy. https://www.americaisallin.com/wp-content/uploads/2021/04/all-in-climate-strategy-report2021rd3-3.pdf

5 PROJECTED GREENHOUSE GAS EMISSIONS

CHAPTER SUMMARY

This chapter provides projections of U.S. greenhouse gas (GHG) emissions through 2035, including the effects of policies and measures implemented as of September 2020, the cutoff date for the Energy Information Administration (EIA) 2021 Annual Energy Outlook's baseline projections of energy-related carbon dioxide (CO_2) emissions (U.S. DOE/EIA 2021). The "With Measures" (WM) scenario, hereafter referred to as the "2020 Policy Baseline" scenario, presented does not include the effects of the President's National Climate Strategy, nor plans or programs in the process of implementation by the Biden administration. The projections of U.S. greenhouse gas emissions described here reflect national estimates considering population growth, long-term economic growth potential (including robust recovery from the COVID-19 pandemic), ongoing evolution of the energy system, and many of the implemented policies and measures discussed in Chapter 4.

Policies that are proposed or planned but had not been implemented as of September 2020, as well existing legislation that require implementing regulations that are not yet final, or funds that have not been appropriated, are not included in this chapter's projections. For example, the projections do not include policies in the process of implementation, such as HFC regulations resulting from the 2021 AIM Act, or recent proposals for updated light-duty vehicle or oil and gas regulations. Projections that take into account the full range of recent and planned new measures are contained in the President's National Climate Strategy, and will be reflected in future reports.[168]

Projections are provided in total by gas and by sector. Gases included in this report are CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF_3). Emissions are presented in CO_2-equivalent values using global warming potential (GWP) conversions from the fourth IPCC assessment report (AR4), which is in alignment with GWP values used for the U.S. Greenhouse Gas Inventory (chapter 3). Sectors reported include energy, transportation, industrial processes, agriculture, waste, and land-use, land-use change, and forestry (LULUCF). Projections for LULUCF through 2035 are presented as a range based on alternative high – and low-sequestration scenarios.

The tables in the chapter present emissions trends from 2005 through 2035.

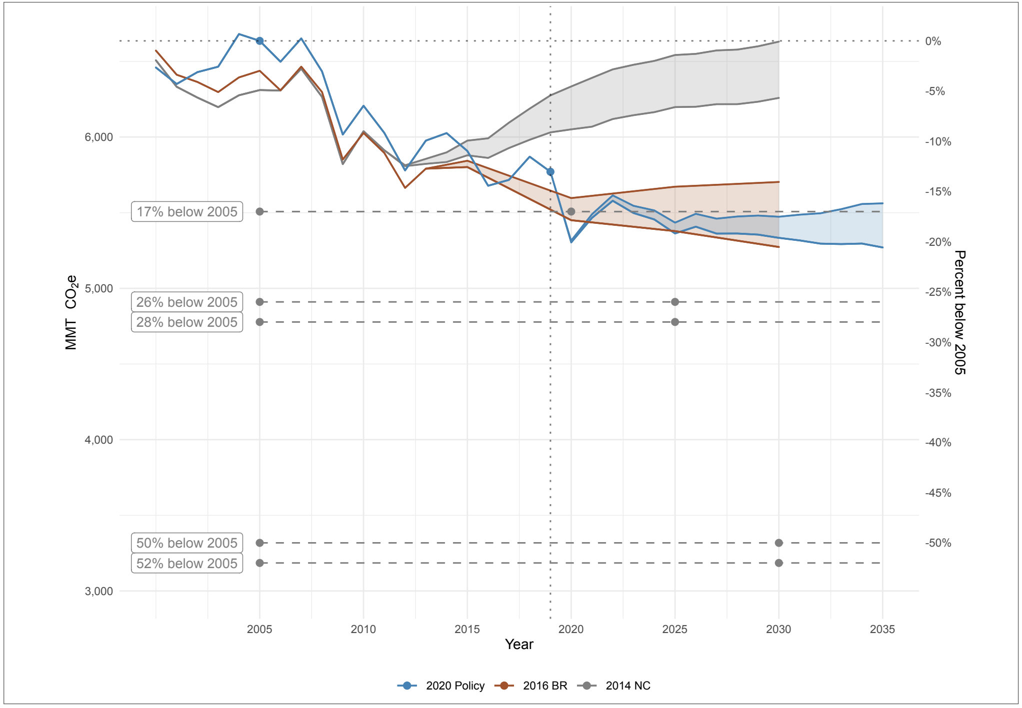
U.S. GREENHOUSE GAS EMISSION PROJECTIONS

The U.S. Department of Energy's (DOE's) Energy Information Administration (EIA) Annual Energy Outlook 2021 (AEO2021) Reference case provided the projection of energy-related CO_2 emissions in the 2020 policy baseline scenario presented in this chapter.[169] Projected CO_2 emissions in the AEO2021 Reference case were adjusted to match international greenhouse gas inventory convention. The U.S. Environmental Protection Agency (EPA) prepared the projections of non-energy-related CO_2 emissions and non-CO_2 emissions. The methodologies used to project non-CO_2 emissions are based on methodologies described in the background document Methodologies for U.S. Greenhouse Gas Emissions Projections: Non-CO_2 and Non-Energy CO_2 Sources[170] with incremental adjustments for changes in data inputs availability and policy characterization, described in Annex 5. The U.S. Department of Agriculture Forest Service (USDA/FS) and EPA collaborated on the projections of net CO_2 fluxes from LULUCF. Historical emissions are drawn from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019* .[171]In general, the projections reflect long-run trends and may not fully capture short-run changes.

Trends in Total Greenhouse Gas Emissions

Given implementation of programs and measures in place as of September 2020 and economic projections from AEO2021, total net U.S. greenhouse gas emissions are projected to be about 18-19 percent below 2005 levels in 2025 and 18-20 percent below 2005 levels in 2030. Between 2005 to 2019, net greenhouse gas emissions decreased about 13 percent. In 2020, emissions dropped sharply in response to Coronavirus pandemic-related changes, resulting in a decrease of 11 percent in energy-related CO_2 emissions from 2019 (EIA).

Figure 5-1 **U.S. Net Emissions Comparison**



Based on the 2020 Policy Baseline and including economic effects of the COVID-19 pandemic, net greenhouse gas emissions in 2020 are provisionally estimated to be about 20 percent below 2005 estimates. However, the U.S. greenhouse gas inventory covering the 1990-2020 timeseries is currently under development, to be published in April 2022.

- Under the "2020 Policy Baseline" (WM) scenario, greenhouse gas emissions are expected to be approximately 18-20 percent below 2005 emissions in 2025 and 2030, based on robust recovery from the Coronavirus pandemic and policies and measures implemented as of late 2020.
- This conclusion does not account for the impact of policy plans from the Biden administration.

Table 5-1 **Historical and Projected U.S. GHG Emissions Baseline, by Gas: 2005-2035 (MMT CO_2e)**
Total Net U.S. greenhouse gas emissions are projected to be 18-20 percent lower than 2005 levels in 2030. Gross CO_2 emissions are projected to decline 22 percent over this period.

	Historical				Projected			
Gas	**2005**	**2010**	**2015**	**2019**	**2020**	**2025**	**2030**	**2035**
CO2	6,135	5,676	5,372	5,256	4,788	4,825	4,803	4,784
CH4	686	692	652	660	643	652	659	666
N2O	456	455	468	458	455	451	450	450
HFCs	128	155	168	175	207	252	273	282
PFCs	7	5	5	4	4	4	5	5
SF6	12	7	5	6	6	5	5	4
NF3	0	1	1	1	1	1	1	1
Total Gross Emissions	7,423	6,991	6,671	6,558	6,103	6,191	6,194	6,192
LULUCF (historical / low-sequestration)	-788	-784	-764	-789	-784	-753	-717	-626
LULUCF (high-sequestration)	—	—	—	—	-796	-824	-857	-918
Total Net Emissions (historical / low-sequestration)	6,635	6,207	5,907	5,769	5,319	5,438	5,477	5,565
Total Net Emissions (high-sequestration)	—	—	—	—	5,307	5,366	5,337	5,274

Note:
LULUCF and Total Net greenhouse gas emissions are presented as a range between "low sequestration" and "high sequestration" scenarios.
•Increase in HFC emissions between 2019 and 2020 does not reflect 1-year growth rate, but instead a contrast between historical estimates from the 2021 greenhouse gas inventory (from which historical estimates are drawn) and more recent calculations used for projections.

Emissions Projections by Sector

Table 5-2 **Historical and Projected U.S. GHG Emissions Baseline, by Sector: 2005-2035 (MMT CO_2e)**

	Historical				Projected			
Sector	**2005**	**2010**	**2015**	**2019**	**2020**	**2025**	**2030**	**2035**
Energy	4,398	4,130	3,776	3,555	3,368	3,317	3,335	3,331
Transportation	1,904	1,731	1,744	1,838	1,527	1,610	1,562	1,539
Industrial Processes	366	362	375	375	410	464	490	506
Agriculture	577	596	616	629	634	631	634	638
Waste	178	170	160	164	164	169	174	178
Total Gross Emissions	7,423	6,990	6,671	6,560	6,103	6,191	6,194	6,192
LULUCF (historical / low-sequestration)	-788	-784	-764	-789	-784	-753	-717	-626
LULUCF (high-sequestration)	—	—	—	—	-796	-824	-857	-918
Total Net Emissions (historical / low-sequestration)	6,635	6,207	5,907	5,769	5,319	5,438	5,477	5,565
Total Net Emissions (high-sequestration)	—	—	—	—	5,307	5,366	5,337	5,274

Notes:
Historical emissions from *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*
Sectors correspond to IPCC inventory source categories except transportation has been disaggregated from the energy sector.

The economic uncertainty presented by the continuing COVID-19 pandemic continues to be a key uncertainty in projecting future economic trends. The U.S. economy contracted by 3 percent in 2020. As of publication in 2021, GDP has trended above the AEO2021 projections due to the ongoing recovery. This short-term economic environment has direct linkages to emission levels, although the longer-term expectations in the AEO2021 reference scenario are used in the 2020 Policy Baseline, as it represents a cohesive and reasonable long-term outlook.

Energy

In the scenarios used, energy-related emissions are relative stable over the time horizon through 2035, although changes occur within and across some sectors. Domestic energy production and consumption continue to shift towards lower-emitting forms of energy, primarily renewable energy and natural gas. Crude oil production and petroleum consumption are expected to increase modestly, while coal production is expected to decline modestly over time. The most notable changes in energy use occur in the electric sector, where significant amounts of new renewable energy are expected to be deployed in response to falling technology costs, and incentives. Most electricity capacity additions come from solar, natural gas, and wind. Industrial energy use drives projected increases in energy use and emissions from 2020 to 2035. Building energy use is relatively stable through the projection, as energy efficiency improvements partially offset population and sector growth.[172] Continuing record-high domestic energy production supports natural gas and petroleum exports. Emissions control regulations and voluntary mitigation activities limit CH_4 emissions growth in the context of expanding energy production.

Transportation

Behavioral changes in response to the COVID-19 pandemic resulted in decreased energy use in the transportation sector more than in other end-use sectors. Over the next few years, recovery is expected to result in short-term growth in energy use and emissions. Energy consumption by light-duty and heavy-duty vehicles remains below 2019 levels for the entire projection period. Although travel demand increases, increasing market adoption of energy efficiency technologies in new vehicles and increasingly stringent fuel economy standards offset consumption growth.[173] Although the market continues to grow for alternative fuel vehicles, particularly battery-electric vehicles, the share of new vehicles which may use gasoline and blended ethanol remains 88 percent in 2035. Consumption of biofuels as a share of the domestic fuel mix increases in the 2020 Policy Baseline.

Industrial Processes

Major industrial processes source categories continue to include use of HFCs in refrigeration and air conditioning, metals, cement, and chemicals production. In the AEO2021 reference scenario, the industrial sector becomes the largest consumer of natural gas starting in the early 2020s, including expanded use as a feedstock in chemical industries as well as for industrial heat and power. Several trends impact projections of HFC emissions from use of ozone-depleting substance (ODS)-substitutes: (1) lower emissions due to the continued replacement of HFC-134a with HFO-1234yf in light duty vehicle air conditioning, due to compliance flexibilities in the light duty CO_2 emissions rule; (2) increasing emissions from the growth in sales of residential air conditioning that use a high-GWP HFC blend, including record-level air conditioning sales and upgrades during the pandemic; (3) some replacement of high-GWP HFCs with low/zero-GWP substances in certain parts of the refrigeration, air conditioning, foams, fire suppression, and aerosols markets.

Agriculture

Across commodities, crop production in the United States through 2035 is projected to increase modestly due to higher demands for food, livestock feed, and fiber products. These higher demands are primarily driven by increasing U.S. and global populations and income levels. With respect to area, however, land in crop production, both in aggregate and for individual commodities, is projected to remain relatively stable at current levels. The combination of increasing production and stable cropland area results from a projected continuation of trends in productivity (i.e., increasing yields per acre) that have been observed for the major crops over the last 10–20 years. For example, yields of corn and wheat have been increasing at annual rates of, respectively, 2.0 and 0.4 bushels per acre per year for over a decade. The projected increases in yields per acre are adequate to meet the projected increases in commodity production without increasing the quantity of land in crop production.

As with the major crops, production of beef, pork, chicken, and dairy products are projected to increase modestly due to rising U.S and global populations and income levels. Unlike crops, projected increases in productivity (i.e., milk or meat per animal) are not sufficient to meet the growing demands for livestock products resulting in modest increases in projected herd and flock sizes. (These projections assume that livestock and crop production continue current practices. There is research ongoing in anaerobic digestion, other manure to energy technologies, livestock feed management and feed additives that reduce enteric methane production, as well as soil health improvements on cropland with will result in an increase in organic matter in cropland soils.)

With respect to greenhouse gas emissions from agricultural sources, the above changes in crop and livestock productivity result in a small increase in projected methane (CH4) emissions, primarily from manure management. Projected emissions of enteric fermentation CH4 emissions, manure nitrous oxide (N2O) emissions, and cropland N2O emissions are relatively stable through 2035 at current levels. Agricultural soils (collectively the sum of cropland remaining cropland, land converted to cropland, grasslands remaining grasslands, and lands converted to grasslands) are also associated with CO2 emissions and removals. Currently, these soils are a net source of emissions (30 MMT CO2e in 2020; EPA 2021) and they are projected to remain a source through 2035. The magnitude of the source is projected to decrease through 2030 to (26 MMT CO2e) and remain at that level through 2035.

Forest and Land Use

As described in the Inventory of Greenhouse Gas Emissions and Sinks 1990-2019, land use, land-use change, and forestry (LULUCF) activities in 2019 resulted in net CO2 removals of nearly of 813 million tonnes CO_2e/year.[174] Total LULUCF carbon stock change (includes carbon stock gains and losses from all land use and land use conversion categories) decreased by approximately 11 percent between 1990 and 2019. U.S. forest land attributes and area are continually changing as the demand for forest products change, as forest management techniques advance, as forests age, and as land use choices shift. Also, climate change is altering forest composition, structure, and dynamics via changes in forest growth, and higher frequency and greater intensity of natural disturbances such as droughts, wildfires and insect and disease outbreaks.

Projecting potential future emissions fluxes from LULUCF is challenging due to the uncertainties associated with estimating the complex carbon dynamics of different terrestrial ecosystems and related market interactions, and the potential extent of land use change between sectors. To reflect these uncertainties, the U.S. LULUCF projections through 2035 in this document are presented as a range (See Figure 5-5). This range incorporates results from three different modeling efforts that use alternate modeling techniques and different perspectives on future macroeconomic outlooks, land use changes, and accounting of forest dynamics. Using a range from alternative models helps bolster the integrity of the projected results. The approaches used to develop this range is discussed further in the methods section, with a brief description of results here.

The high end of the range reflects a maintained and slightly strengthened net forest sink (meaning carbon stocks increase at a flat or increasing rate). This projection indicates strong continued investment in productive private forest lands by landowners, as well as continued net increases in forest land area. These factors are augmented by continued atmospheric enrichment through CO_2 fertilization. Rising investment in silvicultural practices and forest expansion is driven by global demand growth for forest products; rising forest market prices in this estimate engender new forest investments that stimulate increased carbon stocks. Some lands, especially in the Eastern U.S., see moderating harvests and management intensity as landowners increasingly value other outputs besides timber. There is also decreased harvest from less accessible regions over time and increased harvests from more accessible regions.

The lower sequestration range reflects the U.S. forest sector will become a smaller net sink of greenhouse gas emissions (as carbon stocks increase at a decreasing rate) under current policies and management approaches. This projection sees increases in forest harvest for products, a net decrease in forest area, and an aging forest resource influenced by increasing disturbance rates. This trajectory is largely driven by the interaction of increasing harvest with small increases in timber prices and the effects of future disturbance on an aging forest. The increasing price trends do result in investments in forest management and planting, yet in key forest production regions, for example the Southeast, this increased investment serve to shift away from historic decreases in forest plantation area to a stable plantation area in the future. In the United States, forest plantations only account for 10 percent of the forest land base. The remaining 90 percent of the forest land base is typically less intensively managed for timber, managed for other ecosystem services (e.g., water, wildlife, aesthetics, recreation), or managed for multiple uses (see for example Butler et al. 2021). Decreased sequestration is anticipated over time in this larger portion of the forest land base as naturally regenerated forest lands are harvested to meet demand, and forest growth slows due to aging and increased disturbance.

In the interest of transparency, we present this range of LULUCF uncertainty as it reflects many considerations about different possible future economic conditions, population dynamics and land sector response. Ultimately, the range reflects the broad set of activities currently being taken by the United States to maintain our carbon sink.

Waste

An increasing population results in more waste deposition in landfills and wastewater treatment, and corresponding projected increases in emissions.

TOTAL EFFECT OF POLICIES AND MEASURES

Changes in Gross Emission Projections between the 2014 and 2021 National Communications

Projections of gross greenhouse gas emissions in the 2020 Policy Baseline scenario presented in this report are significantly lower than the emission projection presented in the 2014 National Communications. These differences result from a combination of changes in policies, cost of technologies, and economic growth. While responses to the COVID-19 pandemic have led to large changes in activities and emissions in the short run, these are occurring within the context of overall shifts towards a less greenhouse gas emissions intensive economy. This can be observed, for example, by the fact that 2019 greenhouse gas emissions, before the start of the pandemic, were lower than had been previously projected. The current 2020 Policy Baseline projection and the corresponding projections from previous reports are displayed in Table 5-3 and Figure 5-2 for comparison. Adjustments have been made to previous National Communications and Biennial Report projections to reflect Fourth Assessment Report (AR4) GWPs.

Table 5-3 **Comparison of Total Gross GHG Emissions under the 2020 Policy Baseline Projections to Previous U.S. National Communications and Biennial Reports**

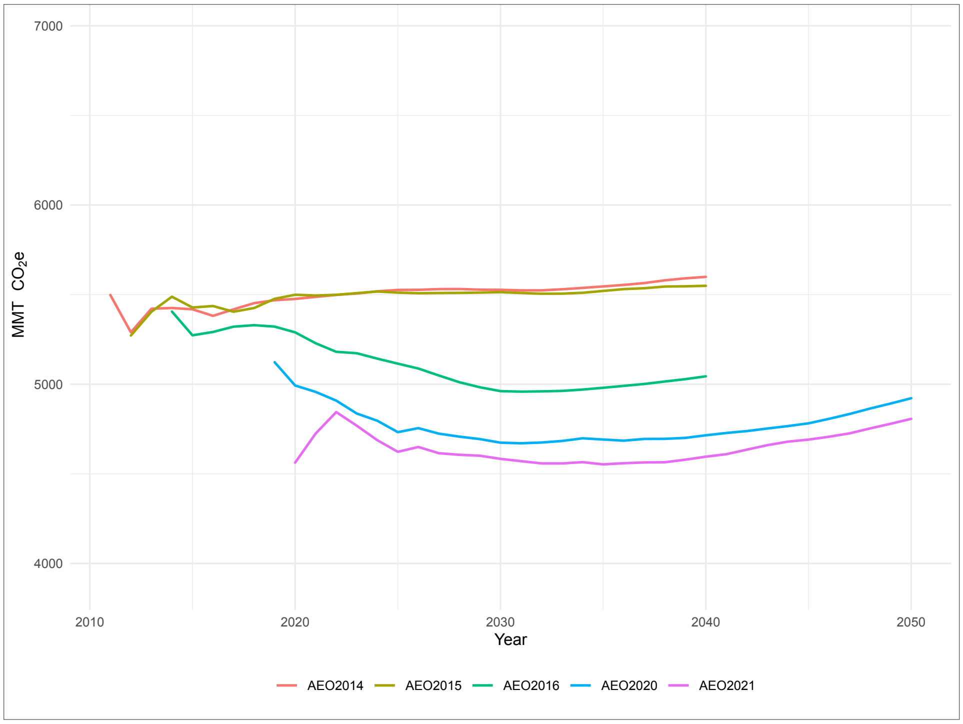
	2005	2010	2015	2019	2020	2025	2030	2035
2021 NC	7,423	6,991	6,671	6,558	6,103	6,191	6,194	6,192
2016 BR	7,350	6,899	6,772	6,668	6,641	6,580	6,392	—
2014 NC	7,283	6,908	6,732	6,892	6,921	7,074	7,160	—
2010 NC	7,257	7,237	7,407	7,564	7,604	—	—	—
2006 NC	7,246	7,648	8,043	8,355	8,433	—	—	—

Notes:

1. Historical and projected years vary between reports. For the 2021 National Communication, the base year inventory is 2019; for the 2016 BR it was 2013; for the 2014 National Communication it was 2011; for the 2010 CAR it was 2007; for the 2006 National Communication it was 2004.
2. Previous National Communication projections have been adjusted for comparability and may vary from tables published in those reports. Where Fourth Assessment Report (AR4) GWP values were not used, CO2-equivalent projections have been adjusted to reflect AR4 GWPs. LULUCF emissions sources that were previously reported as part of gross emissions are now excluded from gross emissions.
3. Historical estimates can vary between National Communication and BR reports because as part of the process of revising inventory methodologies and data sources there are often historical timeseries recalculations.

Figure 5-2 **Comparison of 2020 With Measures Baseline to Previous With Measures Projections**

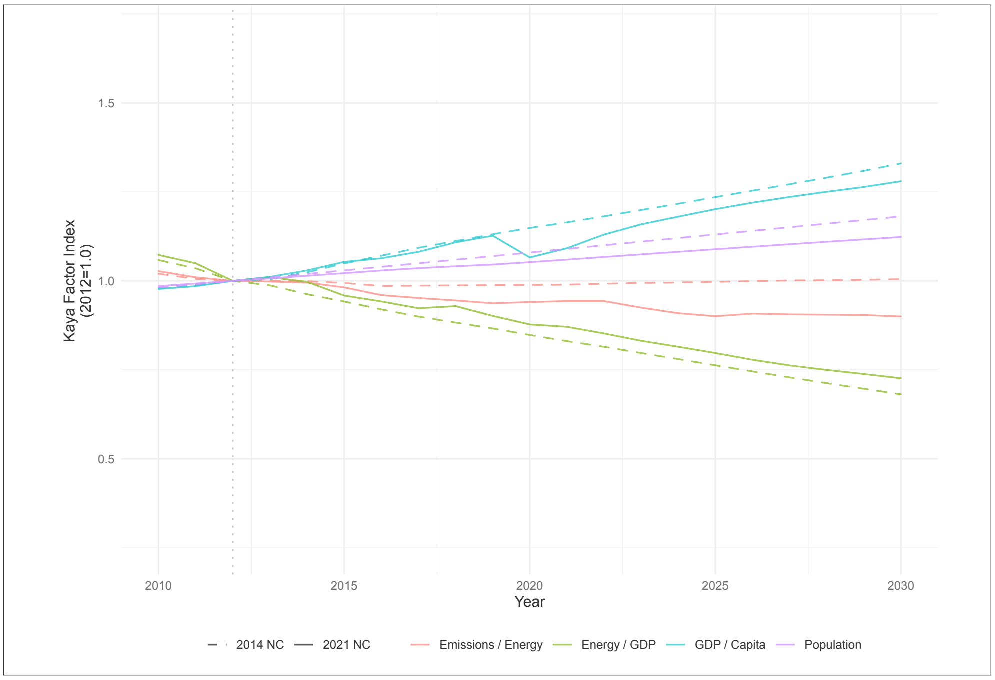
Figure 5-3 **Comparison of Energy-Related CO_2 Projections from Annual Energy Outlook (AEO) 2021 Reference Case to Previous AEO Projections**



Top-Down Estimate of the Effects of New Policies and Measures

An analysis was conducted to disaggregate changes in emission projections due to macroeconomic factors from changes resulting from policies and measures and technology improvements. The analysis decomposes emissions into factors representing population, per capita GDP, energy intensity, and carbon intensity of energy, referred to as a Kaya analysis. Between the 2014 and 2021 National Communications, projections of population, GDP, energy use, and emissions all changed. By changing individual factors, the Kaya analysis can be used to associate proportions of the total change in emissions with each factor in the decomposition equation. By removing the portion of emission change due to population and GDP changes, the remaining emissions change associated with energy and emissions intensity is assumed to relate to new policies and measures, technological change, and energy market conditions over the time period when the two sets of projections were prepared.

Figure 5-4 **Normalized Kaya Identity Factors Used for Assessing the Effects of New Policies and Measures**



Kaya analysis results:

- Within the macroeconomic drivers, population has consistently trended lower than had been projected in the 2014 National Communication. Up to 2019, GDP/capita had trended close to the 2014 projection, but the Coronavirus pandemic has resulted in gap between current projections of GDP/capita and the 2014 estimates. Through 2030 this gap is expected to narrow but not close entirely.
- The result of lower population and GDP/capita than had been projected in the 2014 National Communication means that even without improvements in energy or emissions intensity, we should expect lower energy use and emissions projections in the 2020 Policy Baseline than in the 2012 policy baseline presented in the 2014 National Communication.
- While energy-intensity and emissions-intensity were both projected to decline over time in the 2012 Policy Baseline, the Kaya decomposition shows how those factors are now expected to evolve independently of macroeconomic drivers. Energy-intensity is somewhat higher than had been projected in 2014, while emissions-intensity is significantly lower.
- While some of the change in gross emissions projections between the 2014 CAR and 2021 National Communication for the years 2020, 2025, and 2030 are attributable to changes in macroeconomic expectations, most of the change, particularly in 2025 and 2030, is associated with the Kaya decomposition factors for energy-intensity and emissions-intensity. This indicates a total effect of policies and measures and technological change of 700 MMT CO_2e in 2025 and 700 MMT CO_2e in 2030.

Table 5-4 **Estimates of the Total Effect of New Policies and Measures and Technology Change**

Changes Between 2014 NC and 2021 NC	2020	2025	2030
Gross Emissions (MMT CO2e)	-822	-887	-969
Percent of change associated with energy- and emissions-intensity factors	50 percent	80 percent	70 percent
Emissions change associated with energy- and emissions-intensity factors (MMT CO2e)	400	700	700

Note:

1. Due to uncertainty and sensitivity of Kaya analysis results, percent associations and MMT are presented with 1 significant figure..

While indicative, the Kaya decomposition is somewhat sensitive to methodological choices and adjustments. For example, to ensure comparability, it was necessary to convert the emissions projections from 2014 to AR4 GWP values, and to convert the GDP projections from 2014 to more recent year constant dollar values. Even after these conversions there were discrepancies in the historical series resulting from recalculations and methodological adjustments in the intervening years which limit comparability. Table 5-6 provides a summary of key factors underlying the current estimates for 2030 in comparison to previous projections.

Key Variables and Assumptions

Table 5-5 summarized key variables and assumptions used in the projections included in this report, while Table 5-6 captures changes in key socioeconomic factors over time.

Table 5-5 **Summary of Key Variables and Assumptions Used in the Projections Analysis**

		Historical	Projected						
Key Factor	Units	2005	2010	2015	2019	2020	2025	2030	2035
Energy Intensity	Thousand Btu per Chained (2012) Dollar	6.7	6.2	5.6	5.2	5.1	4.6	4.2	3.9
Population	millions	295.5	309.3	320.7	328.3	330.4	341.8	352.6	362.3
Real Gross Domestic Product	Billion chained (2012) dollars	14,912.5	15,598.8	17,432.2	19,091.7	18,171.4	21,192.6	23,288.8	25,842.0
Coal Consumption	Quads	22.8	20.8	15.5	11.3	9.0	7.8	7.6	7.2
Natural Gas Consumption	Quads	22.6	24.6	28.2	32.2	31.9	32.0	32.1	32.5
Petroleum Consumption	Quads	40.2	35.3	35.4	36.9	33.5	37.0	36.9	37.1
Total Primary Energy Consumption	Quads	100.1	97.5	97.4	100.3	92.9	98.4	98.6	100.0
Vehicle Miles Travelled	Billion miles	2,989.4	2,967.3	3,095.4	3,260.3	2,991.1	3,409.5	3,551.7	3,661.9

Table 5-6. **Summary of Key Variables and Assumptions Used in the Projections Analysis**

		Assumptions for 2030		
Key Factor	Units	2014 NC	2016 BR	2021 NC
Population	Millions	372.00	359.00	353.00
Real GDP	Billion dollars	27,863.67	28,324.49	26,386.00
Energy Intensity	Btu per dollar of GDP	3,686.83	3,635.52	3,733.00
Light-Duty Vehicle Miles Traveled	Billion miles	3,323.00	3,287.00	3,121.00
Average Imported Crude Oil Cost	Dollars per barrel	144.56	106.83	70.00
Henry Hub	Dollars per MMBtu	6.21	6.32	3.34
Minemouth Coal Price	Dollars per ton	64.02	48.55	29.40
Average Electricity Price	Cents per kilo-watt-hour	11.16	12.33	10.30
All-Sector Motor Gasoline Price	Dollars per gallon	4.22	3.56	2.80
Energy Consumption	Quadrillion Btu	103.00	103.00	99.00

METHODOLOGY

The 2020 Policy Baseline (“With Measures”) projections incorporate energy-related CO_2 emissions from the Energy Information Administration’s AEO2021 Reference Case, with adjustments to reflect categorization of emissions in the UNFCCC and in the *U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2019*.

Non-energy CO_2 and non-CO_2 greenhouse gases greenhouse gas emissions projections are developed by EPA and USDA and use change and forestry projections are developed by EPA with USDA and USFS input. These projections are based on the Global Timber Model (GTM) and Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). Further details on this projections approach are provided below, and in Annex 5.

Changes in Projection Methodology from Previous Reports

The projections in this chapter are compiled using the same approach as used in past reports such as the 2014 National Communication and 2016 Biennial Report. Updated versions of data sources and modeling have been used, and each of the underlying data sources reflect updated characterization of macroeconomic, technology, and policy.

Table 5-5 includes information on key drivers and assumptions corresponding to the projections in this chapter, while table 5-6 compares current key factors to those used in past reports.

Energy CO_2 Projections Methodology

Emissions projections of CO_2 from fossil fuel combustion are drawn from the EIA Annual Energy Outlook (AEO) 2021. The AEO2021 is based on the National Energy Modelling System (NEMS), described below. Adjustments are made to the results of the AEO2021 Reference scenario as part of their use in the 2020 Policy Baseline presented here in order to conform to international reporting conventions and categorization and to make them as consistent as possible with the historical greenhouse gas inventory, described below.

Description of NEMS methodology

NEMS is organized and implemented as a modular system. The modules represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system. NEMS also includes macroeconomic and international modules. The primary flows of information among the modules are the delivered prices of energy to end users and the quantities consumed by product, region, and sector. The delivered fuel prices encompass all the activities necessary to produce, import, and transport fuels to end users. The information flows also include other data on such areas as economic activity, domestic production, and international petroleum supply. Each NEMS component represents the impacts and costs of existing legislation and environmental regulations that affect that sector. NEMS accounts for all combustion-related CO_2 emissions, as well as emissions of sulfur dioxide, nitrogen oxides, and mercury from the electricity generation sector. The potential impacts of pending or proposed federal and state legislation, regulations, or standards—or of sections of legislation that have been enacted but that require funds or implementing regulations that have not been provided or specified—are not reflected in NEMS.

Adjustments to Annual Energy Outlook Results

The primary adjustments to energy CO2 emissions projections from AEO are:

4. The AEO energy CO_2 totals include emissions from international shipping and air travel. These emissions are not included in the totals for the projections in this chapter per UNFCCC reporting conventions for international bunker fuel emissions.
5. Emissions from U.S. territories are not generally included in AEO energy CO_2 totals, so they are added in for the purpose of the projections in this chapter.
6. Emissions from feedstock and process uses of fossil fuels are included in the AEO, but do not fully encompass the emission estimated as part of the non-energy uses of fossil fuels category in the I*nventory*. Estimates for the 2020 Policy Baseline are adjusted to reflect the full scope comparable to historical estimates.
7. Sectoral and source categorization are adjusted to reflect designations used in the greenhouse gases I, which sometimes differ from the economic sector categorizations in the AEO (e.g., industry CO_2 emissions in the AEO included in the energy sector here).

Non-Energy CO_2 and Non-CO_2 Greenhouse Gas Projections Methodology

Non-energy CO_2 and non-CO_2 greenhouse gas emissions projections are developed by EPA and USDA. The land use and forestry projections are developed by EPA, USDA, and USFS . Projections are based on the Global Timber Model (GTM), the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG), and results from the USFS Resources Planning Act (RPA) Forest Dynamics model, Land Use Change model, and Global Trade Model (FOROM). Projection methodologies are informed by calculation methodologies published by the IPCC for inventory calculations. EPA used information from the most recent greenhouse gas inventory as the starting point for emissions and underlying activities. EPA projected changes in activity data and emission factors from that base year. Activity data projections include macroeconomic drivers such as population, gross domestic product, and energy use, and source-specific activity data such as fossil fuel production, industrial production, or livestock population and crop production. Where possible, activity projections were drawn from the EIA AEO, USDA Long-Term Agricultural Projections, or EPA Vintaging Model for HFCs from ODS-substitutes. Future changes in emissions factors were based on continuation of past trends and expected changes based on implementation of policies and measures. The methodology document with drivers and equations for each source was published in 2013. A summary of updates relative to that methodology document is included as Annex 5.

USDA projections for agriculture sector CH_4 and N_2O start by using activity data and emissions factors from the 2021 GHGI for historical years and extend to future years assuming a continuation of current trends in acres, production, and yields in the 2021 USDA Long-Term Agricultural Projections.

LULUCF Methodology

To better reflect the uncertainties associated with estimating the complex carbon dynamics of different terrestrial ecosystems and related market interactions, and the potential extent of land use change between sectors, the U.S. LULUCF projections through 2035 are presented in Figure 5-5. This range was developed via a collaborative multi-agency effort using different models reflecting alternate modeling techniques. Using different model types in concert allows for a more robust range of projections. These models represent different perspectives on future macroeconomic outlooks (derived from recent U.S. Government projections for GDP, population, and forest products demand) as well as forest characteristics and management trends.

The high sequestration projection range reflects results from EPA using a dynamic intertemporal optimization forestry model (the Global Timber Model).[175] This model's approach provides a simulation of harvesting, planting, and management intensity (e.g., variety of selection, fertilizer, water management, thinning) decisions that landowners might undertake in response to timber and carbon market demands, including future price expectations. Specifically, it is a dynamic intertemporal economic model that determines timber harvests, timber investments, and land use optimally over time under assumed future market, policy, and environmental conditions. The model generates projections using detailed biophysical and economic forestry data for different countries/regions globally, including the U.S., China, Canada, Russia, and Japan. It used macroeconomic data from AEO2021 for the U.S. and global parameters from Shared Socioeconomic Pathway 2 (SSP2).[176]

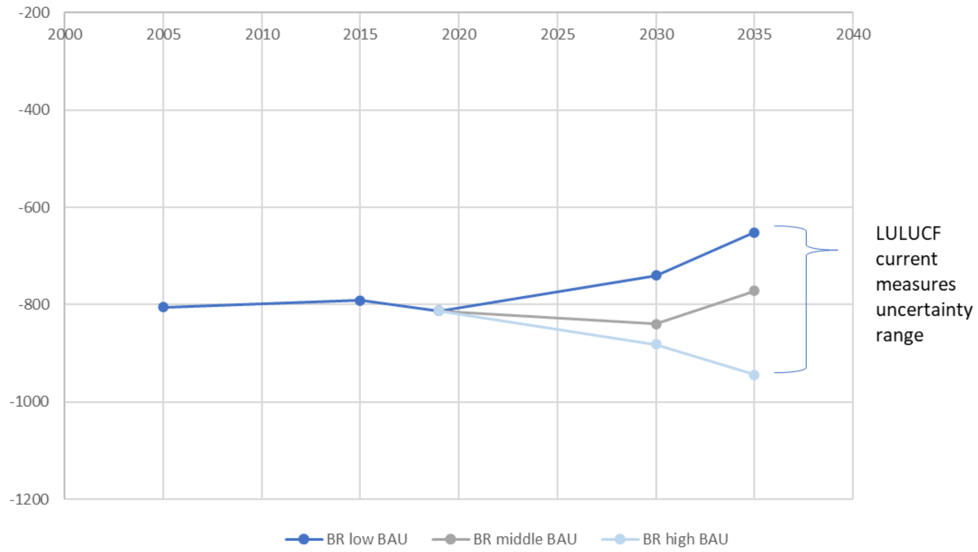
The lower sequestration projection range includes results from the USFS Resources Planning Act (RPA) Forest Dynamics model,[177] Land Use Change model,[178] and Global Trade Model (FOROM).[179] The USFS FOROM model and the USFS Forest Dynamics model are tied to growth under SSP2, which suggests moderate rates of population and socioeconomic growth in the United States.[180] Land use change projections are based on the USFS RPA Land Use Change model and the forest land use change results are integrated into the Forest Dynamics model. The land use change projections are driven by land rents, observed population and income rate changes, and current climate. The storage and flux of carbon in harvested wood products and solid waste disposal sites are projected based on SSP2 using the FOROM model. The Forest Dynamics Model and FOROM were harmonized such that consistent prices and timber removals for products were realized.

Also used to inform this analysis is the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOMGHG), a partial equilibrium dynamic optimization model of the U.S. forestry and agriculture sectors.[181] FASOMGHG includes detailed representations of agricultural and forest product markets, contemporary forest inventories, inter-sectoral resource competition and land change costs, and costs of mitigation strategies. Specifically, FASOMGHG 's detailed representation of the entire U.S. land base is brought into the solution maximizing consumer and producer surplus across the agricultural and forestry sectors, and represents production possibilities for crop production, livestock production, and forestry production. The result provides insight into cross-sectoral inter – and intra-regional responses to policy stimuli reflecting the spatial heterogeneity in production of agriculture and forestry products across the U.S.

The U.S. forest representation for all three modeling approaches is derived from the USFS U.S. forest inventory data (Forest Inventory and Analysis, FIA). The results include representation of the following forest carbon pools: aboveground live biomass (including trees, seedlings, and saplings), belowground live biomass such as roots, litter, and soil carbon, deadwood, and harvested wood products. The harvested wood products carbon pool included in the USFS analysis are based on a suite of data including FIA timber product monitoring data, FAO data, and proprietary industry data sources. Projected estimates for urban forests, agricultural soils and landfilled yard trimmings/food scraps were not included endogenously in the models but were derived using projection methodologies based off the U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2019.[182]

GDP, population and bioenergy demand within GTM and FASOMGHG are based on EIA's Annual Energy Outlook for the U.S. and global parameters are aligned with SSP2 expectations for this analysis.[183] The USDA-FS approach also follows SSP2 expectations as well as observed U.S. population and income changes rates. Increased carbon fertilization (above that embodied in the historic data) and climate change are included in the GTM estimates, but they are not accounted for in the FASOMGHG and USFS models' projections.

Figure 5-5 **Current Measures CO_2 Projections for Forestry and Land Use**



168 Insert reference when available

169 https://www.eia.gov/outlooks/aeo/

170 https://unfccc.int/sites/default/files/resource/USA%20methodologies%20got%20greenhouse%20gas%20 emissions%20projections_0.pdf

171 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

172 AEO2021, p10

173 https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf , p5

174 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

175 Austin, K.G., Baker, J.S., Sohngen, B.L., Wade, CM, Daigneault, A. Ohrel, SB, Ragnauth, S, and Bean, A. 2020. The economic costs of planting, preserving, and managing the world's forests to mitigate climate change. Nature Communications 11, 5946 https://doi.org/10.1038/s41467-020-19578-z

Baker, J.S., Wade, C.M., Sohngen, B.L., Ohrel, S. and Fawcett, A.A. 2019. Potential complementarity between forest carbon sequestration incentives and biomass energy expansion. Energy Policy. 126: 391-401.

Sohngen, B. and R. Mendelsohn. 2003. "An Optimal Control Model of Forest Carbon Sequestration" American Journal of Agricultural Economics. 85(2): 448-457.

176 Riahi, K., Van Vuuren, D.P., Kriegler, E., Edmonds, J., O'neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. and Lutz, W., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global environmental change, 42, pp.153-168.

177 Coulston et al. 2021, forthcoming

178 Mihiar and Lewis 2021, forthcoming

179 Johnston, C; Guo, J; Prestemon, J. 2021. The Forest Resource Outlook Model (FOROM): a technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. SRS-254. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 19 p. https://doi.org/10.2737/SRS-GTR-254.

180 Wear, David N.; Prestemon, Jeffrey P. 2019. Spatiotemporal downscaling of global population and income scenarios for the United States. PLOS ONE. 14(7): e0219242. 19 p. https://doi.org/10.1371/journal.pone.0219242.

181 Beach, R., Adams, D., Alig, R., Baker, J., Latta, G., McCarl, B. A., Murray, B., Rose, S., & White, E. 2010. Model documentation for the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). U.S Environmental Protection Agency. Latta, G. Justin S. Baker, Robert H. Beach, Steven K. Rose, Bruce A. McCarl. 2013. A multi-sector intertemporal optimization approach to assess the GHG implications of U.S. forest and agricultural biomass electricity expansion, Journal of Forest Economics, Volume 19, Issue 4. Wade et al–forthcoming.

182 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

183 Riahi, K., Van Vuuren, D.P., Kriegler, E., Edmonds, J., O'neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. and Lutz, W., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global environmental change, 42, pp.153-168.

6
CLIMATE CHANGE IMPACTS AND ADAPTATION

INTRODUCTION

Human activities have dramatically altered the world's climate, oceans, land, ice cover, and ecosystems, resulting in impacts on human health, agriculture, infrastructure, natural resources, and other sectors of the economy. In the United States, climate change has already resulted in more frequent heat waves, extreme precipitation, larger wildfires, and water scarcity. The last few years have seen record-breaking, climate-related weather extremes and continued decline in Arctic sea ice. These are serious challenges that directly affect individuals, communities, and jobs across the nation and all over the world, and these trends are expected to continue in the future. The United States has scaled up actions that enhance the resilience of communities, infrastructure, and natural resources to the impacts of climate change domestically. (The United States also supports partners around the world in building resilience to climate change; relevant information on these programs is reported in Chapter 7.)

The United States, with its geographic and economic diversity, is exposed to many different types of climate impacts, including droughts and wildfires, inland and coastal flooding, extreme heat, loss of permafrost and sea ice, ecosystem and biodiversity loss, and more. Chapter 2 outlines some of the changes in temperature and precipitation already experienced in the United States. Such climate impacts are expected to increasingly disrupt and damage critical infrastructure and property, labor productivity, and the vitality of rural and urban communities. The rising number of billion-dollar weather and climate disasters, shown in Figure 2-5 (2020 disasters) is one indication of the scale and costs of disasters affecting the United States.

Vulnerabilities are spread widely, but unevenly, across the United States. Disadvantaged communities are often at greater risk to harm from climate impacts. Future climate change is expected to further disrupt many areas of life, exacerbating existing challenges to prosperity posed by aging and deteriorating infrastructure, stressed ecosystems, and economic inequality. Thus, impacts will not be distributed equally. People who are already vulnerable, including lower-income and other historically marginalized communities, are often at greater risk to harm from climate impacts and have lower capacity to prepare for and cope with extreme weather and climate-related events and are expected to experience greater impacts.

Regional economies and industries that depend on natural resources and favorable climate conditions, such as agriculture, forestry, outdoor recreation, tourism, and fisheries, are especially vulnerable to the growing impacts of climate change. Rising temperatures are projected to reduce the efficiency of power generation while increasing energy demands, resulting in higher electricity costs and energy burden for disadvantaged communities. Extreme climate also pose occupational threats to worker's health and safety. Without significant, rapid, and sustained reductions in global greenhouse gas emissions, projected warming is expected to cause substantial net damage to the U.S. economy. In the 2020 report "Managing Climate Risk in the U.S. Financial System", the U.S. Commodity Futures Trading Commission found that climate change is already impacting nearly every facet of the economy and poses a major risk to the stability of the U.S. financial system.[184] The Congressional Budget Office projects that climate change will, on net, reduce average annual real Gross Domestic Product (GDP) growth by 0.03 percentage points from 2020 to 2050, relative to growth that would occur under the climatic conditions that prevailed at the end of the 20th century.[185] The growth differential accumulates to a 1.0 percent reduction in the projected level of real GDP in 2050.

Climate change increasingly threatens the livelihoods, economies, health, and cultural identities of all people, but the impacts are especially acute on Native Americans as interconnected social, physical, and ecological systems are disrupted. Many Tribes rely on, but face institutional barriers to, self-determined management of water, land, other natural resources, and infrastructure that will be impacted increasingly by changes in climate. These institutional barriers include limited access to traditional territory and resources, which severely limits their adaptive capacities.

New observations and new research have increased our understanding of past, current, and future climate change since our 6th National Communication in 2014. An assessment of climate trends, impacts, and risks was published in the two volumes of the *Fourth National Climate Assessment* (NCA4), developed under the direction of the U.S. Global Change Research Program. The first volume, the Climate Science Special Report, published in 2017, provides a detailed analysis of how climate change is affecting the physical earth system. The second volume, published in 2018, focuses on the human, societal, and environmental elements of climate change and variability for 10 regions and 18 national topics, with particular attention paid to current and projected risks, impacts, consideration of risk reduction, and implications under different mitigation pathways. Key findings of NCA4 are summarized in the *Expected Impacts of Climate Change* section below.

Actions to adapt to these present and future impacts of climate change are being taken at every scale of government and in every region. Adaptation actions across the nation have been supported by the U.S. federal government through many mechanisms and federal agencies, and also by state and local governments .

This chapter outlines, discusses, and provides examples of the following key topics:

- *Expected Impacts of Climate Change*: Physical changes to the U.S. climate, driven by human activity
- *Vulnerability Assessment*: Climate risks to human activities in different regions and economic sectors of the U.S.
- *Adaptation Actions*: U.S. Government programs to support climate adaptation within the United States

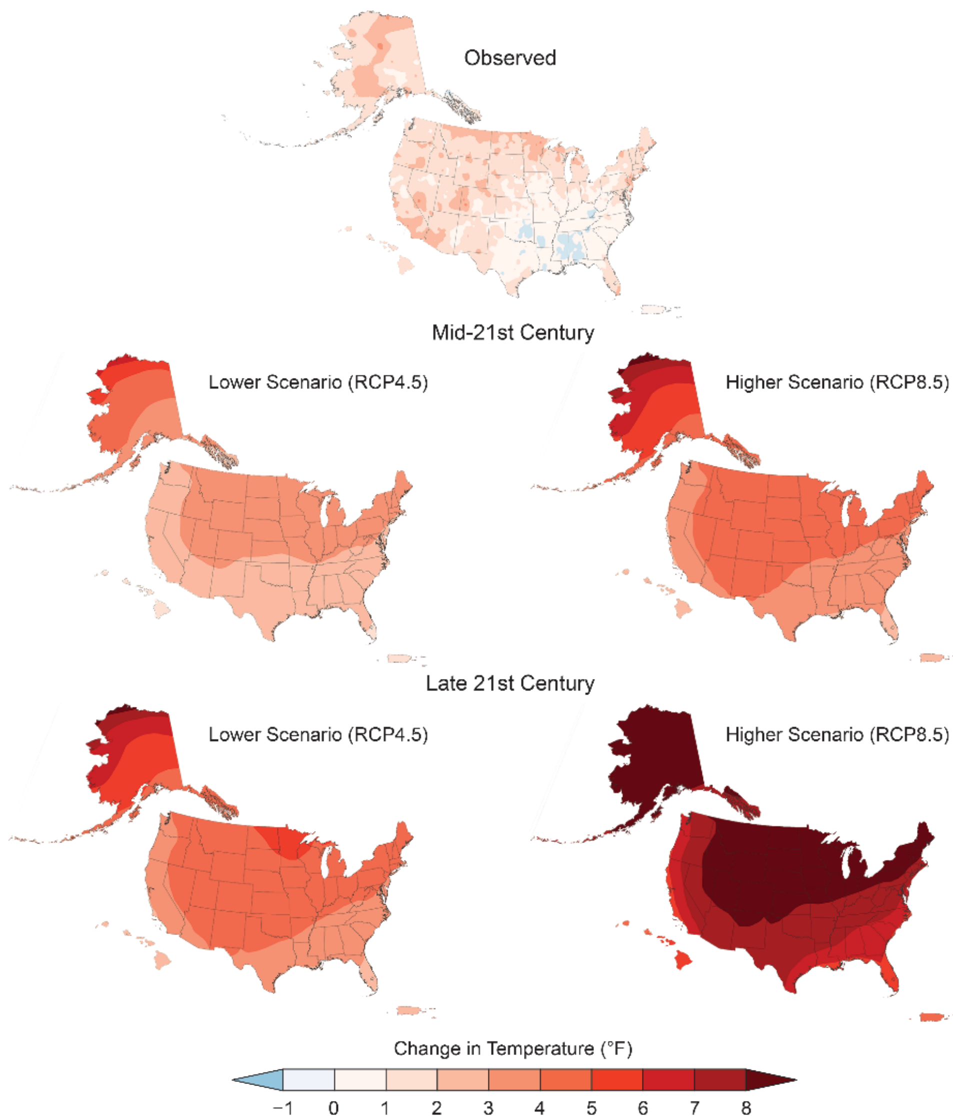
EXPECTED IMPACTS OF CLIMATE CHANGE

The climate of the United States is strongly connected to the changing global climate. Global averaged surface air temperature has increased by about 1.0°C since the beginning of the 20th century, bringing us the warmest period in the history of modern civilization, and this trend is expected to continue. These warmer temperatures will bring changes in precipitation, a rise in sea levels, and more extreme weather events globally, including within the U.S.

As described in Chapter 2, annual average temperature over the United States has risen, and observations are consistent with rapid warming since 1979. There have been marked changes in temperature extremes, with a decrease in the frequency of cold waves and an increase in the frequency of heat waves. Temperatures are projected to continue to rise. In the contiguous U.S., the period 2021-2050 is projected to be about 1.4°C warmer than the period 1976-2005 even in a future with substantial reductions in carbon emissions.[186] Extreme temperatures are projected to increase even more than average temperatures, with less intense cold waves and more intense heat waves.

Figure 6-1 **Projected annual average temperature**

Annual average temperatures across North America are projected to increase, with proportionally greater changes at higher as compared to lower latitudes, and under a higher scenario (RCP8.5, right) as compared to a lower one (RCP4.5, left). This figure compares (top) observed change for 1986–2016 (relative to 1901–1960 for the contiguous United States and 1925–1960 for Alaska, Hawaiʻi, Puerto Rico, and the U.S. Virgin Islands) with projected differences in annual average temperature for mid-century (2036–2065, middle) and end-of-century (2070–2099, bottom) relative to the near-present (1986–2015).



Precipitation patterns have changed, with some areas receiving more precipitation, some less, and warmer temperatures leading to a higher proportion of precipitation falling as rain than snow as compared to the past. Heavy precipitation events in most parts of the United States have increased in both intensity and frequency. Figure 2-4 in Chapter 2 illustrates these observed changes. Heavy precipitation events are projected to continue to increase over the 21st century with important regional and seasonal differences. The largest increases are expected to occur in the northeastern U.S.

The average sea level across the globe has risen at an alarming rate, with about 7 cm of rise occurring just since 1993. The sea level will continue to rise for the rest of this century and beyond, with very high confidence that the global mean sea level rise will be more than 30 cm by 2100 and only low confidence that it will be less than 130 cm. Research into ice sheet stability will establish a higher confidence upper bound to projected sea level rise. Relative sea level rise varies along U.S. coastlines, with above average sea level rise likely in the Northeast and the western Gulf of Mexico, and likely in other areas of the U.S. as well in higher emissions scenarios. With higher sea levels, tidal floods are accelerating and will continue to increase in depth, frequency, and extent. Coastal storm events will also bring about greater extreme flooding.

Recent droughts and heat waves have reached record intensity in some regions of the United States. Higher temperatures are driving increased evapotranspiration, reducing soil moisture. Further decreases in soil moisture are likely as the climate warms. This, along with the reduction in snowpack in the western U.S., means that chronic, long-duration hydrological drought is increasingly likely. This combination of factors has led to the increase in large forest fires in the western U.S. and Alaska, and forest fires are projected to further increase, with profound changes to certain ecosystems.[187]

VULNERABILITY ASSESSMENT

Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth. In a 2017 report, the U.S. Government Accountability Office reviewed two modeling frameworks focused on the U.S. with internally consistent climate and socioeconomic scenarios to analyze a broad range of sectoral impacts, finding that fiscal risks to the federal government could be large and that effects could be unevenly distributed across sectors and regions (GAO, 2017).[188] This section of the report describes identified vulnerabilities and summarizes some of the actions taken to address these vulnerabilities.

EPA's Climate Impacts and Risk Analysis (CIRA) project quantified potential physical and economic damages of climate change to 22 sectors in the U.S.[189],[190] Projected impacts and damages across sectors reveal highly complex patterns, with each region of the country projected to experience a unique mix of physical and economic effects, with some regions experiencing compounding impacts (i.e., high vulnerability across multiple impact sectors, such as poor air quality and extreme temperature mortality).

NCA4 found that impacts in many sectors fall disproportionately on those communities that are least able to anticipate, cope with, and recover from adverse impacts. For instance, it concluded that populations experiencing greater health risks include children, older adults, low-income communities, and some communities of color. To investigate these potential disparities, EPA released a report Climate Change and Social Vulnerability in the United States: A Focus on Six

Impacts quantifying the degree to which four socially vulnerable populations— defined based on income, educational attainment, race and ethnicity, and age—may be more exposed to the highest impacts of climate change.[191]

Many of the sectors impacted by the physical changes described in the previous section and leading to unevenly distributed impacts are crucial to the health and economic wellbeing of people in the U.S., including those summarized in this section.

Water Resources and infrastructure

Water systems in the United States face considerable risk, even without anticipated future climate changes. Across the nation, much of the critical water and wastewater infrastructure is nearing the end of its useful life. Limited surface water storage, as well as a limited ability to make use of long-term drought forecasts and to trade water across uses and basins, has led to a significant depletion of aquifers in many regions in the country. Across the nation, much of the critical water and wastewater infrastructure is nearing the end of its useful life. Especially over the Ogallala Aquifer region, adaptive management strategies may be prevalent given large crop insurance payouts due to drought, less irrigation water availability, and a declining water table.[192]

A central challenge to water planning and management is learning to plan for plausible future climate conditions that are wider in range than those experienced in the 20th century. Doing so requires approaches that evaluate plans over many possible futures instead of just one, incorporate real-time monitoring and forecast products to better manage extremes when they occur, and update policies and engineering principles based on an understanding and projection of climate-related changes.

While this represents a break from historical practice, recent examples of adaptation responses undertaken by large water management agencies, including major metropolitan water utilities and the U.S. Army Corps of Engineers, are promising. New York City, for example, altered existing operational guidelines to implement adaptive reservoir operations based on current hydrologic conditions to better meet new concerns for ecological flow requirements in addition to water supply goals.[193] Tampa Bay Water employed 1,000 realizations of future demand and future supply to evaluate their preparedness for future conditions.[194] In another example, the International Joint Commission adopted a new operating plan for Upper Great Lakes water levels; the plan is based on the ability to provide acceptable performance, as defined by stakeholders, over thousands of possible future climates.[195] The plan includes forecast-based operations and a funded adaptive management process linking observatories and information systems to water-release decisions to address unanticipated change.[196] The U.S. Army Corps of Engineers is exploring robustness to a wide range of trends and expected regret as metrics for evaluating flood management strategies,[197] including the increased incorporation of natural infrastructure.198

Energy Infrastructure

The United States' economic security is dependent on an affordable and reliable supply of energy. Every sector of the economy depends on energy, from manufacturing to agriculture, banking, healthcare, telecommunications, and transportation. Increasingly, climate change and extreme weather events are affecting the energy system, threatening more frequent and longer-lasting power outages and fuel shortages. Such events can have cascading impacts on other critical sectors, potentially affecting the nation's economic and national security.

Hurricane Harvey, which struck Houston, Texas, in August 2017, provides a clear example of how impacts from extreme weather events can cascade through tightly connected natural, built, and social systems exposed to severe climate-related stressors. Harvey knocked out power to 300,000 customers in Texas,[199] with cascading effects on critical infrastructure facilities such as hospitals, water and wastewater treatment plants, and refineries. Eleven percent of U.S. refining capacity and a quarter of oil production from the U.S. Gulf of Mexico were shut down. Actual and anticipated gasoline shortages caused price spikes regionally and nationally. The energy sector is undergoing substantial policy, market, and technology-driven changes that are projected to affect this type of vulnerability.

The impacts of extreme weather and climate change on energy systems will differ across the United States. Low-lying energy facilities and systems located along inland waters or near the coasts are at elevated risk of flooding from more intense precipitation, rising sea levels, and more intense hurricanes. Increases in the severity and frequency of extreme precipitation are projected to affect inland energy infrastructure in every region. Rising temperatures and extreme heat events are projected to reduce the generation capacity of thermoelectric power plants and decrease the efficiency of the transmission grid. Rising temperatures are projected to also drive greater use of air conditioning and increase electricity demand, likely resulting in increases in electricity costs and energy burden for disadvantaged communities. The increase in annual electricity demand across the country for cooling is offset only marginally by the relatively small decline in electricity demand for heating. Extreme cold events, including ice and snow events, can damage power lines and impact fuel supplies. Severe drought, along with changes in evaporation, reductions in mountain snowpack, and shifting mountain snowmelt timing, is projected to reduce hydropower production and threaten oil and gas drilling and refining, as well as thermoelectric power plants that rely on surface water for cooling. Drier conditions are projected to increase the risk of wildfires and damage to energy production and generation assets and the power grid.

Coastal Economies

Rising water temperatures, ocean acidification, retreating Arctic sea ice, sea level rise, high-tide flooding, coastal erosion, higher storm surge, and heavier precipitation events threaten our oceans and coasts. These effects are projected to continue, putting ocean and marine species at risk, decreasing the productivity of certain fisheries, and threatening communities that rely on marine ecosystems for livelihoods and recreation, with particular impacts on fishing communities in Hawai‘i and the U.S.-Affiliated Pacific Islands, the U.S. Caribbean, and the Gulf of Mexico.

Lasting damage to coastal property and infrastructure driven by sea level rise and storm surge is expected to lead to financial losses for individuals, businesses, and communities, with the Atlantic and Gulf Coasts facing above-average risks. Impacts on coastal energy and transportation infrastructure driven by sea level rise and storm surge have the potential for cascading costs and disruptions across the country. Nationally, a sea level rise of 1 meter could expose dozens of power plants that are currently out of reach to the risks of a 100-year flood (a flood having a 1 percent chance of occurring in a given year). This would put an additional cumulative total of 25 gigawatts (GW) of operating or proposed power capacities at risk.[48] In Florida and Delaware, sea level rise of 1 meter would double the number of vulnerable plants (putting an additional 11 GW and 0.8 GW at risk in the two states, respectively); in Texas, vulnerable capacity would more than triple (with an additional 2.8 GW at risk).

Even if significant emissions reductions occur, many of the effects from sea level rise over this century—and particularly through mid-century—are already locked in due to past emissions, and many communities are already dealing with the consequences. Actions to plan for and adapt to more frequent, widespread, and severe coastal flooding, such as shoreline protection and conservation of coastal ecosystems, would decrease direct losses and cascading impacts on other sectors and parts of the country. More than half of the damages to coastal property are estimated to be avoidable through well-timed adaptation measures. Substantial and sustained reductions in global greenhouse gas emissions would also significantly reduce projected risks to fisheries and communities that rely on them.

Agriculture

Climate change presents numerous challenges to sustaining and enhancing crop productivity, livestock health, and the economic vitality of rural communities. While some regions (such as the Northern Great Plains) may see conditions conducive to expanded or alternative crop productivity over the next few decades, overall, yields from major U.S. crops are expected to decline as a consequence of increases in temperatures and possibly changes in water availability, soil erosion, and disease and pest outbreaks. In 2012, severe drought impacted 80 percent of agricultural land in the United States, causing more than two-thirds of its counties to be declared disaster areas. The drought greatly affected livestock, wheat, corn, and soybean production in the Great Plains and Midwest and accounted for $14.5 billion in loss payments by the federal crop insurance program. In 2015, drought impacts to California's agricultural sector resulted in $1.84 billion in direct costs and a loss of 10,100 seasonal jobs.[200]

Increases in temperatures during the growing season in the Midwest are projected to be the largest contributing factor to declines in the productivity of U.S. agriculture. Projected increases in extreme heat conditions are expected to lead to further heat stress for livestock, which can result in large economic losses for producers. Climate change is also expected to lead to large-scale shifts in the availability and prices of many agricultural products across the world, with corresponding impacts on U.S. agricultural producers and the U.S. economy. These changes threaten future gains in commodity crop production and put rural livelihoods at risk. Numerous adaptation strategies are available to cope with adverse impacts of climate variability and change on agricultural production. These include altering what is produced, modifying the inputs used for production, adopting new technologies, and adjusting management strategies. However, these strategies have limits under severe climate change impacts and would require sufficient long – and short-term investment in changing practices.

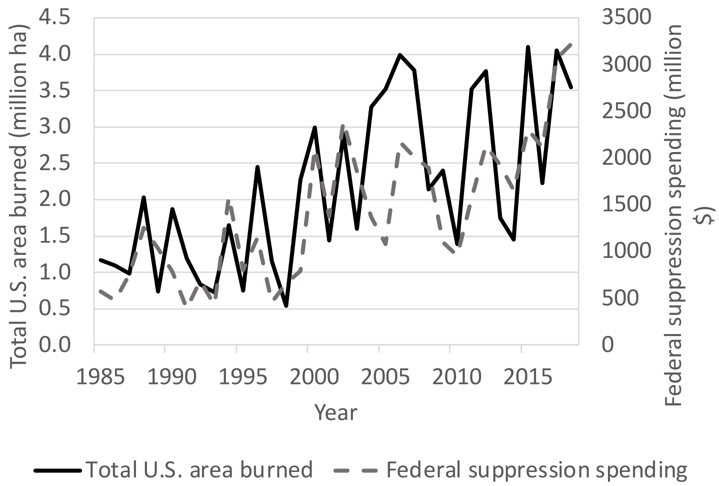
Forests

Over the past two decades, a warm, dry climate has contributed to an increased area burned across the western United States.[201] Increased temperatures, drier conditions, and longer fire seasons with climate change will likely lead to increased fire frequency, area burned, and incidence of large fires in fire-prone forests across the country, including those in the West and Southeast.[202,203] Annual area burned in the U.S. may increase by 2-6 times by mid-21st century compared to present, depending on ecosystem and local climate.[204,205,206] Wildfires will also likely be more difficult to suppress[207], with climbing costs for fire suppression. These changes in fire under projected climate change will likely result in increased smoke production, with implications for human health.[208,209,210] Decreases in forest stand density, coupled with hazardous fuel treatments, can increase forest resilience to fire. However, fuel treatments must be maintained over time to remain effective.[211]

Increasing extremes in precipitation, hurricanes, decreasing snowpack accumulation, and increasingly severe heatwaves are producing a number of other risks for forests and infrastructure supporting forest management and recreation. In many parts of the country worsening drought conditions are causing forest mortality through insect outbreaks, disease, and wildfire.[212] Drought-related mortality and resultant time-concentrated thinning and harvest efforts are producing shocks to lumber supplies for mills,[213],[214] yielding reduced investment and more mobile or temporary investments in mills in the western U.S.

Floods are endangering roads and bridges used to access forests for management, harvest, and recreation. Hydrologic projections are being used to improve road facility design and location in light of expected changes.[215] Increased drought, flooding, and heat waves are also disrupting water-related ecosystem services from forests, such as provision of clean drinking water and miles of high-quality aquatic habitat.[216] Riparian restoration activities, including development of more complex channels that better connect with floodplains, increase local habitat quality, reduce downstream flooding, and reduce thermal shocks to streams.[217]

Figure 6-2 **Total Wildfire Area Burned, and Federal Fire Suppression Spending**

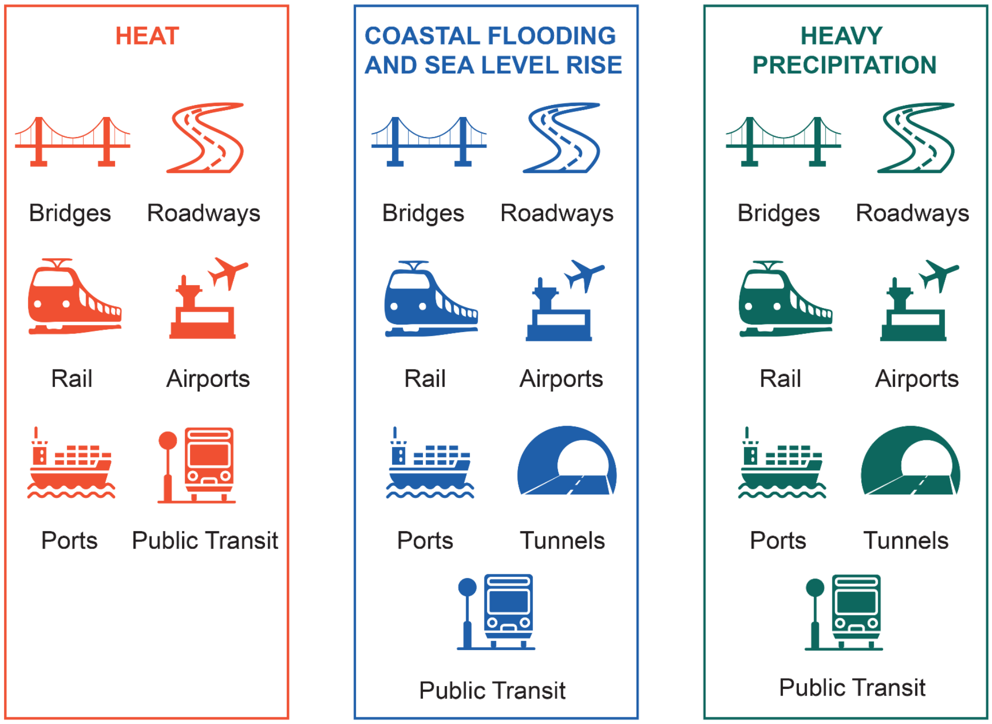


Annual wildfire area burned in the United States, and annual Federal wildfire suppression expenditures, scaled to constant 2016 U.S. dollars (Consumer Price Index deflated). Trends for both area burned and wildfire suppression indicate about a four-fold increase over a 30-year period. (Source: National Interagency Fire Center, U.S. Bureau of Labor Statistics).

Transportation

Transportation is the backbone of economic activity, connecting manufacturers with supply chains, consumers with products and tourism, and people with their workplaces, homes, and communities across both urban and rural landscapes. However, the ability of the transportation sector to perform reliably, safely, and efficiently is undermined by a changing climate. Heavy precipitation, coastal flooding, heat, wildfires, freeze–thaw cycles, and changes in average precipitation and temperature impact individual assets across all modes. These impacts threaten the performance of the entire network, with critical ramifications for economic vitality and mobility, particularly for vulnerable populations and urban infrastructure.

Figure 6-3 **Climate Change and Notable Vulnerabilities of Transportation Assets**



Heavy precipitation, coastal flooding, heat, and changes in average precipitation and temperature affect assets (such as roads and bridges) across all modes of transportation. The figure shows major climate-related hazards and the transportation assets impacted. Photos illustrate national performance goals (listed in 23 U.S.C. § 150) that are at risk due to climate-related hazards. Source: USGCRP.

Sea level rise is progressively making coastal roads and bridges more vulnerable and less functional. On the U.S. East Coast alone, more than 7,500 miles of roadway are located in high tide flooding zones.[218] Many coastal cities across the United States have already experienced an increase in high tide flooding that reduces the functionality of low-elevation roadways, rail, and bridges, often causing costly congestion and damage to infrastructure. US Route 17 in Charleston, South Carolina, for example, currently floods more than 10 times per year and is expected to experience up to 180 floods annually by 2045, with each flood costing the city approximately $13.75 million (in 2015 dollars).[219]

Inland transportation infrastructure is highly vulnerable to intense rainfall and flooding. Inland flooding, projected to increase over the coming century, threatens approximately 2,500 to 4,600 bridges across the United States and is anticipated to result in average annual damages of $1.2 to $1.4 billion each year by 2050 (in 2015 dollars, undiscounted, five-model average).[220] In some regions, the increasing frequency and intensity of heavy precipitation events reduce transportation system efficiency and increase accident risk.

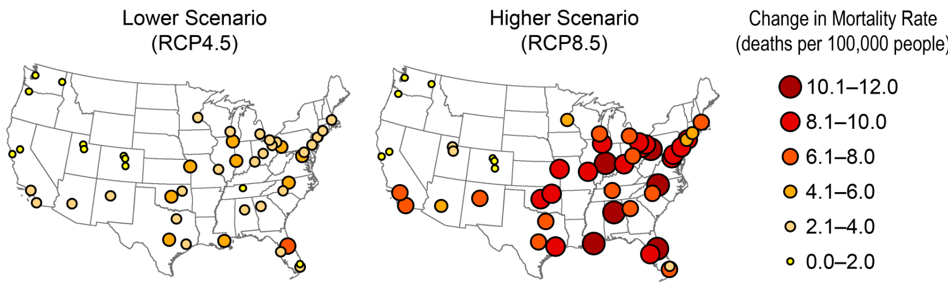
Record-breaking summer temperatures and heat waves have immediate and long-term impacts on transportation. Across the United States, 5.8 million miles of paved roads are susceptible to increased rutting, cracking, and buckling when sustained temperatures exceed 90°F.[221] High temperatures can stress bridge integrity and have caused more frequent and extended delays to passenger and freight rail systems and air traffic.

Transportation is not only vulnerable to impacts of climate change but also contributes significantly to the causes of climate change. In 2016, the transportation sector became the top contributor to U.S. greenhouse gas emissions. The transportation system is rapidly growing and evolving in response to market demand and innovation. This growth could make climate mitigation and adaptation progressively more challenging to implement and more important to achieve. However, transportation practitioners are increasingly invested in addressing climate risks, as evidenced in more numerous and diverse assessments of transportation sector vulnerabilities across the United States.

Human Health

Climate change has contributed to health risks. Increasing intensity and frequency of extreme heat can lead to fatalities. These impacts also disproportionately affect disadvantaged communities, Blacks in the US are 52 percent more likely to reside in areas that are prone to heat-related risks, as are non-Hispanic Asians (32 percent) and Hispanics (21 percent), compared with non-Hispanic Whites. Wildfire smoke is also continuing to increase health risk. There are an estimated 7.4 million children in the United States affected by wildfire smoke annually, many of them in the Southeast, Pacific Northwest, and California. The increase in wildfires in recent years suggests that this population at risk has only grown. In parts of the USA, up to 20 percent of the fine particulate matter to which children are exposed results from wildfires. Due to our warming climate, the exposure to wildfire smoke is likely to only increase, with more children exposed to wildfire smoke as the century goes on.

Figure 6-4 **Annual Net Mortality Due to Extreme Hot and Cold Days : 2080-2099 projected vs 1989-2000.**



The maps show estimated changes in annual net mortality due to extremely hot and cold days in 49 U.S. cities for 2080–2099 as compared to 1989–2000. Across these cities, the change in mortality is projected to be an additional 9,300 deaths each year under a higher scenario (RCP8.5) and 3,900 deaths each year under a lower scenario (RCP4.5). Assuming a future in which the human health response to extreme temperatures in all 49 cities was equal to that of Dallas tODAy (for example, as a result of availability of air conditioning or physiological adaptation) results in an approximate 50% reduction in these mortality estimates. For example, in Atlanta, an additional 349 people are projected to die from extreme temperatures each year by the end of century under RCP8.5. Assuming residents of Atlanta in 2090 have the adaptive capacity of Dallas residents tODAy, this number is reduced to 128 additional deaths per year. Cities without circles should not be interpreted as having no extreme temperature impact. Data not available for the U.S. Caribbean, Alaska, or Hawai'i & U.S.-Affiliated Pacific Islands regions. Source: adapted from EPA 2017.[222]

Rising air and water temperatures and more intense extreme events are expected to increase exposure to waterborne and foodborne diseases, affecting food and water safety. The frequency and severity of allergic illnesses, including asthma and hay fever, are expected to increase as a result of a changing climate. Climate change is also projected to alter the geographic range and distribution of disease-carrying insects and pests, exposing more people to ticks that carry Lyme disease and mosquitoes that transmit viruses such as Zika, West Nile, and dengue, with varying impacts across regions. Communities in the Southeast, for example, are particularly vulnerable to the combined health impacts from vector-borne disease, heat, and flooding. Extreme weather and climate-related events can have lasting mental health consequences in affected communities, particularly if they result in degradation of livelihoods or community relocation. Populations including older adults, children, low-income communities, and some communities of color are often disproportionately affected by, and less resilient to, the health impacts of climate change. Adaptation and mitigation policies and programs that help individuals, communities, and states prepare for the risks of a changing climate reduce the number of injuries, illnesses, and deaths from climate-related health outcomes.

ADAPTATION MEASURES

Across the United States, many regions and sectors are already experiencing the direct effects of climate change. For these communities, climate impacts—from extreme storms made worse by sea level rise, to longer-lasting and more extreme heat waves, to increased frequency and severity of wildfires and floods—are an immediate threat, not a far-off possibility. Because these impacts are expected to increase over time, communities throughout the United States face the challenge not only of reducing greenhouse gas emissions, but also of adapting to current and future climate change to help mitigate climate risks. This section describes some of the actions undertaken to adapt to climate change, in addition to the measures taken to address vulnerabilities described above.

For example:

- In Colorado, Denver Water used future climate and socioeconomic development scenarios to explore possible future vulnerabilities and develop robust plans and actions.[223] The water sector is pioneering approaches for incorporating uncertainty in water utility adaptation, including scenarios and other robust decision methods aimed at making successful decisions insensitive to a wide range of uncertainty.[224]
- California is preparing forests and associated ecosystems for climate change by treating public and private land through forest thinning, prescribed fire and reforestation and by hardening homes, buildings and infrastructure.[225] In addition, the State requires its water agencies to address climate change in their water management plans.[226] Ranchers in California are using alternative cattle breeds to cope with extended drought conditions.[227]
- The City of Baltimore, Maryland used climate-informed estimates of increased current and future storm intensity to design its storm water master plan, which includes green space and bio-swales that capture runoff, to improve water quality and reduce flood risk.[228]
- In October 2012, Hurricane Sandy caused unprecedented damage to the electricity system across New York City—flooding shut down one-third of the city's generating capacity and five major substations. More than two million people lost electricity during the storm. Since then, New York City has collaborated with the utility company Con Edison to reduce the potential for future damage from extreme weather events. Based on an extensive review of which assets are most vulnerable to future flooding, Con Edison is strengthening flood barriers, making equipment submersible, raising or relocating critical equipment, reconfiguring networks for greater redundancy and flexibility, replacing vulnerable overhead lines with underground infrastructure, and expanding their use of monitoring sensors, switches, and related smart grid technologies.[229]
- In Northeastern Puerto Rico, private landowners are working with the nongovernmental organization Center for Landscape Conservation and federal agencies to better prepare for hurricanes by integrating climate change in forest management planning. Plans emphasize reforestation after hurricanes, planting and managing for changing future climates, and developing uses for hurricane savaged timber.[230]
- Miami-Dade County's Capital Improvement Program is addressing hazards related to sea level rise include raising roads, installing pump stations, protecting existing buildings with temporary flood panels and building new infrastructures higher.[231]
- The State of Louisiana's Coastal Protection and Restoration Authority's 2017 Coastal Master Plan has more than 100 structural and coastal restoration projects designed to provide benefits over the next decade and up to 50 years into the future.[232]
- In Wisconsin, the Menominee Tribe have adapted forest management practices to address the growing threats of climate change including more prevalent pests and diseases like Oak Wilt, an invasive fungus that kills red oak trees. In their efforts to regenerate areas of the forest disturbed by oak wilt, foresters are planting species more adapted to future conditions. The plantings also help to increase forest diversity, reduce the risks of any one species being negatively impacted by climate or forest health issues, and provide for high-quality forest products in the future.[233]

- After extreme flooding destroyed or damaged nearly 500 miles of public roads, the State of Colorado is rebuilding roadways to be more resilient to future flooding.[234]
- The City of Phoenix, Arizona has an ordinance requiring rental units to have cooling capable of maintaining safe temperatures to avoid the health risks of extreme heat.[235] The City also recently created a new Office of Heat Response and Mitigation to address the growing hazard of urban heat, which threatens the City's economic viability and health and well-being of vulnerable residents.[236]
- In Puerto Rico, natural infrastructure such as mangrove forests and coral reefs are being restored to help provide protection against future storms.[237]

Adaptation takes place at many levels—national and regional leadership is important for providing support, and most adaptation actions are implemented locally —as governments, businesses, communities, and individuals respond to tODAy's altered climate conditions and prepare for future change based on the specific climate impacts relevant to their geography and vulnerability.

While these examples illustrate the breadth of action by cities and states across the country, it remains difficult to tally the extent of adaptation implementation in the United States because there are no common reporting systems, and many actions that reduce climate risk are not labeled as climate adaptation.[238] NCA4 found that community awareness and planning for extreme climate events underway throughout the United States, but there is a shortage of on-the-ground implementation to build community resilience. In general planning and implementation of community resilience is not yet commonplace, or fully integrated throughout society and the economy. Adaptation can generate significant benefits in excess of its costs. Formal benefit analysis is still in its early stages, and more research is needed to assess comprehensively the benefits of specific strategies being considered by individuals and organizations.[239]

Federal agencies of the U.S. Government use a number of mechanisms to increase the pace of adaptation actions and increase community resilience to climate impacts, including these illustrative examples.

- *Funding local action:* The U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) has grant programs to support states and municipalities that take action to increase resilience to future climate impacts and mitigate the damage of natural hazards. The changing intensity, frequency, and duration of various impacts is changing risks and exposing new vulnerabilities, and to prepare for that, FEMA's Hazard Mitigation Assistance Grants fund actions that reduce long-term risk to people and property from future disasters. FEMA's Building Resilient Infrastructure and Communities (BRIC) program offers grants, on a competitive basis, with a special emphasis on climate-related hazards such as wildfires, floods, drought, and extreme heat.

- *Engineering design and implementation*: the U.S. Army Corps of Engineers, part of the Department of Defense, is the nation's largest manager of water resources, and has as its policy to integrate climate change adaptation and actions into its missions, operations, programs, and projects. As an example, its civil works are informed by Engineer Pamphlet 1100-2-1, *Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation*, published in 2019, so that projects consider future conditions, including tipping points and thresholds, and investments are made to be resilient to climate impacts.

- *Guidance and resources*: the Climate Resilience Toolkit, an initiative operated under the U.S. Global Change Research Program and managed by NOAA's Climate Program Office, is designed to help people find and use tools, information, and subject matter expertise to build resilience. The Toolkit builds on agency resources from across the government and is designed to improve people's ability to understand and manage their climate-related risks and opportunities, and to help them make their communities and businesses more resilient to extreme events. The Toolkit includes case studies, the "Steps to Resilience" framework to help guide decision-making, and the Climate Explorer, an interactive tool to view historic and projected climate parameters for any county in the contiguous United States, as well as other resources.

- *Information about current and coming risks:* the National Risk Index for Natural Hazards offers information about 18 natural hazards – actually or potentially aggravated by climate change – and offers data about expected annual losses, magnitude of vulnerability, and community resilience. It is designed to give planners and citizens a "snapshot" of existing risks and to motivate further steps toward adaptation and resilience.

- *Use-inspired research:* To help plan and design water treatment systems to prevent overflow of untreated water into rivers, lakes, and other water bodies, EPA scientists are investigating the increased occurrence and intensity of extreme precipitation events. This research is important to help states, cities, and communities better prepare for increases in precipitation to reduce potential public health and environmental impacts. The information also can enable cities and rural areas to better prepare and respond to frequent flooding from extreme precipitation to protect public health and property.

- *Coordination*: the U.S. Global Change Research Program coordinates the interagency Federal Adaptation and Resilience Group (FARG), which brings together over 100 experts from bureaus and agencies across the Federal Government. The FARG fosters collaboration to increase the resilience of federal investments to climate change impacts. This is done by sharing information and experience, producing publications, and supporting co-investment and co-development of tools and information resources to help agencies align their climate adaptation strategies and priorities.

As noted above, climate change will impact many sectors and regions of the United States, and so adaptation measures will have to address many fronts. Below are examples of federal agencies taking adaptation actions in response to the vulnerabilities identified above.

Water Infrastructure

EPA's Office of Water is supporting water utilities nationwide in preparing for the impacts of climate change through many publicly available tools and resources. For example, the Climate Resilience Evaluation and Awareness Tool (CREAT) is a risk assessment application that helps utilities adapt to climate change impacts by providing a better understanding of current and long-term weather conditions. Utility managers and policy makers can find out which extreme weather events pose significant challenges in their area and build scenarios to identify potential impacts, identify critical assets and potential actions to protect those assets from the consequences of extreme weather on utility operations, and generate reports describing the costs and benefits of risk reduction strategies. CREAT is just one of a range of tools and resources available under the Creating Resilient Water Utilities initiative.

Coastal Impacts

To address the impacts of climate change on coastal ecosystems and the services that they provide, the Fish and Wildlife Service's Coastal Program restores and protects fish and wildlife habitat on public and privately-owned lands. In 2020, the program restored more than 8,600 acres across priority coastal areas, along the Atlantic and Pacific Oceans, Gulf of Mexico, Great Lakes, and in the Caribbean. Working with partners, locally-based program staff provide technical assistance for habitat conservation design and planning, and financial assistance for habitat restoration and protection projects.

States and territories that participate in the National Coastal Zone Management Program, a state-federal partnership with NOAA, are working to enhance resilience to coastal hazards. State and territorial coastal management programs provide information, guidance, and resources to support community-resilience efforts. They are also working to integrate information on coastal hazards into policies and planning efforts.

Agriculture and Forestry

USDA addresses climate adaptation through many of its programs and activities, one example of which is the Climate Hubs, a unique cross-agency collaboration. The USDA Climate Hubs[240] develop and deliver science-based information and technologies to natural resource and agricultural managers to enable climate-informed decision making, reduce agricultural risk, and build resilience to climate change. Since 2014, the ten regional Climate Hubs have been helping farmers, ranchers, forest and land managers, and rural communities plan for and manage weather – and climate-related risks and vulnerabilities. The Climate Hubs are a unique collaboration across USDA's agencies. The regional Hubs are led and hosted by the Agricultural Research Service and United States Forest Service, with contributions from many USDA agencies including the NRCS, among others. The Climate Hubs link USDA research and program agencies in their regional delivery of timely and authoritative tools and information to forest managers, farmers, ranchers and other stakeholders.

The Climate Hubs are a focal point for delivering accessible, usable research and tools for both climate adaptation and mitigation in the agriculture and forestry sectors and rural economies, towards building resilience. The USDA Climate Hubs' work focuses on three main areas: 1) science and data synthesis, 2) tool and technology co-development and support and 3) outreach, convening, and training to help stakeholders implement climate-smart adaptation strategies. In each of these areas, the Hubs work closely with extension organizations, universities, technical service providers, and the private sector to be a source of user-friendly information and tool developed from a wide variety of sources. The Hubs work at the regional, state, Tribal and local levels to improve access to usable regional information and climate change projections and forecasts in support of risk management and climate adaptation planning.

At USDA, investments in soil and forest health also help to build resilience on working lands across the landscape. Through the technical and financial assistance of its conservation programs, its planning resources and tools, and technical guidance on appropriate plant materials and timing, NRCS works with producers to alleviate immediate climate impacts including from drought, implement practices to address resource concerns that may be exacerbated in a changing climate, and adapt their operations to build long term resilience.

Transportation

The Federal Highway Administration (FHWA) under the Department of Transportation published a Vulnerability Assessment and Adaptation Framework in 2017 as a manual to help transportation agencies and their partners assess the vulnerability of transportation infrastructure and systems to extreme weather and climate effects. It also can help agencies integrate climate adaptation considerations into transportation decision-making. In addition, in 2019 the FHWA published an Implementation Guide for Nature-based Solutions for Coastal Highway Resilience, which is designed to help transportation practitioners understand how and where nature-based solutions can be used to improve the resilience of coastal roa

Human Health

CDC's Climate and Health Program helps states, cities, territories, and tribes protect human health from a changing climate. CDC provides data, tools, and technical guidance to help U.S. health agencies reduce vulnerability and increase resilience to the health effects of climate change.

CDC's Climate-Ready States and Cities Initiative (CRSCI) funds 16 state and two city health departments. CRSCI grantees use the Building Resilienc e Against Climate Effects (BRACE) framework to identify likely climate impacts in their communities, potential health effects associated with these impacts, and their most at-risk populations and locations. The BRACE framework then helps states develop and implement health adaptation plans and address gaps in critical public health functions and services.

For example, in 2018, CRSCI supported Minnesota Climate & Health Program to conduct a vulnerability assessment related to flooding and private wells. The assessment found 22,000 private wells in floodplains, spurring new collaborations with other programs within the Minnesota Department of Health. Staff in the Well Management Section prioritized efforts to enhance services and improve communications for private well users impacted by or preparing for a flood.

In New York City, CRSCI supported the Be A Buddy (BAB) pilot project to increase local climate resilience. Launched in 2017, BAB aims to strengthen relationships between residents and local organizations to reduce vulnerabilities to extreme heat and other weather emergencies in four low-income communities in New York City. Participating community organization partners implemented risk assessment screenings to identify residents at greater risk for heat-related illness and recruited and trained 64 volunteers to their “Be A Buddy networks” to check on those at-risk residents. In 2018-2019, they activated 17 times for extreme heat and winter/cold weather events, reaching 454 at-risk residents by phone or in person during the activations.

BUILDING ON PROGRESS

In the last several years, major progress has been made on adaptation planning and implementation across all levels of government in the United States. At the national level, NCA4 is a major step forward in building both scientific understanding and important partnerships focused on reducing risk, and the forthcoming NCA5 is expected to further advance this work. Although much more work needs to be done both domestically and internationally, the U.S. has made major progress since publishing the Sixth National Communication in 2014. Future reports will highlight this work.

184 https://www.cftc.gov/sites/default/files/2020-09/9-9-20%20Report%20of%20the%20Subcommittee%20on%20Climate-Related%20Market%20Risk%20-%20Managing%20Climate%20Risk%20in%20the%20U.S.%20Financial%20System%20for%20posting.pdf

185 https://www.cbo.gov/system/files/2020-09/56505-Climate-Change.pdf

186 4th NCA Climate Science Special Report. https://science2017.globalchange.gov/downloads/CSSR2017_FullReport.pdf

187 Vose, James M.; Clark, James S.; Luce, Charles H.; Patel-Weynand, Toral, eds. 2016. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 289 p.

https://doi.org/10.2737/WO-GTR-93b

188 U.S. Government Accountability Office. 2017. Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure. GAO-17-720

189 Martinich, J., and A. Crimmins (2019). Climate damages and adaptation potential across diverse sectors of the United States. Nature Climate Change, 9, 397–404.

190 EPA, 2017: Multi-model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. EPA 430- R- 17- 001. U.S. Environmental Protection Agency (EPA), Washington, DC

191 EPA. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency, EPA 430-R-21-003. www.epa.gov/cira/social-vulnerability-report

192 Reyes et al., 2019 https://www.sciencedirect.com/science/article/pii/S037837741931368X?via%3Dihub

193 Kolesar, P., and J. Serio, 2011: Breaking the deadlock: Improving water-release policies on the Delaware River through operations research. Interfaces, 41 (1), 18–34. doi:10.1287/inte.1100.0536.

194 Asefa, T., A. Adams, and N. Wanakule, 2015: A level-of-service concept for planning future water supply projects under probabilistic demand and supply framework. JAWRA Journal of the American Water Resources Association, 51 (5), 1272–1285. doi:10.1111/1752-1688.12309

195 Brown, C., W. Werick, W. Leger, and D. Fay, 2011: A decision-analytic approach to managing climate risks: Application to the Upper Great Lakes. JAWRA Journal of the American Water Resources Association, 47 (3), 524–534. doi:10.1111/j.1752-1688.2011.00552.x.

196 IUGLSB, 2012: Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels. Final Report to the International Joint Commission. March 2012. International Upper Great Lakes Study Board, Ottawa, ON , 236 pp.

197 Spence, C. M., and C. M. Brown, 2016: Nonstationary decision model for flood risk decision scaling. Water Resources Research, 52 (11), 8650–8667. doi:10.1002/2016WR018981

198 Poff, N. L., C. M. Brown, T. E. Grantham, J. H. Matthews, M. A. Palmer, C. M. Spence, R. L. Wilby, M. Haasnoot, G. F. Mendoza, K. C. Dominique, and A. Baeza, 2016: Sustainable water management under future uncertainty with eco-engineering decision scaling. Nature Climate Change, 6, 25–34. doi:10.1038/nclimate2765

199 ERCOT, 2017: ERCOT Responds to Hurricane Harvey [web page]. Electric Reliability Council of Texas (ERCOT), http://www.ercot.com/help/harvey

200 https://www.drought.gov/sectors/agriculture

201 Abatzoglou, J.T. and C.A. Kolden, 2013: Relationships between climate and macroscale area burned in the western United States. International Journal of Wildland Fire 22 (7): 1003–1020. Figure 1

202 Barbero, R., J.T. Abatzoglou, N.K. Larkin, C.A. Kolden, and B. Stocks. 2015. Climate change presents increased potential for very large fires in the contiguous United States. International Journal of Wildland Fire 24: 892–899.

203 Liu, Z., M.C. Wimberly, A. Lamsal, T.L. Sohl, and T.J. Hawbaker, 2015: Climate change and wildfire risk in an expanding wildland–urban interface: A case study from the Colorado Front Range Corridor. Landscape Ecology 30 (10): 1943–1957.

204 McKenzie, D., Z. Gedalof, D.L. Peterson, and P. Mote, P. 2004. Climatic change, wildfire, and conservation. Conservation Biology 18: 890−902.

205 Litschert, S.E., T.C. Brown, and D.M. Theobald, 2012: Historic and future extent of wildfires in the Southern Rockies ecoregion, USA. Forest Ecology and Management 269: 124–133.

206 Kitzberger, T., D.A. Falk, A.L. Westerling, and T.W. Swetnam, T.W. 2017. Direct and indirect climate controls predict heterogeneous early-mid 21st century wildfire burned area across western and boreal North America. PloS ONE 12: e0188486.

207 Fried, J.S., J.K. Gilless, W.J. Riley, T.J. Moody, C.S. De Blas, K. Hayhoe, M. Moritz, S. Stephens, and M. Torn. 2008. Predicting the effect of climate change on wildfire behavior and initial attack success. Climatic Change 87: 251–264.

208 McKenzie, D., U. Shankar, R.E. Keane, E.N. Stavros, W.E. Heilman, D.G. Fox, and A.C. Riebau. 2014. Smoke consequences of new wildfire regimes driven by climate change. Earth's Future 2(2): 35–59.

209 Stavros, E.N., D. McKenzie, and N. Larkin. 2014. The climate–wildfire–air quality system: interactions and feedbacks across spatial and temporal scales. Wiley Interdisciplinary Reviews: Climate Change 5(6): 719–733.

210 Litschert et al. 2012, Kitzberger et al. 2017

211 Agee. J.K., and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211: 83–96.

212 Vose, J. M., Clark, J. S., Luce, C. H., Patel-Weynand, T. (Eds.), 2016. Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis. Gen. Tech. Rep. WO-93b. U.S. Department of Agriculture, Forest Service, Washington Office, Washington, D.C.

213 Insley, M., Lei, M., 2007, Hedges and trees: incorporating fire risk into optimal decisions in forestry using a no-arbitrage approach, Journal of Agricultural and Resource Economics, 492-514.

214 Sims, C., 2011, Optimal timing of salvage harvest in response to a stochastic infestation, Natural Resource Modeling, 24, 383-408.

215 Vose, J. M., Peterson, D. L., Domke, G. M., Fettig, C. J., Joyce, L. A., Keane, R. E., Luce, C. H., Prestemon, J. P., L.E. Band, Clark, J. S., Cooley, N. E., D'Amato, A., J.E. Halofsky. 2018. Forests [Ch. 6], pp. 232-267, In Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L. M., Maycock, T. K., and Stewart, B. C., editors. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program, Washington, DC, USA.

216 Wenger, S. J., Isaak, D. J., Luce, C. H., Neville, H. M., Fausch, K. D., Dunham, J. B., Dauwalter, D. C., Young, M. K., Elsner, M. M., Rieman, B. E., Hamlet, A. F., Williams, J. E., 2011, Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change, Proceedings of the National Academy of Sciences, 108, 14175-14180, doi:10.1073/pnas.1103097108

217 Luce, C. H., Morgan, P., Dwire, K., Isaak, D., Holden, Z., Rieman, B. 2012. Climate Change, Forests, Fire, Water, and Fish: Building resilient landscapes, streams, and managers, General Technical Report RMRS-GTR-290. USDA Forest Service, Fort Collins, CO.

218 Jacobs, J. M., L. R. Cattaneo, W. Sweet, and T. Mansfield, 2018: Recent and future outlooks for nuisance flooding impacts on roadways on the US East Coast. Transportation Research Record, doi:10.1177/0361198118756366.

219 Sweet, W. V., R. E. Kopp, C. P. Weaver, J. Obeysekera, R. M. Horton, E. R. Thieler, and C. Zervas, 2017: Global and Regional Sea Level Rise Scenarios for the United States. NOAA Tech. Rep. NOS CO-OPS 083. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 75 pp. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

220 EPA, 2017: Multi-model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. EPA 430- R- 17- 001. U.S. Environmental Protection Agency (EPA), Washington, DC, 271 pp. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=OAP&dirEntryId=335095

221 Childress, A., E. Gordon, T. Jedd, R. Klein, J. Lukas, and R. McKeown, 2015: Colorado climate change vulnerability

study. University of Colorado Boulder and Colorado State University, Boulder and Fort Collins, CO, 176 pp. https://wwa.colorado.edu/climate/co2015vulnerability/

222 EPA, 2017: Multi-model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. EPA 430- R- 17- 001. U.S. Environmental Protection Agency (EPA), Washington, DC, 271 pp. URL

223 Stratus Consulting and Denver Water, 2015: Embracing uncertainty: A case study examination of how climate change is shifting water utility planning. Prepared for the Water Utility Climate Alliance (WUCA), the American Water Works Association (AWWA), the Water Research Foundation (WRF), and the Association of Metropolitan Water Agencies (AMWA) by Stratus Consulting Inc., Boulder, CO (Karen Raucher and Robert Raucher) and Denver Water, Denver, CO (Laurna Kaatz). Stratus Consulting, Boulder, CO, various pp. URL.

224 Stratus Consulting and Denver Water, 2015: Embracing uncertainty: A case study examination of how climate change is shifting water utility planning. Prepared for the Water Utility Climate Alliance (WUCA), the American Water Works Association (AWWA), the Water Research Foundation (WRF), and the Association of Metropolitan Water Agencies (AMWA) by Stratus Consulting Inc., Boulder, CO (Karen Raucher and Robert Raucher) and Denver Water, Denver, CO (Laurna Kaatz). Stratus Consulting, Boulder, CO, various pp https://www.wucaonline.org/assets/pdf/pubs-uncertainty.pdf

225 https://fmtf.fire.ca.gov/media/cjwfpckz/californiawildfireandforestresilienceactionplan.pdf

226 https://nca2018.globalchange.gov/chapter/28/

227 Heritage Genetics to Increase Cattle Resilience during Drought (arcgis.com); Criollo cattle: Heritage Genetics for Arid Landscapes–ScienceDirect

228 https://nca2018.globalchange.gov/chapter/28/

229 https://toolkit.climate.gov/case-studies/working-together-keep-lights-new-york-city

230 Plan de Manejo–Centro para la Conservación del Paisaje (conpaisaje.org)

231 https://www.miamidade.gov/global/economy/resilience/sea-level-rise-flooding.page

232 Coastal Protection and Restoration Authority of Louisiana, 2017: Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana, Baton Rouge, LA, 171 pp. https://coastal.la.gov/our-plan/2017-coastal-master-plan/

233 https://toolkit.climate.gov/case-studies/and-trees-will-last-forever

234 https://toolkit.climate.gov/case-studies/rebuilding-roads-maximize-resilience

235 https://www.phoenix.gov/nsdsite/Documents/3rd%20draft%20Our%20Neighborhood%20Newsletter%20Summer%202016_ENGLISH.pdf

236 https://www.phoenix.gov/newsroom/city-manager/2060

237 https://www.nfwf.org/2020-conservation-investments/puerto-rico

238 Vogel, J., K. M. Carney, J. B. Smith, C. Herrick, M. Stults, M. O'Grady, A. S. Juliana, H. Hosterman, and L. Giangola, 2016: Climate Adaptation–The State of Practice in U.S. Communities. Kresge Foundation, Detroit. http://kresge.org/sites/default/files/library/climate-adaptation-the-state-of-practice-in-us-communities-full-report.pdf

239 https://nca2018.globalchange.gov/chapter/28/

240 https://www.climatehubs.usda.gov

7

SUPPORTING THE GLOBAL COMMUNITY– MOBILIZING SUPPORT TO DRIVE CLIMATE AMBITION

INTRODUCTION

The United States is committed to leading efforts to mobilize resources for developing countries in their efforts to mitigate and adapt to climate change. This includes helping communities anticipate, prepare for and manage climate change impacts, establishing the enabling conditions for climate-resilient, low-emissions development; facilitate the establishment of high-integrity markets; supporting partner countries to establish and achieve ambitious NDC targets; and mobilizing public and private climate finance. Tackling the climate crisis is a central priority for U.S. foreign policy and national security and has been integrated into the core operations of all major U.S. foreign assistance agencies.

Climate finance, technology transfer, and capacity building are fundamental to these efforts. The United States is using the full range of institutions—bilateral and multilateral—to scale up financial flows for climate action, mobilize public and private finance, and invest strategically in a sustainable future. This includes: building lasting resilience to unavoidable climate impacts; reducing emissions land through conservation, sustainable management, and restoration; supporting the transition to clean energy production; and supporting the transition to whole-of-economy low-carbon development. The United States is working to ensure that its capacity-building and investment support is efficient, effective, innovative, based on country-owned plans and strategies, and focused on achieving measurable results with a long-term view toward economic and environmental sustainability.

Climate change and its impacts on developing countries represents one of the greatest impediments to sustainable and equitable development. As noted in Chapter 6, social groups that experience systemic and intersecting forms of discrimination, injustice, and insecurity are also at risk of compounded and increasingly harmful climate impacts. Inclusive climate action employs an intersectional approach that recognizes the multiple and confounding vulnerabilities, insecurity, and threats that these populations face. Inclusive climate action centers on those in geographically- and socially-vulnerable sitiations and empowers them as sources of solutions and agents of positive change, as they possess unique knowledge and networks.

The United States has made tackling the climate crisis at home and abroad a top priority. The climate crisis represents an existential threat to the security and prosperity of communities around the world. At the same time, responding to the climate crisis offers one of the greatest opportunities in history for innovation, sustainable economic growth, and the creation of high-quality jobs. The United States has consistently maintained support for developing countries to address the climate crisis, including through technical assistance, capacity building, technology development and transfer, and investments. The Biden Administration is committed to enhancing this leadership, and has pledged to work with Congress to quadruple, by 2024, its annual public climate finance to developing countries, relative to the previous high-water mark for U.S. climate finance, FY 2013-2016. Further, the United States intends to increase our adaptation finance six-fold over the same period. Future reports will contain additional detail on this renewed leadership.

The United States also continues to work with other developed countries to collectively mobilize $100 billion per year in climate finance as soon as possible, drawing on a wide variety of sources to support the needs and priorities of developing countries, in the context of meaningful mitigation actions and transparency on implementation.

This chapter provides details on U.S. climate finance by channels and instruments, thematic pillar, and region; describes U.S. efforts to mobilize private climate finance; and illustrates examples of U.S. contributions to capacity building and transfer of technology. It focuses on fiscal years (FY) 2015-2018 (October 1, 2014-September 30, 2018).

FINANCING CLIMATE CHANGE ACTION—OVERVIEW OF U.S. CLIMATE FINANCE IN FYS 2015-2018

Between FY 2015-2018, the United States committed $8.78 billion to help developing countries mitigate and adapt to the adverse effects of climate change, including $5.58 billion in FY 2015-2016 and $3.20 billion in FY 2017-2018. As illustrated in Table 7-1, this finance can be explored across a number of dimensions—including the institutional channels through which it is delivered, the financial instruments used, the geographies targeted, and its ultimate end use in terms of building resilience, reducing emissions, or conserving, restoring, and sustainably-managing land.

Table 7-1 **Dimensions of U.S. Climate Finance**

Channels	Instruments	Geography	Use (or "Pillar")

Bilateral channels
• Grant-based bilateral climate assistance
• Development finance
• Export credit
	• Grants
	• Cooperative agreements
	• Contracts
	• Loans
	  • Concessional
	  • Market Rate
		• Country-specific activities
		• Global, regional, and multicountry activities
			• Adaptation
			• Clean Energy
			• Sustainable Landscapes

Multilateral channels • Multilateral climate change funds • Multilateral development banks (MDBs)	• Guarantees and • insurance		

Climate Finance Channels

The United States provides climate finance through both bilateral and multilateral channels.

Bilateral Channels

From FY 2015-2018, the United States committed more than $6.67 billion in bilateral climate finance to its developing country partners, including $3.77 billion in FY 2015-2016 and $2.90 billion in FY 2017-2018. This finance was provided in one of three forms:

- Grant-based bilateral climate assistance—This finance is programmed directly through country-specific, regional, and global programs. Grant-based programs, and those supported by cooperative agreements and contracts, are mainly administered by the United States Agency for International Development (USAID), but are also supported by the Department of State, the Millennium Challenge Corporation (MCC), and other U.S. government agencies. This assistance amounted to more than $3.38 billion from FY 2015-2018, including $1.89 billion in FY 2015-2016 and $1.49 billion in FY 2017-2018.
- Development finance—The United States, primarily through the Development Finance Corporation (DFC) (formerly the Overseas Private Investment Corporation, OPIC and USAID's Development Credit Authority), is one of the world's largest financiers of clean energy projects in developing countries, committing more than $3.15 billion through bilateral development finance agencies from FY 2015-2018, including $1.76 billion in FY 2015-2016 and $1.39 billion in FY 2017-2018. In addition to standard lending, DFC provides senior secured loans to private equity funds—making it one of the largest supporters of private equity funds in developing countries—and political risk insurance to project lenders and equity investors operating in emerging markets.
- Export credit—From FY 2015-2018, the Export-Import Bank of the United States (EXIM) committed $117.1 million of financing to support climate-specific activities in developing countries, including $109.9 million in FY 2015-2016 and $7.2 million in FY 2017-2018.

Multilateral Channels

- Multilateral climate change funds—These entities feature institutional structures governed jointly by developed and developing countries. They play an important role in promoting a coordinated, global response to climate change. From FY 2015-2018, the United States committed $2.11 billion to multilateral climate change funds, including $1.81 billion in FY 2015-2016 and $302.4 million in FY 2017-2018. This includes contributions to the Global Environment Facility (GEF) ($409.5 million), the Least Developed Countries Fund (LDCF) ($25 million), the Green Climate Fund (GCF) ($1 billion), the Clean Technology Fund (CTF) ($355.7 million) and the Forest Investment Program (FIP) ($100 million).
- Multilateral development banks (MDBs)—U.S. contributions to the MDBs, as well as those from other development partners, play a key role in enabling these institutions to provide billions in climate support to developing countries. From 2015-2018, the MDBs committed more than $130 billion in total climate finance. However, since countries' contributions to MDBs are not earmarked for specific purposes, it is not possible to specify the exact proportion of U.S. support that ultimately finances climate change activities in developing countries. Thus, U.S. contributions to the ordinary capital resources of the MDBs are not included in figures presented in this chapter. Although we do not include it here, MDB financing for climate activities is included in the $100 billion climate finance goal according to the methodology developed by the Organization for Economic Co-operation and Development (OECD).

Financial Instruments

The United States uses a range of financial instruments and interventions to mobilize climate finance through these channels. These include grants; risk mitigation tools, such as guarantees and insurance; and low-cost, long-term debt financing, including both concessional and market-rate loans. Together, these instruments are helping to mobilize finance by providing a robust, yet flexible, toolkit that is prioritized and adapted according to each country's unique needs, circumstances, and specific financing and investment barriers. From FY 2015-2018, the U.S. provided climate finance predominantly in the form of grants ($3.70 billion in FY 2015-2016, $1.79 billion in FY 2017-2018), followed by concessional and market-rate loans ($648.6 million in FY 2015-2016, $870.0 million in FY 2017-2018), loan guarantees ($1.13 billion in FY 2015-2016, $89.6 million in FY 2017-2018), insurance products ($89.5 million in FY 2015-2016, $436.7 million in FY 2017-2018), and other instruments ($13.3 million in FY 2015-2016, $10.5 million in FY 2017-2018).

Geography

U.S. climate finance is provided through both country-specific programs and multi-country programs that often have a regional or global focus. While finance provided by DFC and EXIM is more demand-driven and available for all eligible countries to access, U.S. grant-based assistance (other than funds used for multilateral activities) is often designated by Congress for specific countries or regions, with the exception of funds that are appropriated for multilateral climate activities. Figure 7-2 presents a geographic breakdown of U.S. congressionally appropriated assistance that can be attributed to a particular region. From FY 2015-2018, approximately 21.8 percent of this finance went to Asia, 30.2 percent to Africa, 10.3 percent to Latin America and the Caribbean, 30.1 percent to global or multi-regional programming, and the balance to developing economies in Europe and the Middle East

Figure 7-1 **Geographic Breakdown of U.S. Climate Finance: FY2015-2016**

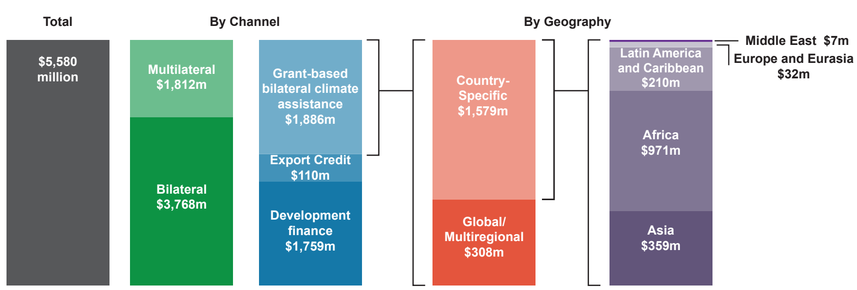
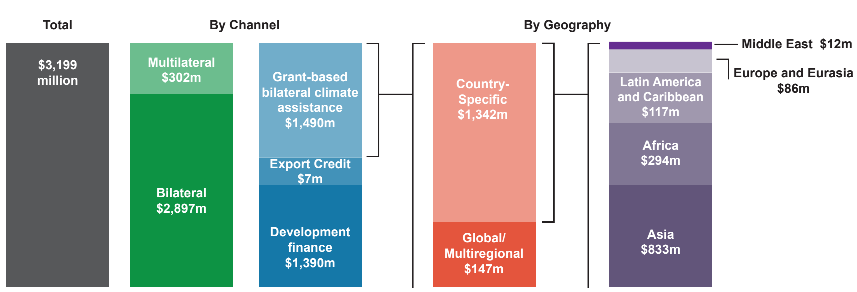


Figure 7-2 **Geographic Breakdown of U.S. Climate Finance: FY2017-2018**



Note: Figures are in millions of USD

Pillars

U.S. climate finance supports activities across three main pillars: adaptation, clean energy, and sustainable landscapes (forests, agriculture, and other land uses). As illustrated in Figure X-3, for FY2015-2018 approximately 48.5 percent of U.S. congressionally appropriated climate finance supported clean energy activities, 30.9 percent supported adaptation activities, and 20.7 percent supported sustainable landscape activities. Finance committed through more demand-driven U.S. climate finance channels, such as DFC and EXIM, typically supported clean energy activities. The following sections provide a sample of initiatives within each pillar

Figure 7-3 **Breakdown of U.S. Climate Finance by Pillar: FY2015-2016**

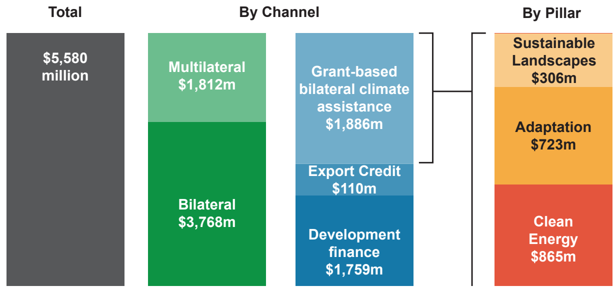
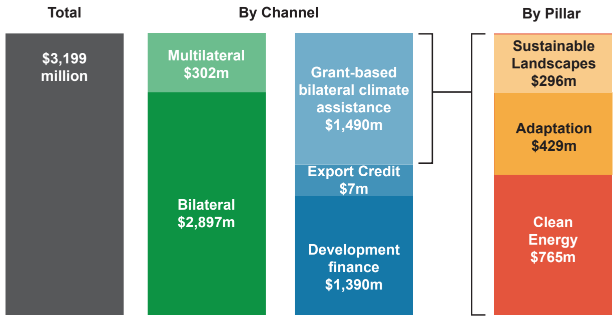


Figure 7-4 **Breakdown of U.S. Climate Finance by Pillar: FY2017-2018**



Note: Figures are in millions of USD

Adaptation

The United States is committed to helping vulnerable countries adapt to climate change and enhance the resilience of their communities and economies. The United States committed $1.72 billion from FY 2015-2018 to activities that promote climate resilience in developing countries, including $1.28 billion in FY 2015-2016 and $439.2 million in FY 2017-2018.

The United States has prioritized climate adaptation assistance for countries, regions, and populations that are highly vulnerable to the impacts of climate change, with particular emphasis on small island developing states (SIDS), and least-developed countries (LDCs), especially in sub-Saharan Africa. By increasing resilience in key areas such as food security, water, coastal management, and public health, our support helps vulnerable countries prepare for and respond to increasing climate – and weather-related risks.

For example, USAID's Pastoralists' Areas Resilience Improvement through Market Expansion (PRIME) project increased household incomes and enhanced resilience to climate change through market linkages in Ethiopia's dryland areas. The project facilitated community-based natural resource management solutions to address climate risks, increase livestock productivity, improve access to alternative livelihoods, and improve nutritional outcomes. In Burkina Faso and Niger, USAID's Resilience and Economic Growth in the Sahel – Enhanced Resilience (REGIS-ER) project worked to increase the resilience of chronically vulnerable people, households, communities, and systems in the agriculture and aquaculture sectors by increasing sustainability, strengthening governance and institutions, and improving health. The project enabled effective, flexible, and inclusive natural resource management that is capable of adapting to changing conditions associated with population pressure and climate change. Because of REGIS-ER, more than 17,000 vulnerable stakeholders were trained in climate change adaptation techniques to improve natural resource use and productivity and 1,100 hectares of degraded lands were restored for tree or crop production.

USAID's Adaptasi Perubahan Iklim dan Ketangguhan (APIK), or Climate Change Adaptation and Resilience, supported the government of Indonesia in improving resilience to sea level rise, droughts, floods, and landslides across the Indonesian archipelago. APIK helped integrate climate change adaptation and disaster risk reduction into national and subnational governance frameworks, built the capacity of local communities and the private sector to address climate change and weather-related hazards, and supported information for climate and disaster risk management. Notably, APIK contributed to the development of Indonesia's National Action Plan for Climate Change Adaptation. In another example, MCC worked with the Moldovan Government to reform water laws, develop a plan to better manage water resource and consolidate information to address increasing floods and droughts. Together these actions helped the country manage water resources more adaptively, strengthened engagement with civil society and improved water allocation.

USAID's $5 million joint initiative with the Inter-American Foundation entitled, "Building Community Resilience in the Eastern and Southern Caribbean" supports communities to become more resilient to the impact of natural hazards through capacity building grants to community-based organizations.

Also in the Caribbean, NOAA provides technical and scientific expertise to expand the availability and use of climate information. By enhancing regional networks and cooperation mechanisms such as the Caribbean Regional Climate Outlook Forum, NOAA has helped build capacity for monitoring, understanding, communicating and applying climate information to support decision makers in the areas of disaster preparedness, agriculture, water management and public health.

U.S. adaptation assistance helps deepen understanding of the impacts of climate change, provides needed climate services—including actionable science, data, information, tools, and training— and develops capacity to plan for and implement adaptation solutions . It builds the capacity of partner governments and civil society partners to respond to climate change risks through programs, such as the Climate Services for Resilient Development partnership and U.S.-Caribbean Resilience Partnership. U.S. support also helps developing countries advance their National Adaptation Planning (NAP) processes, including through programs such as the NAP Global Network.

At the same time, the magnitude of the challenge requires not only dedicated adaptation programming and finance flows, but also a broader approach to international development that fully integrates resilience to climate change. Development investments in areas as diverse as malaria prevention and treatment, building hydropower facilities, improving agricultural yields, and developing urban infrastructure will not be effective in the long term if they do not account for such impacts such as shifting ranges of disease-carrying mosquitoes, changing water availability, or rising sea levels.

Clean Energy

From FY 2015-2018, the United States committed $5.87 billion to finance clean energy activities in developing countries, including $3.57 billion in FY 2015-2016 and $2.30 billion in FY 2017-2018. This climate assistance focused on countries and sectors offering significant emission reduction potential over the long term, as well as countries that offered the potential to demonstrate leadership in sustained, large-scale deployment of clean energy. In terms of sector coverage, clean energy includes renewable energy and energy efficiency, and excludes direct expenditures on natural gas and other fossil fuel power plant construction or retrofits.

The United States is supporting countries to place the building blocks to scale up renewable energy, for example, by providing technical assistance to energy system planners, regulators, and grid operators to improve the capability of regional energy grids to distribute clean energy. The United States also supports global programs that focus chiefly on information sharing and building coalitions for action on clean energy technologies and practices.

The United States also actively supports the Clean Energy Ministerial (CEM) and Mission Innovation (MI), which advance clean energy deployment and innovation respectively through voluntary collaborative engagement among major economies. The Clean Energy Ministerial (CEM) is a high-level global forum to promote policies and programs that advance clean energy technology deployment, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. Members represent over 80 percent of global climate-related emissions. The CEM combines annual Ministerial discussions with year-round voluntary, cooperative workstreams that are based on areas of common interest among participating governments and other stakeholders. Mission Innovation was launched with U.S. support at the Paris COP in 2015. Mission Innovation is a global initiative of 22 countries and the European Commission that represent over 90 percent of global public investments in clean energy innovation. It is a catalyst for strengthened global cooperation on clean energy innovation as part of the urgent and lasting response to climate change. It combines annual ministerial-level discussions with year-round cooperative research activities, knowledge exchange, analysis, and other work.

The United States is also helping countries expand access to clean, affordable electricity through such programs as Power Africa, the Hydrogen collaborative research mission under Mission Innovation, the U.S.-Africa Clean Energy Finance initiative, and the Partnership for Transatlantic Energy and Climate Cooperation. The United States is also a supporter of a number of Clean Energy Ministerial initiatives, including the 21st Century Power Partnership,[241,242] Nuclear Innovation: Clean Energy Future initiative (NICE Future), Carbon Capture Utilization, and Storage initiative (CEM CCUS), International Smart Grid Action Network (ISGAN), Clean Energy Solutions Center, Hydrogen Initiative (CEM H2I), and the Biofuture Platform Initiative (CEM BfPIn).

The United States also supports a number of bilateral and regional programs to help countries achieve their goals transitioning to non-fossil fuel power sources. In South Africa, USAID's Power Africa initiative has helped bring 27 procurements to financial close under the Renewable Energy Independent Power Producer Procurement Program, resulting in 2,200 megawatts (MW) of new renewable energy generation and approximately USD $4 billion in investment through support to the Government of South Africa. Finance small-scale renewable energy projects through a 15-year (2016-2031), $200 million loan portfolio guarantee to South Africa's Industrial Development Corporation. In Nigeria, Power Africa has achieved nearly two million new on – and off-grid connections, more than $4.3 billion of power sector investment mobilized through U.S. Government assistance, and an increase of 662 megawatts of on-grid electricity delivery capacity since 2013. Power Africa also helped develop the $330 million Solar Power Naija Program to provide concessionary financing to private sector developers to deploy five million new solar connections by year 2023. In India, since 2016, USAID has helped mobilize $1.1 billion of private sector investments, installed and integrated about 6,000 megawatts of clean energy, and improved energy access for five million people.

Our work through the Climate and Clean Air Coalition and Global Methane Initiative is reducing emissions of short-lived climate pollutants, such as methane, black carbon, and many HFCs. The United States is also supporting efforts to identify and pursue country-driven, low-carbon development strategies that make the most sense for them through the Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program and the LEDS Global Partnership.

Sustainable Landscapes

For activities related to land-use mitigation (or "sustainable landscapes"), including reducing emissions from deforestation and forest degradation (REDD+), dedicated U.S. climate change assistance works to (1) reduce greenhouse gas emissions from deforestation and other land uses; (2) increase the sequestration of carbon stored in trees, plants, and soils; and through these actions (3) generate additional social and environmental benefits, such as good governance, enhanced resilience, and biodiversity conservation. From FY 2015-2018, the United States committed $1.20 billion to support developing countries in protecting and restoring carbon-rich ecosystems; improving agricultural practices; enhancing land-use planning; building monitoring capacity; attracting investment that supports forest and climate objectives; and enhancing the systems that underpin these activities. This includes $731.8 million in financing in FY 2015-2016 and $436.2 million in FY 2017-2018. U.S. support prioritizes the mitigation potential of investments; countries with the political will to implement large-scale efforts to reduce emissions from deforestation, forest degradation, and other land-use activities; and potential for complementary investments in monitoring, reporting, and verification of forest cover and greenhouse gas emission reductions.

Greenhouse gas emissions from deforestation, agriculture, and other land uses constitute approximately one-quarter of global emissions. In some developing countries, land sector greenhouse gas emissions can account for as much as 80 percent of total emissions. At the same time, conserving, sustainably managing, and restoring forests and other ecosystems could contribute around one-third of the pre-2030 mitigation potential. To meet the challenge of reducing these emissions, the United States is working with partner countries to put in place the systems and institutions necessary to significantly reduce global land-use-related emissions, supporting the provision of data and information about forests and land use, and creating new models for rural development that generate climate benefits, while conserving biodiversity, protecting watersheds, and improving livelihoods.

For example, the Forest Finance and Investment Incubator (FFII), supported by the Department of State, is intended to spur private sector financing of national and sub-national climate strategies. FFII supports partner governments in the development of concrete financial investment plans for forests and other landscapes, and helps develop more mature ideas into bankable projects to help mobilize financial resources for downstream forest activities and projects. The Offset National Emissions through Sustainable Landscapes (ONE-SL) project, also funded by the Department of State, supports partner countries in developing enhanced understanding and capacity for successful implementation of nested jurisdictional Reducing Emissions from Deforestation and Forest Degradation (REDD+) programs among countries, project developers and potential buyers.

Support from the U.S. Department of the Treasury and the Department of State for multilateral initiatives such as the Forest Carbon Partnership Facility and the BioCarbon Fund Initiative for Sustainable Forest Landscapes also capacity and facilitating implementation of REDD+ strategies and other sustainable landscape programs in dozens of developing countries.

USAID's Central Africa Regional Program for the Environment (CARPE) programs support sustainable land use practices in the Democratic Republic of the Congo (DRC) by improving management of primary and secondary forests, establishing sustainable financing models for community forest concessions through private sector partnerships, and developing and promoting alternatives to charcoal. Beyond the emissions reductions achieved, key results from USAID's support to the DRC Government include management of 17.1 million hectares of biologically sensitive forests improved, and 1,267,228 hectares of community forest concessions established.

In Indonesia, USAID's LESTARI Project worked with the national government to reduce greenhouse gas emission from land use and to conserve biodiversity in forest and mangrove ecosystems. The project applied a landscape approach, integrating forest and peatland conservation with low emissions development on degraded land. Through LESTARI, USAID targeted six strategic landscapes in three provinces (Aceh, Central Kalimantan, Papua) with the most intact primary forest cover and greatest carbon stocks. Among other aims, LESTARI worked to improve land use governance and succeeded in bringing 3.47 million hectares of forest and/or natural resources under improved management and succeeded in reducing 1976 MMT of greenhouse gas emissions from the land use sector.

Annex 3 contains information on U.S. provision of public financial support: contribution through multilateral channels for FY15 and 16, and FY17 and 18 (biennial report common tabular format 7a). It also contains a summary of U.S. provision of public financial support: contribution through bilateral, regional and other channels. The full version of common tabular format 7b can be found in the electronic common tabular format submissions for Biennial Report 3 and Biennial Report 4.

PROMOTING EFFECTIVENESS

To promote effective use of climate finance, the United States works to ensure that our support is efficient, effective, and innovative; based on country-owned plans and strategies; and focused on achieving measurable results, with a long-term view of economic and environmental sustainability.

Supporting Country-Driven Approaches

U.S. support across all pillars is country-driven, responding to the needs and priorities of partner countries. This is achieved in a variety of ways, including reviewing country-specific documents such as NDCs, Biennial Update Reports, national greenhouse gas inventories, and NAPs to target projects; working directly with partner governments to identify needs and develop implementation plans; and building multi-country programs around challenges or priorities identified across multiple countries during prior work.

Building Effective Enabling Environments

The United States also acknowledges the critical role our partner countries play in promoting the effectiveness of climate finance. Where our partners set in place systems that reflect high standards of transparency, good governance, and accountability, climate finance contributors and investors are better able to respond directly to country priorities, making new contributions in line with established national strategies and country development plans based on broad consultation. This in turn empowers partner governments to drive development and sustain outcomes by working through national institutions, rather than around them.

Moreover, our experience in climate finance has shown that the ability of any public financial instrument or intervention to mobilize and deploy additional finance depends largely on the broader policy framework in place in a specific country. This can involve climate-specific policies, such as energy sector regulations and carbon pricing, as well as broader, non-climate-specific policies and legal frameworks. The United States remains committed to working with our development partners to identify complementary solutions to address domestic investment barriers and achieve their low-carbon, climate-resilient development strategies.

Scaling Down Support for Carbon-Intensive Fossil Fuels

Achieving our shared climate objectives depends not only on how much we are investing in low-carbon activities, but also on how much we are scaling down support for high-carbon activities. Shifting investment from those that support fossil fuel use, or other high-emission activities, towards lower-emission alternatives remains a priority of the United States.

ENSURING TRANSPARENCY

The United States views transparent tracking and reporting of climate finance as key to ensuring accountability, promoting effectiveness, and building trust. To ensure robust reporting, each implementing government agency or entity follows strict guidelines and eligibility criteria when collecting information on support of activities related to adaptation, clean energy, and sustainable landscapes. For instance, activity descriptions provided by USAID missions are reviewed by climate change specialists to ensure compliance with USAID climate change goals. For the purpose of our climate finance reporting to the UNFCCC, the United States only includes programs that have mitigation and/or adaptation as a primary objective, or as an intentional significant co-benefit (e.g., for relevant biodiversity and food security activities). In the case of programs for which only part of the activity is targeted toward a climate objective, only the relevant portion of financial support is counted, rather than the entire program budget.

NEW AND ADDITIONAL CLIMATE FINANCE

Scaling up international assistance for climate change is a significant priority for the United States. New and additional funding to support international climate efforts are appropriated by the U.S. Congress each year on an annual basis, in response to the President's budget request. As described above, this funding supports programs to advance adaptation, clean energy, and sustainable landscapes efforts globally. It also underpins efforts by agencies such as the Millennium Challenge Corporation, Development Finance Corporation, and Export-Import Bank to incorporate climate change into their programming. Since ratifying the UNFCCC in 1992, U.S. international climate finance increased from virtually zero to around $2.79 billion per year during the period FY 2015-2016 and $1.60 billion per year in FY 2017-2018.

MOBILIZING PRIVATE FINANCE

While maintaining a strong core of public climate finance is essential, the United States is actively pursuing strategies to encourage private investment in low-carbon, climate-resilient activities in developing countries. We are working to combine our significant, but finite, public contributions with targeted, smart policies to mobilize maximum private investment in climate-aligned activities. More efficient leveraging of private investment can allow limited public resources to be concentrated in areas and sectors where the private sector is less likely to invest on its own, particularly in adaptation activities in the most vulnerable countries and LDCs. This effectively multiplies the financing available to support partner countries' climate objectives. The key role of public finance in de-risking private investments can catalyze significant additional resources.

In many cases, the barriers to mobilizing private finance relate to a combination of factors, including poor incentives, challenges in engaging with host government regulatory processes, perceived risk, and lack of knowledge in the commercial banking sector about climate-friendly opportunities. As noted above, U.S. bilateral assistance through agencies such as USAID and the Department of State targets technical assistance to address these and other issues.

Moreover, the United States is committed to working with partners to make finance flows consistent with a pathway towards low greenhouse gas emission and climate-resilient development, shifting the trillions of dollars under financial management to support climate action at scale.

For example, the Partnership Platform for the Amazon was initiated by USAID/Brazil, and brought together large companies such as Beraca and Ambev; large Amazon-based companies such as Bemol and Rede Amazônia, medium and small enterprises, plus philanthropic and civil society institutions. The Platform acceleration and investment program enables environmentally sustainable startups in the Amazon to grow and generate employment.

The Integrated Gorongosa and Buffer Zone Program (IGBZ) is a Global Development Alliance with the Gorongosa Project that aims to strengthen environmental governance, reduce threats to the park's biodiversity, and improve livelihood opportunities for buffer zone communities. This long-term partnership has committed to creating a conservation culture that extends beyond just teaching people about the importance of biodiversity conservation, and recognizes that we must also address their immediate health, education, and food needs if we are to reduce threats to the park. The partnership has expanded continuously since 2008. This type of partnership then encouraged the creation of the HEARTH (Health, Ecosystems and Agriculture for Resilient Thriving Societies) Program, whose design began in 2018 to expand partnerships with the private sector (with USAID funds leveraged at least 1:1 by the private sector) for the sustainable conservation of threatened landscapes and the well-being of local communities.

Improving the Tracking of Mobilized Private Finance

For our common methodological framework and tracking progress toward the $100 billion goal, we consider mobilized climate finance to include private finance for climate-relevant activities that has been mobilized by public finance or by a public policy intervention, including technical assistance to enable policy and regulatory reform.

The United States and other developed countries continue to work to enhance our ability to track the amount of private finance mobilized by public interventions. Building on the work of the Research Collaborative on Tracking Private Climate Finance, we have worked with other developed countries to reach a common understanding of the scope of mobilized climate finance and a common methodology for tracking and reporting toward our collective goal. The institutions and agencies of participating countries continue to use this framework as a basis going forward, and we work with relevant multilateral and other institutions to harmonize our approaches over time.

While developing our methodology, we have been guided by the following principles: (1) ensure that only finance mobilized by developed country governments is counted toward the $100 billion goal and that, where multiple actors are involved, the resulting finance is only counted once in tracking our collective progress; and (2) ensure that our reporting framework encourages and incentivizes the most effective use of climate finance.

To account for mobilized private climate finance, we assess the amount of private finance mobilized on an activity-by-activity basis and to report on private finance associated with activities both where there is a clear causal link between a public intervention and private finance and where the activity would not have moved forward, or moved forward at scale, in the absence of our government's intervention. In recognition of the role that developing countries play in mobilizing private finance, our governments will report only on our share of private finance mobilized, excluding the share of private finance that developing countries' public finance has mobilized.

It is important to note that current data and methodological limitations prevent us from accounting for the full range of flows that we are mobilizing toward the $100 billion goal at this time—in particular, those mobilized through public policy interventions, and those mobilized through improvements in institutional capacity and the enabling environment. As such, estimates throughout this chapter are necessarily partial, and omit some—possibly a substantial amount of—climate finance mobilized. We intend to continue to improve our methodology as data availability increases and measurement methods evolve. As a result, we expect our reporting to become more complete over time.

TECHNOLOGY DEVELOPMENT AND TRANSFER

Speeding climate-related technology transitions abroad is a powerful lever for the United States to address the climate crisis and keep the goal of limiting global temperature rise to 1.5 degrees C alive. Developing and driving down the costs of critical clean technologies will make it easier for countries around the world to raise their ambition, for energy-intensive sectors of the global economy to mitigate emissions, and strengthen resilience to climate impacts at the necessary scale, cost-effectively and quickly. This will advance sustainable development internationally and provide immediate domestic benefits to the United States. As multitrillion-dollar international markets for clean energy technologies emerge, the United States supports the development of technologies that other countries need to decarbonize and aligns its clean energy diplomacy and investments with its domestic industrial agenda. This also applies to technologies that support reduced emissions from land use, and technologies that support adaptation and resilience to climate impacts. The United States supports voluntary technology transfer on mutually agreed terms and promotes enabling environments conducive to trade and investment in climate-related technology, including the protection of intellectual property, to incentivize technology innovation and deployment.

The United States has engaged in a number of activities to enhance the development, deployment, and diffusion of climate technologies and practices to developing countries from FY 2015-2018. Table 7-6 provides an illustrative—though not exhaustive—list of efforts undertaken by the United States over these years to build endogenous capacities and technologies at the national level in developing countries. The principal U.S. focus is to facilitate the development and implementation of the policies, regulations, and capacity building to enhance technology innovation and deployment.

The United States has continued to play a leading role in support of the UNFCCC Technology Mechanism, composed of the Technology Executive Committee (TEC) and the Climate Technology Center & Network (CTCN). This included active engagement in the development of a new Technology Framework, which the UNFCCC Conference of the Parties, serving as the meeting of the Parties to the Paris Agreement, adopted in December 2018 (Decision 15/CMA.1) The United States has financed a wide range of programs that support climate-related technology development and transfer, including funding for the CTCN, the Climate Investment Funds, the Global Environment Facility, and the Green Climate Fund. As part of this effort, the United States worked through the Global Environment Facility, the TEC, and the CTCN to support implementation of the Poznan Strategic Program on Technology Transfer. The Department of Energy's National Renewable Energy Laboratory (NREL) has continued to play an active role in the CTCN as one of 11 regional core Consortium Partners. NREL's engagement helped enable the CTCN to fulfill its mission to help the global community expand access to the advanced knowledge and policy planning expertise necessary to advance clean-energy and climate-resilient technologies at the national level. The United States was the second-largest financial contributor to the CTCN during the period covered by this report, including providing $4.5 million in assistance through the CTCN in FY 2015-18.

Changes in Policies and Activities Since the Second Biennial Report

In addition to the information contained herein and in Table 7-6, we encourage readers to review U.S. contributions to the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, specifically its reporting requirements under Article 66.2 (which is similar to the UNFCCC Biennial Report obligation with some notable differences, including that Article 66.2 only applies to LDCs and covers all technologies). The United States also submits a parallel report under Article 67 of the TRIPS agreement regarding capacity-building programs, which provides a chronological list of programs conducted by the United States in 2020.

Challenges in Delivering Technology Transfer and Development

While the initiatives listed in Table 7-6 provide insight into some of the success stories related to U.S engagement in technology transfer and development, challenges remain. One key challenge has been to attract the finance necessary to successfully develop, demonstrate and deploy climate technologies. This may be due to limited domestic capacity in host countries, but also to insufficient frameworks for investment (i.e., including how to manage market adoption risk in parallel with managing technology risk) or protection of intellectual property rights. Lack of investment in demonstration, or limited work to understand the deployment economics across a value chain to ensure economically sustainable business models for every player to drive deployment, and a lack of connection between domestic needs and domestic technology development are other common barriers. To address these challenges, the United States has supported a number of programs such as those highlighted below, including a partnership between the Clean Energy Solutions Center (CESC) and the CTCN, to assist developing countries in designing clean energy finance measures that will help mobilize investment in priority technologies.

Technology Development and Transfer Activities at the National, Regional, and Global Levels

This section highlights several technology activities at the national, regional, and global levels. These examples are non-exhaustive and illustrative in nature. Several others programs are contained in Table 7-2.

Table 7-2 **Examples of Implemented U.S. Technology Development and Transfer Activities**

Name of Activity and Recipient Country and/or Region	Targeted Area/ Sector	Measures and Activities Related to Technology Development and Transfer	Sources of Funding and Implementation
UNFCCC Climate Technology Center & Network (CTCN)	Global support for climate technology deployment in developing countries Mitigation/Energy, Adaptation, Sustainable Landscapes	The United States is a leading supporter of the UNFCCC Climate Technology Center & Network. The CTCN is the implementation body of the UNFCCC Technology Mechanism. It accelerates the development and transfer of technologies through three services: 1) providing technical assistance at the request of developing countries on technology issues; 2) creating access to information and knowledge on climate technologies; and 3) fostering collaboration among climate technology stakeholders via its network of regional and sectoral experts.	Public
Clean Energy Ministerial Members: Australia, Brazil, Canada, Chile, China, Denmark, European Commission, Finland, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Saudi Arabia, South Africa, Spain, Sweden, United Arab Emirates, United Kingdom, United States	Mitigation/ Energy	The Clean Energy Ministerial (CEM) is a high-level global forum to promote policies and programs that advance clean energy technology deployment, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. Members represent over 80 percent of global climate-related emissions. The CEM combines annual Ministerial-discussions with year-round voluntary, cooperative workstreams that are based on areas of common interest among participating governments and other stakeholders.	Public
Clean Energy Ministerial Global Lighting Challenge Participants: Australia, China, European Commission, France, Germany, India, Indonesia, Korea, Mexico, Russia, South Africa, Sweden, United Arab Emirates, United Kingdom, United States	Mitigation/ Energy	Launched in 2015 and concluded in 2018, the Global Lighting Challenge was a race to reach cumulative global sales of 10 billion high-efficiency, high-quality, and affordable advanced lighting products, such as light-emitting diode (LED) lamps, as quickly as possible. It featured commitments by countries, cities, companies, NGOs, and more to promote adoption of advanced lighting products. This high-level CEM campaign achieved a cumulative commitment of 14 billion energy-saving lighting products.	Public / Other
Mission Innovation Members: Australia, Austria, Brazil, Canada, Chile, China, Denmark, European Union, Finland, France, Germany, India, Italy, Japan, Morocco, Netherlands, Norway, Korea, Saudi Arabia, Sweden, UAE, United Kingdom, United States	Mitigation/ Energy	Launched at leader-level at the Paris COP in 2015, Mission Innovation is a global initiative of 22 countries and the European Commission that represent over 90percent of global public investments in clean energy innovation. It is a catalyst for strengthened global cooperation on clean energy innovation. It combines annual ministerial-level discussions with year-round cooperative research activities, knowledge exchange, analysis, and other work.	Public

Name of Activity and Recipient Country and/or Region	Targeted Area/ Sector	Measures and Activities Related to Technology Development and Transfer	Sources of Funding and Implementation
U.S- India Energy Partnership	Mitigation/ Energy	The U.S.-India Energy Partnership focuses on energy security, energy innovation and low-carbon energy development. The initial five-year R&D tracks (2012-2017) focused on solar energy, building efficiency, and advanced biofuels. In 2017, the U.S. and India launched a new five-year R&D track on smart grids and energy storage to modernize the power grid.	Public
Partnership for Resilient Infrastructure Investment in Pacific Island Countries	Adaptation	Partnership for Resilient Infrastructure Investment in Pacific Island Countries improves	Public
Private Investment for Enhanced Resilience Bangladesh, Ghana, Guyana, Indonesia, Mozambique, Peru, Tanzania, and Vietnam	Adaptation	The Private Investment for Enhanced Resilience (PIER) project mobilizes private-sector investment to support resilience to climate change. PIER supports the development and implementation of National Adaptation Plans by working with for-profit companies to build climate change resilience through strategic investments that support technology deployment in climate risk-reducing products, services, and infrastructure	Private and Public
U.S.-India Partnership for Climate Resilience	Adaptation	The United States has supported the U.S.-India Partnership for Climate Resilience since 2015, which links U.S. government climate scientists with their counterparts in India to produce climate data and information to inform local decisionmakers.	Public
SERVIR 50+ countries	Adaptation and Sustainable Landscapes	SERVIR provides developing countries access to satellite information and geospatial technologies to help them manage risks associated with climate and land-use change. More than 10,000 people have been trained through the program to predict, monitor, and assess risks, and more than 600	Public
SilvaCarbon 25+ countries	Sustainable Landscapes	SilvaCarbon partners work with more than 25 developing countries to build capacity for monitoring and managing forest and terrestrial carbon. SilvaCarbon has assisted countries in enhancing national forest inventories and national GHG inventories, develop NDC and REDD+ baselines, improve national forest monitoring systems, access and interpret remove sensing data, and integrate data and information into improved policymaking and land-use planning.	Public

NOTE: The full version of common tabular format 8 can be found in the electronic common tabular format submissions for Biennial Report 3 and Biennial Report 4.

Energy Activities

Clean Energy Ministerial and Mission Innovation

The United States actively engages in these two leading international cooperative forums on clean energy, both of which the United States helped create and lead. Launched in 2010, the Clean Energy Ministerial (CEM) is a high-level global forum of 28 countries and the European Commission to promote policies and programs that advance clean energy technology deployment, to share lessons learned and best practices, and to otherwise support the transition to a global clean energy economy. Members represent over 80 percent of global climate-related emissions. Launched at leader-level at the Paris COP in 2015, Mission Innovation is a global initiative of 22 countries and the European Commission that represent over 90 percent of global public investments in clean energy *innovation*. It is a catalyst for strengthened global cooperation on clean energy innovation as part of the urgent and lasting response to climate change. Both initiatives support a range of technology-related work. For example, the CEM Global Lighting Challenge was a race to reach cumulative global sales of 10 billion high-efficiency, high-quality, and affordable advanced lighting products, such as light-emitting diode (LED) lamps, as quickly as possible, and ultimately achieved a cumulative commitment of 14 billion energy-saving lighting products.

The CEM and MI membership bring together advanced economies with major, forward-leaning developing economies, enabling knowledge exchange and technical support. CEM and MI couple annual Ministerial-discussions with year-round voluntary, cooperative workstreams that are based on areas of common interest among participating governments and other stakeholders.

U.S. – India Energy Partnership

The Department of Energy (DOE) co-chairs a longstanding interagency energy partnership with India focused on energy security, energy innovation and low-carbon energy development. In 2018, the partnership was elevated to a Strategic Energy Partnership and revamped again in 2021 as the U.S.-India Strategic Clean Energy Partnership (SCEP) to accelerate development and deployment of critical clean energy technologies. As part of this dialogue, DOE has also led R&D efforts under the Partnership to Advance Clean Energy-Research (PACE-R). The initial five-year R&D tracks (2012-2017) focused on solar energy, building efficiency, and advanced biofuels. DOE committed $25M matched by the Indian Government and consortia members for a total commitment of $125M for the three tracks. In 2017, the U.S. and India launched a new five-year R&D track on smart grids and energy storage with $7.5M in DOE funding matched by the Indian Government and the research consortium for a $30M total commitment to modernize the power grid.

Adaptation Activities

Partnership for Resilient Infrastructure Investment in Pacific Island Countries

The State Department and NOAA are working to improve adaptation capacity in the Pacific through better weather and climate monitoring technology. The Partnership for Resilient Infrastructure Investment in Pacific Island Countries, implemented under the Indo-Pacific Strategy, is increasing predictive capabilities in the Pacific through the provision of weather monitoring technologies and training in observation and forecasting. These increased predictive capabilities support the Indo-Pacific region's ability to plan for and respond to extreme weather events, including tropical cyclones, droughts, tsunamis, and rising sea levels, which threaten economic growth and prosperity.

Private Investment for Enhanced Resilience

The Private Investment for Enhanced Resilience (PIER) project mobilizes private-sector investment to support resilience to climate change in Bangladesh, Ghana, Guyana, Indonesia, Mozambique, Peru, Tanzania, and Vietnam. PIER supports the development and implementation of National Adaptation Plans by working with for-profit companies to build climate change resilience through strategic investments that support technology deployment in climate risk-reducing products, services, and infrastructure. For example, In Peru, PIER built the capacity of the Development Bank of Peru (COFIDE) to design climate proof credit and lending products, enabling the bank to invest more than $45 million towards climate risk reduction measures for major road infrastructure. In Indonesia, PIER has **s**upported financing and market development for solar irrigation pumps for small holder farmers. In Ghana, PIER Designed and deployed a financial tool to determine returns on investment in resilient cocoa farms, which was utilized to make major investment decisions in climate smart cocoa across West Africa.

Using Climate Information Services to Improve Malaria Forecasts

To better target the delivery of malaria control services where they are most needed, the U.S. President's Malaria Initiative (PMI) is helping the Ethiopian government integrate climate and disease surveillance data in an early warning system to identify two months in advance the districts most likely to experience upsurges in malaria cases. This doubles the forecast accuracy compared to predictions based only on malaria surveillance data. Using machine learning, the forecasting model can currently predict 85% of the weekly variation in malaria cases 1 week in advance and 67% of the weekly variation in malaria cases 12 weeks in advance. PMI is also prototyping a global version of this Ethiopia model within its data integration platform to provide similar climate-based forecasts to as many of its 27 focus countries as possible. Early work on this activity was done through a National Institutes of Health grant.

U.S.-India Partnership for Climate Resilience

Since 2015, the United States has supported the Partnership for Climate Resilience which links U.S. government climate scientists with their counterparts in India to produce climate data and information to inform local decisionmakers. Key activities facilitated by U.S. support include science and technical capacity building to promote climate resilience, training activities on accessing and interpreting downscaled climate projections and data sets; improving the use and application of climate model projections for risk identification by local, regional and national institutes, and organizations, and addressing climate information needs and informing planning and climate resilient sustainable development, including for India's State Action Plans.

Sustainable Landscapes Activities

SERVIR

The United States continues to support the SERVIR program, which provides developing countries access to satellite information and geospatial technologies to help them manage risks associated with climate and land-use change. USAID and the National Aeronautics and Space Administration provide technology, data, capacity building, scientific models, and data analysis methods to leading regional organizations in 4 regions serving more than 50 countries. SERVIR helps meet the needs of local decision makers facing challenges related to food security, water resources, disasters, weather and climate, and land use. More than 10,000 people have been trained through the program to predict, monitor, and assess risks, and more than 600 institutions have been engaged in these activities. SERVIR collaborates with 20 US-based universities and research centers and partners with leading US technology companies

SilvaCarbon

SilvaCarbon is a whole-of-government technical cooperation program that draws on the strengths of various technical agencies in the U.S. government, nongovernmental organizations, academia, and industry. SilvaCarbon and its partners work with more than 25 developing countries to build capacity for monitoring and managing forest and terrestrial carbon. SilvaCarbon helps to identify, test, and disseminate good practices and cost-effective, accurate technologies, building on the needs and priorities identified by partner countries. SilvaCarbon has assisted countries in enhancing national forest inventories and national greenhouse gas inventories, develop NDC and REDD+ baselines, improve national forest monitoring systems, access and interpret remove sensing data, and integrate data and information into improved policymaking and land-use planning.

Clean and Technologies for Sustainable Landscapes Program (CTSL)

Organized in 2020 and coordinated by DOE's National Renewable Energy Laboratory, the Clean and Advanced Technologies for Sustainable Landscapes Program (CTSL) is providing technical assistance to several countries in Africa and Southeast Asia on analyzing and implementing advanced energy technologies to improve and scale up agricultural production.

CAPACITY BUILDING

Since a long-term view of climate change and development is crucial to sustainability and results, the United States is approaching the issue of capacity building for climate change in an integrated manner. Linking capacity building directly to projects and programs helps ensure that capacity built is relevant, effective, and tied to results. Capacity-building needs are addressed throughout all U.S. support activities, not as separate line items or projects, and are provided as a means for taking action on a mutually shared goal.

The Climate Fellows program, funded by the Department of State and managed by the U.S. Forest Service, is one example of a successfully capacity-building approach. Climate Fellows embeds experts in a host country to serve as technical advisors to key ministries or other government institutions. These experts help build local expertise to manage forest resources sustainably while meeting the country's climate and development goals. The Transparency Accelerator program, funded by the Department of State and managed by the Environmental Protection Agency, represents another approach. The Transparency Accelerator draws on the expertise of U.S. government agencies and partners to help improve the technical capacity of developing countries to improve inventory reporting and transition to the use of the IPCC 2006 IPCC Guidelines. This directly supports future reporting under the Enhanced Transparency Framework.

Building local capacity through greater reliance on local cooperating agencies is an explicit goal of USAID. USAID provides technical assistance and capacity building to government agencies for improved data and analytical tools, monitoring reporting and verification systems, and implementation of best practices and new approaches for effective policy development and data-driven decision-making. For example, USAID's support to the Democratic Republic of Congo Government to reduce land-based emissions helped build the capacity of 19,595 individuals from state institutions and non-governmental organizations, including through training on climate change mitigation or natural climate solutions issues.

USAID also strengthens the capacity of national governments, regional institutions and civil society organizations to mitigate the negative effects of climate change. For example, from 2013 to 2018, USAID improved the capacity of the Republic of the Marshall Islands to prepare for and respond to disasters in coordination with the National Disaster Management Office. USAID strengthened the capacity of local, state, and national disaster response networks, training 262 people on first responders, essentials of humanitarian assistance, and disaster search and rescue.

Table 7-3 highlights examples of U.S. capacity-building support. Please note that this table is purely illustrative and does not represent an exhaustive list of U.S. capacity building activities.

Table 7-3 **Examples of U.S. Capacity Building Initiatives Currently Being Implemented**

Recipient country / region	Targeted area	Programme or project title	Description of programme or project
Global	Mitigation	Climate Fellows	This Department of State-U.S. Forest Service program enhances the capacity of partner developing countries to measure, monitor, and report on forest landscapes with respect to greenhouse gas inventories, forest management and/or forest monitoring. Climate Fellows are technical experts embedded in relevant ministries. They provide long-term in-depth, and accountability-enhancing technical assistance for forest inventories, monitoring, and reporting systems. To date, Climate Fellows have supported the design of national forest monitoring systems, adoption of harmonized mapping methodologies, and monitoring, reporting, and verification institutional frameworks.
Central America	Adaptation and Mitigation	Climate and Food Security in Central America	This program helps developing country governments in Central America adopt climate-smart agricultural policies and strategies, as well as pilot sustainable agriculture production practices to address the main drivers of deforestation, habitat degradation, and economic prosperity. The program works on three tracks: (1) improving trade and access to markets by linking farmers and fishers to global and regional demand for more sustainable agricultural products; (2) increasing sustainable and climate-resilient productivity by countering natural habitat conversion or degradation and conserving sensitive fishery replenishment areas; and (3) strengthening agricultural and environmental management by promoting government and producer adoption of landscape – and seascape-scale planning for sustainable agricultural and fisheries development.
Global	Mitigation	Enhancing Capacity for Low Emission Development Strategies (EC-LEDS)	EC-LEDS is a Department of State-led initiative that supports partner countries to design and implement their national low-emission development strategies, which promotes sustainable development and reduces greenhouse gas emissions. This program supports national development and economic growth objectives by scaling up clean energy capacity, increasing the area of land under improved management, and advancing targeted actions that significantly reduce projected emissions from a business as usual pathway while monitoring their progress.
Global	Mitigation	POWER	The wPOWER program is the world's first women-led social enterprise, unlocking women's clean energy entrepreneurship and climate change leadership at scale. This program brings women into the energy access value chain, provides business and technical training, facilitates exchanges among climate leaders, and builds public awareness of the critical role women plan in increasing energy access and driving green growth at a local level.

Recipient country / region	Targeted area	Programme or project title	Description of programme or project
Global	Mitigation	SilvaCarbon	SilvaCarbon is an interagency technical cooperation program that enhances the capacity of partner governments to measure, monitor, and manage forest and terrestrial carbon. The program helps developing countries to design and implement comprehensive systems for tracking forest change and terrestrial GHG emissions. Such monitoring systems are essential for sustainable landscape management and contribute to climate change mitigation and low emission development by providing input to national measurement, reporting, and verification systems for REDD+ and other forest carbon initiatives.
Global	Adaptation	National Adaptation Planning Global Network (NAP-GN)	The National Adaptation Planning Global Network builds capacity in developing countries to meet their medium and long-term adaptation needs, implement national adaptation plans, and identify climate risks to protect key development sectors from climate change. The NAP-GN Secretariat facilitates activities and technical workshops, provides strategic guidance to relevant planning ministries, and improves donor coordination to build capacities and accelerate the formulation and implementation of national adaptation processes. Since it was founded in 2015, NAP-GN has provided direct technical support to over 50 countries and connected over 150 countries and practitioners on national adaptation planning and action.
Indonesia	Adaptation	The Adaptasi Perubahan Iklim dan Ketangguhan (APIK) , or Climate Change Adaptation and Resilience	The Adaptasi Perubahan Iklim dan Ketangguhan (APIK), or Climate Change Adaptation and Resilience (2015 – 2020), supported the government of Indonesia in improving resilience to sea level rise, droughts, floods, and landslides across the Indonesian archipelago.
South Africa	Mitigation	The Southern Africa Energy Program (SAEP)	The Southern Africa Energy Program (SAEP) provides technical assistance and capacity building to South Africa's clean energy sector as a Power Africa-funded regional Program (2017-2022). South Africa Low Emissions Development Program assisted South Africa in developing the skills and resources needed to build a more sustainable and green economy (2015-2020).

Recipient country / region	Targeted area	Programme or project title	Description of programme or project
Global	Mitigation	Transparency Accelerator	This Department of State-Environmental Protection Agency program helps ensure developing countries have the capacity to meet the same greenhouse gas reporting standards as the United States and in line with the Paris Agreement's transparency requirements. EPA's technical experts provide training workshops, technical assistance to improve inventory management systems, sector-specific instructions for compiling greenhouse gas emission estimates, and new and enhanced tools and templates for preparing national greenhouse gas inventories, among other activities.
Kenya	Adaptation	The Africa Groundwater Exploration and Assessment Program	The Africa Groundwater Exploration and Assessment Program supports groundwater exploration and assessment, and is building local capacity to plan and manage groundwater resources under varying climate change scenarios.

NOTE: The full version of common tabular format 9 can be found in the electronic common tabular format submissions for Biennial Report 3 and Biennial Report 4.

8 RESEARCH AND SYSTEMATIC OBSERVATIONS

OVERVIEW

Global change research and systematic observations are the foundation for understanding the significant changes occurring in our climate system and their impacts, for developing response measures and for evaluating the effectiveness of those measures over time. Recent assessments from the Intergovernmental Panel on Climate Change (IPCC) and the U.S. National Climate Assessment (NCA) show that global change related impacts such as drought and wildfire, flooding, changing sea levels and changing precipitation patterns are being experienced now and may be accelerating. With their effects on, for example, the energy, agriculture, health, transportation, housing and water sectors, the effects can be extensive and costly. In 2020, NOAA reported a record-setting 22 separate billion-dollar weather and climate disasters across the United States alone, with $95B in damages.

In 1990, the United States enacted the Global Change Research Act (GCRA), which established the U.S. Global Change Research Program (USGCRP) to develop and coordinate “a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change.” Its 13 member agencies[243] conduct and use fundamental and translational research to advance scientific understanding and provide information and tools to help the nation and the world prepare for and respond to global change. For the period 2016–2020, the USGCRP member agencies invested roughly $12.5 billion in global change science.

USGCRP’s flagship product is the congressionally-mandated National Climate Assessment (NCA), with the 5th NCA now under development. Intended for a scientifically-interested but not – expert audience, the report synthesizes and distills climate science and climate impacts literature for key sectors and the different regions of the U.S. and Caribbean, and produces climate trends and projections for the next 25 and 100 years. The NCA and USGCRP special assessments (e.g., on carbon cycle, climate and health, climate and food security) are published on the globalchange.gov website where content is searchable and shareable. USGCRP assessments use the Global Change Information System (GCIS) to provide metadata traceability from key findings to the underlying literature sources and data sets. The assessments have embedded clickable links to citations in the narrative and references to data sets used in figures, making it an outstanding research and teaching tool.

Research on Global Change

U.S. global change research is distributed across USGCRP's 13 member agencies, each according to their mandates and missions, with USGCRP playing a coordinating role. An increasing number of non-member science-using agencies also participate in USGCRP. Key areas include Earth observations, model development and use, assessments of climate change and impacts in the United States and worldwide, science for adaptation and data and information sharing. USGCRP agencies are greatly improving integrated natural and human system models and the spatial and temporal resolution of climate change models, and are building much faster computers that will enhance climate modeling. USGCRP is increasing its work in adaptation science and aims to increase its integration of socioeconomic sciences with natural-system global change science.

USGCRP works closely with a number of international science coordination groups, reflecting the inherently international nature of global change and the directives of the GCRA. USGCRP provides partial funding support to the World Climate Research Programme (WCRP), the SysTem for Analysis, Research and Training (START) and Future Earth. Member agencies support the Belmont Forum's Collaborative Research Actions (CRAs), and the U.S. has played a major role in development of the first and second CRAs on Climate, Environment and Health.

Observing Systems

The U.S. maintains an extensive and diverse observing portfolio that includes in-situ, airborne, autonomous vehicle and satellite-based sensors on land, and in the oceans, atmosphere and cryosphere. Observing field campaigns are sometimes combined with other approaches to provide comprehensive understanding of shorter – and longer-term processes on local scales, nested regionally or globally. For an extensive list of examples of ongoing, planned, and completed observational efforts through Fiscal Year 2020 that illustrate the breadth and depth of the Program's capabilities, please see the USGCRP Observations Compendium (https://www.globalchange.gov/about/iwgs/obsiwg/observation_compendium).

Small satellites, artificial intelligence, and new sensor development are providing new and improved ways to observe the Earth and ingest data. USGCRP member agencies often support private-public partnerships to promote innovation in observing approaches and data treatment. The National Academies of Sciences, Engineering and Medicine (NASEM) prepared the second Decadal Strategy for Earth Observations from Space[244] for NASA, NOAA and USGS in 2018, which is helping to inform future satellite mission planning.

The U.S. remains committed to making observing data freely and openly available to all. The agencies most active in satellite observations (NASA, NOAA and USGS) have extensive resources to aid scientific users. There is a growing effort to also make data more relevant, useful and usable for decision makers and managers. For example, NASA and USGS provide LANDSAT data free of charge from multiple websites: LandsatLook Viewer,[245] USGS GloVis: The Global Visualization Viewer,[246] and USGS Earth Explorer.[247] The USGS also freely offers the Landsat data collection[248] which consists of a global set of high-quality, relatively cloud-free imagery from Landsats 1-5 and 7. This dataset was selected and generated through NASA's Commercial Remote Sensing Program, as part of a cooperative effort between NASA and the commercial remote sensing community to provide users with access to quality-screened, high-resolution satellite images with global coverage over the Earth's land masses. Over 16,000 images are freely available.

GENERAL POLICY ON AND FUNDING OF RESEARCH AND SYSTEMATIC OBSERVATION

USGCRP member agencies fund global change research, observations and related activities through support for scientists working in federal agencies, federally-supported laboratories and the academic community. Agency budgets for global change research are based on annual appropriations from Congress and are reported yearly in the USGCRP annual report to Congress, *Our Changing Planet* (see https://www.globalchange.gov/browse/reports/our-changing-planet-FY-2020). The reported budget numbers do not reflect agency investments in operations (e.g., NOAA weather satellites) that provide data also used for climate change research. The reported USGCRP Research and Development budget has remained relatively flat since 2009, at ~ $2.5B per year, including for the period 2016-2020. USGCRP member agencies work together on coordinated calls for proposals on selected topics nationally, and internationally through the Belmont Forum.

Data developed through US federal funding sources is required to be made publicly available nationally and internationally to both the private and public sectors. While different agencies have different policies, data is typically available on agency websites within a few weeks for remote sensing data and within a year for results determined by individual scientists. Major resources for global change data, and tools from multiple agencies - including the Climate Resilience Toolkit - are available at https://www.data.gov/climate/ .

RESEARCH

When Congress established the USGCRP in 1990, it recognized the need for multi-agency coordination to build the scientific understanding needed to tackle global and climate change, and to use that science to inform responses; they established USGCRP to provide that coordination. USGCRP uses decadal strategic plans and their updates to guide the program and annual updates to Congress, *Our Changing Planet,* to report on progress.

USGCRP's Strategic Planning

The USGCRP National Research Plan 2012-2021 and its update in 2017 (both available at globalchange.gov) represented a major shift for the whole-of-government program. They added a major new emphasis on informing decisions and developing a sustained assessment process to the traditional focus on fundamental understanding of the climate system and its interplay with wider global change. Selected outcomes from USGCRP's work in informing decisions and sustained assessments are highlighted in Chapter 6.

USGCRP is now developing its next decadal strategic plan, intended for release in 2022. The National Academies of Sciences, Engineering and Medicine (NASEM) has a Committee to Advise USGCRP; their recently released report "Global Change Research Gaps and Opportunities, 2022-2031"[249] will help inform the next USGCRP plan. The plan will be developed by senior career climate officials from the USGCRP member agencies. During plan development, USGCRP is soliciting input from a wide swathe of federal agencies with climate-related responsibilities and will hold public engagement sessions via NASEM. A draft version of the plan will be open for public comment and reviewed by the NASEM Committee to Advise USGCRP.

The Research Framework

This section highlights advances in climate and global change modeling. These clearly don't stand alone but rather tie closely to observations and process understanding work conducted by USGCRP agencies. Key observational capabilities are discussed in the following section.

Modeling Capabilities

Each year since 2015, USGCRP has hosted a 'Climate Modeling Summit' for representatives from the six major US climate model development centers and operational climate and weather prediction programs with the goal to improve the coordination and communication involving national climate modeling goals and objectives. Adjacent to each annual Summit, USGCRP also organizes a topical workshop that serves as a venue for focused technical discussion on a high-priority modeling topic facing the US and international prediction research communities.

The US climate modeling community is a serious participant in the World Climate Research Programme (WCRP), e.g., with commitments to provide model ensemble runs as part of all 23 Model Intercomparison Projects (MIPs). These MIPs are used by US research institutions to guide scientific priorities across federal agencies, e.g., as a means to more rapidly advance climate science, foster international collaborations, and serve societal needs.

To support the climate prediction community, the US federal agencies have made significant investments in the archiving and analysis of climate model outputs, in high performance computing for climate prediction, and linking climate models to impacts models over a variety of human sectors. The Earth System Grid Federation (ESGF) archives model ensemble runs for all climate models world-wide. It occupies a network of international nodes, and investments in its capabilities are provided by DOE, NASA, the European Union, Australia, and other countries. Finally, climate modeling supported by a variety of USGCRP agencies continues to evolve with more sophisticated predictions that combine climate change with impacts across a variety of agricultural, energy, water, and land use sectors, so that stakeholders have actionable information that meets their needs.

International Research Programs and Partnerships

The long-term strength of U.S. global change research—from sustaining Earth observations, to assessing global climate, to preparing for global change—depends on close engagement with international efforts. As part of its mandate under the Global Change Research Act, USGCRP works to improve coordination of U.S. activities with the programs of other nations and international organizations in order to promote international cooperation on global change research and build global change research capacity in developing countries.

The United States is the single largest contributor to intellectual content of IPCC reports, with well over 100 writing team members serving during the AR6 cycle, including on the four volumes comprising the AR6, three Special Reports (SR1.5, SRCCL, SROCC), and a Task Force on Green House Gases (TFI) Methodology Refinement. The U.S. Government routinely provides comprehensive reviews of the draft reports, involving a process open to the general public, hundreds of targeted reviewers, and convened expert panels to ensure rigor of submitted comments. The USGCRP also provides travel support to facilitate non-Federal U.S. scientist participation in international assessment activities (IPCC, UNEP OAP, IPBES, Arctic Council).

In support of its international mandate, USGCRP currently helps provide core budget support to three international science organizations: Future Earth, which builds interdisciplinary, cross-sectoral partnerships to advance global sustainability science; the SysTem for Analysis, Research, and Training (START), which provides opportunities for research, education, and training to scientists, policymakers, and practitioners in developing countries; and the World Climate Research Program (WCRP), which is the primary international coordination mechanism for climate system research.

The SERVIR program, also described in Chapter 7, is another example of international programming to support research and systematic observation. SERVIR is a joint initiative between NASA and USAID that develops demand-driven services, tools, and training for decision-makers in more than 50 countries. By connecting USAID's development network with NASA's science, geospatial technologies, and extensive satellite data, SERVIR helps strengthen local capacity to integrate science and technology into decision-making. Since 2004, SERVIR has collaborated with leading regional organizations in partner countries to help people and institutions track land use and land use changes, identify and manage climate risks, and prepare for and respond rapidly to hydroclimatic disasters and other hazards. In March 2019, USAID and NASA initiated activities for SERVIR-Amazonia, a five-year effort tto addresses the impacts of climate change on the Peoples' lives and livelihoods, and development challenges in the Amazon Basin, home to the world's largest tropical rainforest. SERVIR-Amazonia is one of five SERVIR regional hubs currently operating around the world, and is implemented through a network of local and international partners serving the Amazon region.

The United States played a leading role in the development of a Belmont Forum international Collaborative Research Action (CRA). CRA, launched in April 2019, focuses on issues at the intersection of climate, environment, and human health. The CRA will support international research teams of natural, health, and social scientists and stakeholders, working together to understand how climate variability and change influence human health and well-being, and to support effective responses. The initiative aims to generate scientific evidence and tools to support policy and decision-making that can enhance health system resilience to climate impacts and provide significant public health benefits.

Research and development of mitigation and adaptation approaches, including technologies

Federal agencies are prioritizing research and development investments into mitigation and adaptation solutions to reduce climate pollution in every sector of the economy and increase resilience to the impacts of climate change. Government investments include research, development, demonstration, and deployment to support the scale-up and transition to operations of emerging clean energy and other emissions mitigation enabling technologies, such as utility-scale energy storage and other zero-carbon grid resilience technologies; carbon capture, utilization and storage; clean hydrogen; advanced nuclear power; rare earth element separations; floating offshore wind; and sustainable biofuels/bioproducts. Chapters 4 provides information on a number of relevant programs. Other examples of federal agencies pursuing research investments include:

- The U.S. Department of Energy's Office of Energy Efficiency & Renewable Energy (EERE), whose mission is to accelerate the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions and ensure the clean energy economy benefits all Americans. EERE's strategy includes investments in five priority areas: decarbonizing the electricity sector; decarbonizing transportation across all modes; decarbonizing energy-intensive industries; reducing the carbon footprint of buildings; and decarbonizing the agriculture sector.
- The U.S. Department of Agriculture's Forest Service pursues research to conserve forests, increase carbon sequestration in forest ecosystems, and provide new energy efficient products and technologies for society. Forest Service science investigates the pools and fluxes of carbon in various ecosystems throughout the country and around the world. This work includes understanding the carbon cycle as influenced by forest type and age, but also knowing the impacts of forest management practices over time on carbon sequestration and patterns of carbon emissions. By understanding the dynamics of the carbon cycle, decision-makers can better incorporate carbon sequestration into management objectives.

Climate adaptation and resilience is also a priority for federal research, and agencies are pursuing greater understanding of adaptation approaches. Chapter 6 provides examples of this work; the programs below also illustrate these investments:

- The U.S. Geological Survey National and Regional Climate Adaptation Science Centers (CASCs) is a partnership-driven program that teams scientific researchers with natural and cultural resource managers and local communities to help fish, wildlife, waters, and lands across the country adapt to changing conditions. The CASC network places emphasis on generating actionable science, information and products that address identified science needs and are directly usable in supporting resource management decisions, actions, and plans. Development of actionable science requires scientists to work iteratively with the intended end users of the scientific product, such as resource managers and native communities.

- The U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) provides innovative and environmentally sustainable solutions to the nation's water resources challenges. Climate change is putting increasing pressure on water resources, and ERDC's technologies help provide safe and resilient communities and infrastructure. ERDC science and technology help the Army Corps of Engineers manage existing water resources infrastructure sustainably in the face of climate change and other challenges.

Systematic Observations

The United States has been a global leader in observing the ocean, atmosphere, land, space, and cryosphere. Along with international partners, observing networks have enabled monitoring of all domains for improved understanding of the integrated Earth system.

The U.S. Earth observation community has been developing new capabilities that leverage federal investments in artificial intelligence (AI), sensor miniaturization, small satellites, and private-public partnerships. Recent advances in machine learning have enabled automated image analysis as well as enhanced algorithm capabilities to accelerate the detection of climate change and provide near real time actionable information on evolving climate impacts for decision makers. The combination of sensor miniaturization and the lower costs of launching small satellites (smallsats) into orbit has created an opportunity for several private-public partnerships to design, build, and start to deploy constellations of satellites to fill gaps in Earth observation needs.

U.S. Group on Earth Observations (USGEO) is the interagency coordination mechanism for Federal Agencies' civil Earth observations activities, and for participation in the GEO international voluntary partnership. USGEO is a Subcommittee under the White House National Science and Technology Council's (NSTC) Committee on the Environment (CE). Its membership consists of 13 Federal Agencies and components of the Executive Office of the President; the 2019 National Plan for Civil Earth Observations guides this work.[250]

Applied uses of USGCRP agency observations

There are numerous applications of observations supported by the USGCRP federal agencies. The Observations Interagency Working Group (ObsIWG) supports a Compendium of Federal Earth Observation Activities[251] that is used to support coordination of field campaigns and other observing efforts across agencies. The compendium is also used to identify gaps in the sustained observing networks. The compendium provides data and information useful to scientists, policy makers and decision makers in all areas of climate science to better understand, assess, predict, and respond to global change.

Challenges for Earth Observations

Under the challenges of an Earth stressed by a changing climate, it is essential to monitor the environment to build our understanding of the functioning of the Earth system. Remote sensing and in situ systems are critical to collecting long-term, high-quality observations. Aging infrastructure and instrumentation is a concern facing our networks of tODAy and tomorrow. A number of instrument manufacturers have gone out of business during COVID, presenting a real challenge to observing communities. Natural hazards (e.g., volcanic eruptions, wildfires, severe storms) have also impacted field sites in vulnerable coastal and mountainous environments and other regions where climate change is impacting biomes. There are also general challenges attaining high temporal resolution at space-based stations and high spatial resolution data at ground sites. Ensuring a commitment to maintaining and strengthening our observing networks is essential to improve our ability to make appropriate decisions based on high quality observations.

Documentation of U.S. Climate Observations

Long-term data records enable development of indicators of climate and climate change. The Environmental Protection Agency (EPA) produces the Climate Change Indicators in the U.S. report [252]while the USGCRP manages an interagency indicators platform.[253] A Global Climate Dashboard[254] (https://www.climate.gov/) shows the time series for variables focused on climate change, climate variability, and climate projections.

The United States also contributes to work on Essential Climate Variable (ECV) datasets[255]–time series to enable understanding of the evolution of climate. They are also useful to guide mitigation and adaptation measures, and help attribute climate events to underlying causes while underpinning climate services. High priority ECVS for future investment include: cloud and radiation properties to help improve climate models, Arctic indicators to improve our understanding of highly complex and changing high latitude environments, soil moisture to understand drought and the potential for wildfire, and greenhouse gas fluxes. Key time series include greenhouse gases, sea ice, sea level/temperature, ocean heat, and polar ice mass.

Observing capabilities enable a plethora of scientific applications ranging from informing the global stocktaking exercises, improving severe weather forecasts and climate monitoring, and enabling better decision making for navigation, transportation, agriculture, wildfire and smoke forecasts, and resource management, to name a few.

Current surface and satellite based observations of land, oceans, atmosphere and cryosphere

Since we cannot observe all variables at all times, the growth of sustained in situ observing networks to provide point data, development of satellite networks to view large regions of earth from space, and planning of intensive field campaigns to systematically observe many variables over a short period to improve climate and other models are all essential to obtain a global view of earth's dynamic system. Following is a sampling of current observational networks and efforts leading to improved understanding of each domain.

In situ Atmospheric Observations

- The U.S. Climate Reference Network (USCRN) is a systematic and sustained network of climate monitoring stations with 114 commissioned stations in the contiguous United States, 21 stations in Alaska (with a plan to eventually have a total of 29), and 2 stations in Hawaii. These stations use high-quality instruments to measure temperature, precipitation, wind speed, soil conditions, and more.
- Stations in the Global Climate Observing System (GCOS) Surface Network (GSN), the GCOS Upper Air Network (GUAN), and in the Global Atmosphere Watch (GAW) are distributed geographically as prescribed in the GCOS and GAW network designs. The data (metadata and observations) from these stations are shared according to GCOS and GAW protocols.
- The Southern Hemisphere ADditional OZonesondes (SHADOZ) provides a consistent dataset from balloon-borne ozonesondes for ground verification of satellite tropospheric ozone measurements at 17 sites across the tropical and subtropical regions of the southern hemisphere.

In situ Ocean Observations

- Argo (https://argo.ucsd.edu/) is an international program that collects information from the ocean using a fleet of robotic instruments that drift with the ocean currents and move up and down between the surface and a mid-water level.

In situ Terrestrial Observations

- The National Science Foundation's National Ecological Observatory Network (NEON–https://www.neonscience.org/) is a continental-scale observation facility designed to collect long-term open access ecological data to better understand how U.S. ecosystems are changing. NEON monitors 81 ecosystems across the U.S. including freshwater and terrestrial ecosystems. It has been fully operational since 2019.
- The AmeriFLUX network (https://ameriflux.lbl.gov/) was established to monitor long-term measurements of CO , water, and energy exchange from a variety of ecosystems. The system helps define the current global CO budget, enable improved projections of future concentrations of atmospheric CO , and enhance the understanding of carbon fluxes, net ecosystem production, and carbon sequestration in the terrestrial biosphere.

In situ Cryosphere Observations

- NASA's Operation IceBridge (OIB), attempted to bridge the observing gap of Earth's Polar ice caps between the end of ICESat-1 mission in 2009 and the successful start of ICESat-2 observations in 2019 using a highly specialized fleet of research aircraft and the most sophisticated suite of innovative science instruments ever assembled to characterize annual changes in thickness of sea ice, glaciers, and ice sheets. In addition, IceBridge collected critical data used to predict the response of Earth's Polar ice to climate change and resulting sea-level rise.
- Oceans Melting Greenland (OMG) is a multi-year (2016-2021) NASA airborne field campaign to understand the role that the ocean plays in melting Greenland's glaciers. From the sky and the sea, OMG gathers in situ data about water temperatures and the glaciers all the way around Greenland to get a better idea of the impact of ocean water on the Greenland ice sheet to better understand global sea levels rise.

Satellite Based Measurements

- NOAA National Environmental Satellite Data and Information Service (NESDIS) currently has four geostationary and four polar orbiting satellites that continuously monitor the Earth's climate system. Since 2014, NOAA has launched two geostationary satellites which provide advanced imagery and atmospheric measurements of Earth's Western Hemisphere, real-time mapping of lightning activity, and improved monitoring of solar activity and space weather. In 2017, NOAA's first Joint Polar Satellite System (JPSS) satellite successfully launched to extend NOAA's global low earth orbit observations that serve as the backbone of both short – and long-term forecasts, including those that help NOAA to predict and prepare for severe weather events. In addition, NOAA NESDIS has a ninth satellite, DSCOVR, launched in 2015 to deep space to monitor solar activity.

- The NASA Earth Science Division currently has more than twenty-one Earth observing satellites in low Earth orbit. Since 2014, NASA has helped to launch fourteen satellite systems to monitor various parts of the climate system, including: precipitation, atmospheric carbon dioxide, soil moisture, hurricane winds, Earth's surface mass and water changes, ice-cloud-land elevation, forest canopy density, sea surface height, surface temperature and plant evaporative stress, carbon dioxide flux estimates, total solar irradiance, lightning, and stratospheric ozone and aerosols.

- NOAA has developed a new program, GeoXO, for the next generation of geostationary Earth observations, while NASA is implementing the Earth System Observatory, a set of five complimentary Earth-focused missions to provide information about climate change, natural hazards, wildfires, and agricultural processes. NASA is also working with various national and international partners to construct and prepare at least nine new satellites for launch in the next several years. These satellites will observe: precipitation intensity & storm structure, hazards and environmental change, land surface, CO_2/CH_4/CO over the Americas, hourly air quality for North America, megacity air pollution & human health, plankton & ocean ecosystems, far infrared energy escaping the polar regions, and coastal biogeochemistry for North America.

US Involvement in International Observing

The United States works with partners around the world on global climate observations, including through organizations such as the World Meteorological Organization (WMO) to coordinate global climate observations. Many U.S. observing communities work together in contribution to the international climate observing community under the Global Climate Observing System (GCOS). The mission of GCOS is to provide continuous, reliable, comprehensive data and information on the state of the global climate system. GCOS consists of the climate-relevant components of existing atmospheric, oceanic and terrestrial observing systems intended to meet the totality of national and international user needs for climate observations. The United States also contributes to Global Atmosphere Watch (GAW) which provides information and services on atmospheric composition to the public and to decision-makers relating to: the abundance greenhouse gases, the protective stratospheric ozone layer, and the levels urban air pollution and its impact on human health.

Another example of U.S. international collaboration is our support for the international expedition MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate)[256]–https://mosaic-expedition.org/), the first year-round expedition (2019-2020) exploring the central Arctic and the Arctic climate system. This was the largest international polar expedition in history with the German research icebreaker Polarstern spending a year trapped and drifting in ice across the Arctic Ocean to closely inspect the Arctic as the epicenter of immense warming in order to improve our understanding of global climate change. Hundreds of researchers from 20 countries participated and scientists are analyzing the free and openly accessible data to determine the key outcomes and next steps.

Data Management and Information Systems

While federally-managed Earth observations are typically collected for a specific purpose, these data are often found to be useful in other applications, including use by state, local, and international decision makers and in the private sector. It is therefore essential to manage and preserve observations data so that users can find, evaluate, understand, and utilize them in new and unanticipated ways. Examples of data management systems and guidance include:

- *Common Framework for Earth Observations Data*,[257] a USGEO product that provides guidance to data producers in Federal agencies for improving and standardizing their data-management practices.
- *Earth Observing System Data and Information System*,[258] which includes updated description and statistics from NASA
- *Socioeconomic Data and Applications Center*,[259] which includes updated description and statistics on SEDAC from NASA
- *National Integrated Drought Information System*,[260] a multi-agency partnership that coordinates drought monitoring, forecasting, planning, and information at federal, tribal, state, and local levels across the country.
- *Global Change Information System*,[261] which coordinates and integrates information about changes in the global environment and related societal effects, serves as a key access point to assessments, reports, and tools produced by the USGCRP, and guides users to global change research produced by the 13 USGCRP member agencies.
- *Data Access Tools for Climate and Health*[262]: the Climate and Health Monitor and Outlook (CHMO) is a multifaceted, experimental, interpretive product intended to improve the utility of seasonal-to-subseasonal information for heat health risk management.
- *U.S. Climate Resilience Toolkit*,[263] a website designed to help people find and use tools, information, and subject matter expertise from across the U.S. government to build climate resilience.

- *Climate.gov*[264] provides science and information to help people make decisions on how to manage climate-related risks and opportunities they face.
- *State of the Climate Report*,[265] NOAA's annual report, based on contributions from scientists around the world, and providing a detailed update on global climate indicators, notable weather events, and other data collected by environmental monitoring stations and instruments located on land, water, ice, and in space.
- U.S. EPA Climate Change Indicators in the United States[266] is a compilation of a key set of indicators related to the causes and effects of climate change by more than 50 data contributors from various government agencies, academic institutions, and other organizations.

242 https://www.21stcenturypower.org/

243 Departments of Agriculture, Commerce, Defense, Energy, Health & Human Services, Interior, State, Transportation; Environmental Protection Agency, National Aeronautics & Space Agency, National Science Foundation, Smithsonian Institution, U.S. Agency for International Development.

244 https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth

245 http://landsatlook.usgs.gov/

246 http://glovis.usgs.gov/

247 http://earthexplorer.usgs.gov/

248 https://lta.cr.usgs.gov/Tri_Dec_GLOO

249 https://www.nap.edu/catalog/26055/global-change-research-needs-and-opportunities-for-2022-2031

250 https://usgeo.gov/uploads/Natl-Plan-for-Civil-Earth-Obs.pdf

251 https://www.globalchange.gov/about/iwgs/obsiwg/observation_compendium

252 https://www.epa.gov/climate-indicators

253 https://www.globalchange.gov/indicators

254 https://www.climate.gov/

255 https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

256 https://mosaic-expedition.org/

257 https://usgeo.gov/uploads/common_framework_for_earth_observation_data.pdf)

258 https://earthdata.nasa.gov/eosdis

259 https://sedac.ciesin.columbia.edu

260 https://www.drought.gov/about

261 https://data.globalchange.gov

262 https://ephtracking.cdc.gov/Applications/heatTracker/

263 https://toolkit.climate.gov/

264 https://climate.gov/

265 https://www.ncdc.noaa.gov/sotc/

9
CLIMATE EDUCATION, ENGAGEMENT, WORKFORCE DEVELOPMENT AND TRAINING

Introduction

Diverse actors at the federal, state, tribal, and local levels in the United States are advancing many programs and curricula intended to educate the public and students about the science of and solutions to climate change. Workforce development programs at each of these levels also contribute to ensuring we support and empower workers to prepare them for work in modern, 21st century careers. The recently increased strategic focus of the federal government and its partners on climate change communication, engagement, and education programs in the United States seeks to promote a deeper understanding of the science of climate change, behavioral change, and stewardship, and to support informed decision making by individuals, organizations, and institutions. Additionally, there is increased focused on supporting a green jobs sector that provides good jobs and supports worker organizing and collective bargaining.

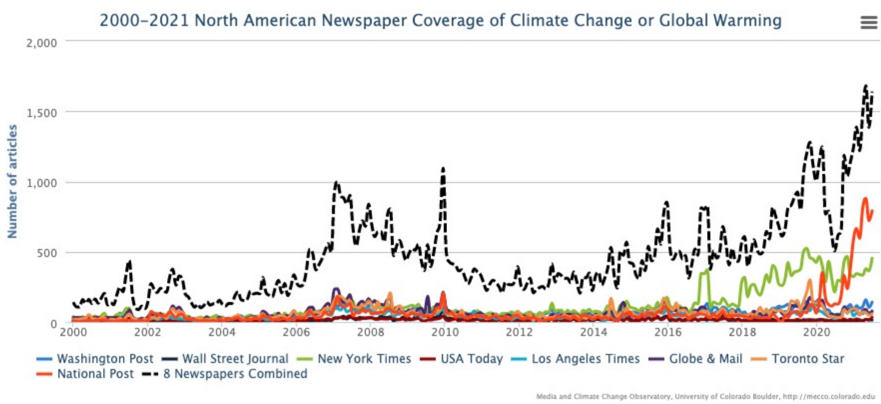
National Context in the United States

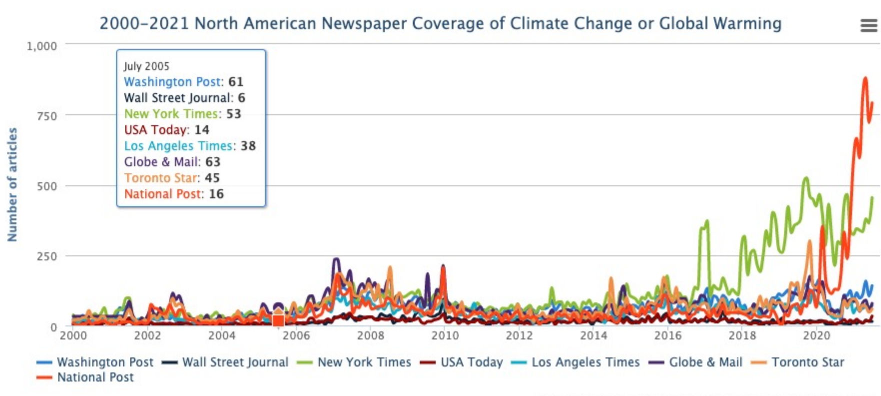
In a 2018 Climate Change in the American Mind survey conducted by Yale and George Mason Universities, only six percent of respondents said that humanity can and will reduce global warming, despite about half of respondents saying that global warming could be reduced if appropriate actions are taken. The same survey found that only about one-third of the public talks about global warming with family and friends "often" or "occasionally." Yet public concern about climate change reached an all-time high in 2020, with nearly 58 percent falling into the two most worried categories in the "Global Warming's Six Americas" survey.[267] Such a wide gulf between high levels of concern and low levels of confidence and engagement highlights the critical importance of effective climate change education, training, public awareness, public participation and public access to information. These activities are key to marshalling creativity, initiative, and collaboration among communities, organizations, and individuals—and are absolutely essential to creating a just transition to a low-carbon and resilient world.

Climate reporting and awareness

In 2019, news media coverage of climate change in North America increased substantially (Figure 9-1). Recent studies on the role of mass media in communicating climate science, mitigation, and adaptation have been mixed or more positive. The Center for Science and Technology Policy Research at the University of Colorado has tracked media coverage of climate change since 2000. Researchers there saw a worldwide uptick across all media in 2019 to present. However, more media coverage isn't always better. Depending on the sources, more media coverage can actually do a fair bit of damage–confusing and propagating disinformation, misinformation, or poor information. The cumulative effect of this increased media coverage is an active research topic.

Figure 9-1 **2000–2021 North American Newspaper Coverage of Climate Change or Global Warming**
The Center for Science and Technology Policy Research at the University of Colorado has tracked media coverage of climate change since 2000. Researchers there saw a worldwide uptick across all media in 2020 and 202112 in the five largest U.S. daily newspapers. https://sciencepolicy.colorado.edu/icecaps/research/media_coverage/north_america/index.html





In the United States, Millennials (born between 1981 and 1996) and adults in Generation Z (born after 1996) stand out in a 2021 Pew Research Center survey[268] with high levels of engagement on the issue of climate change. The Pew report finds "Compared with older adults, Gen Zers and Millennials are talking more about the need for action on climate change; among social media users, they are seeing more climate change content online; and they are doing more to get involved with the issue through activities such as volunteering and attending rallies and protests."

Updates since NC6

Climate change education, training, and outreach efforts have matured significantly since the 2014 6th National Communication even in the constrained budgetary environment of that time period. NGOs and federal, state, and local governments have conducted major communications campaigns to raise awareness and educate the nation about a variety of climate issues. As noted above, this chapter is not an exhaustive compilation of all of these actions.

Federal action

- **Climate Education and Literacy Initiative:** In 2014, the White House Office of Science and Technology Policy launched the Climate Education and Literacy Initiative[269] as part of President Obama's Climate Action Plan. This initiative helped American students gain access to science-based education about climate change over its active period. The initiative held roundtable discussions in which government officials, educators, and leaders from nonprofits and the private sector discussed ways to improve climate education and engagement in the U.S. through improving educators' access to educational resources and other methods, engaging citizens through place-based and informal climate education and providing a way for leaders across sectors to work together to improve understanding of climate risks and solutions. Participants included hundreds of educators, students, and engaged citizens, and have reached tens of thousands directly through their work, and countless more through social media and by delivering quality educational resources online and through other channels.[270]

- **U.S. Climate Resilience Toolkit:** As described in Chapter 6, the U.S. Climate Resilience Toolkit (toolkit.climate.gov), a federal website, was launched in 2014 and designed for state and local decision makers to bolster capacity for resilience to climate-related hazards. The toolkit introduced the Steps to Resilience, which incorporate risk management and decision making for climate-related hazards. The site structure and content support that framework.[271] It includes documents that chronicle the development, conceptual foundation, and evolution of this project to illustrate how to put data and tools into context for decision makers, by framing climate resilience within risk management, focusing on end users' stories, and engaging directly with users.

- **National Climate Assessments:** As noted in Chapters 6 and 8, the (USGCRP) is mandated is to develop and coordinate "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The NCA4 completed in 2018, was developed by a team of more than 300 federal and non-federal experts—including individuals from federal, state, and local governments, tribes and Indigenous communities, national laboratories, universities, and the private sector. A series of regional engagement workshops reached more than 1,000 individuals in over 40 cities, while listening sessions, webinars, and public comment periods provided valuable input to the authors. Participants included decision-makers from the public and private sectors, resource and environmental managers, scientists, educators, representatives from businesses and nongovernmental organizations, and the interested public. These stakeholder engagement processes were critical for ensuring that the communities, sectors, and industries most affected by climate change contributed to the creation of processes for continuous dialogue of informed and effective policy or planning decision-making.[272] Development of the Fifth National Climate Assessment (NCA5) is currently underway, with anticipated delivery in 2023.

- **Federal Program Coordination:** Federal agencies coordinate climate change educational, capacity-building, and engagement efforts through the USGCRP and other cross-cutting initiatives. USGCRP coordinates and integrates climate research across 13 government agencies: the Department of Agriculture, Department of Commerce, Department of Defense, Department of Energy, Department of Health and Human Services, Department of the Interior, Department of State, Department of Transportation, Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, Smithsonian Institution, and U.S. Agency for International Development. USGCRP focuses on encouraging greater public understanding of the science through the dissemination of relevant, timely, and credible global change information, as well as gaining further understanding of the public's science and information needs through engagement and dialogue. Many other federal agencies, such as the U.S. Environmental Protection Agency (EPA), National Park Service (NPS), Department of Energy (DOE), National Oceanic and Atmospheric Administration (NOAA), and National Institute of Food and Agriculture (NIFA), also communicate with citizens on specific aspects of climate change and climate justice. Many of these agencies have supported educational institutions and non-governmental organizations in developing a pipeline to create a workforce for a just and climate-safe future. While individual agency actions are important and their contributions in the aggregate are significant, one of the greatest strengths of USGCRP is its ability to develop synergies across federal agencies to coordinate efforts. USGCRP builds on the strengths of the participating agencies to coordinate the development of multi-agency products and programs, grow and expand the reach of information beyond single agencies, and ensure that feedback from public engagement is shared broadly within the federal climate change science community.

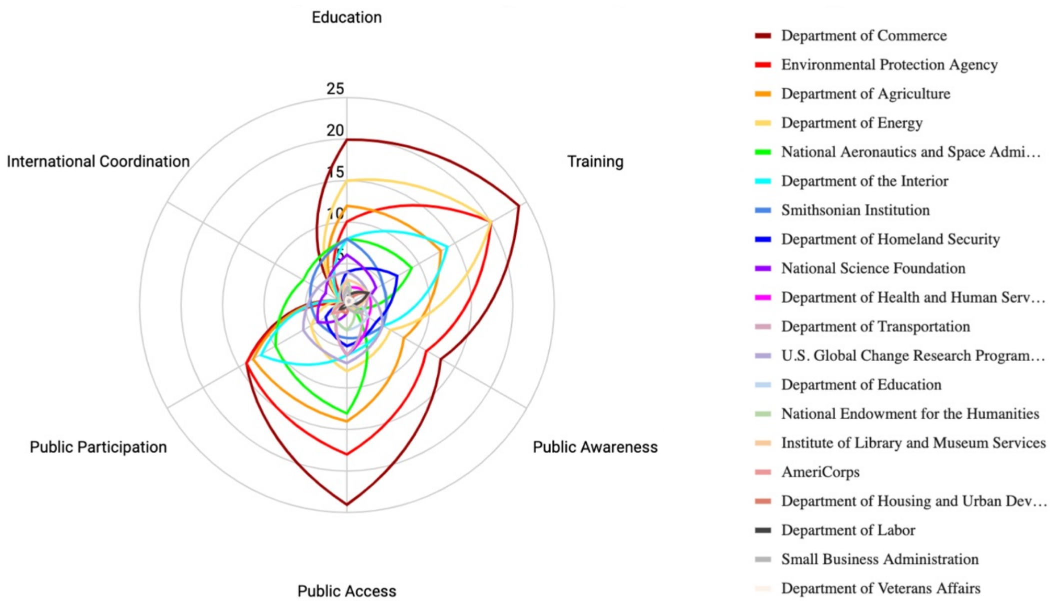
- **Federal Agency Education, Engagement, Workforce Development, and Training Program Overview:** A significant number of federal agencies provide state and local governments, industry, NGOs, and the public with information, education, workforce development, and engagement opportunities surrounding national and global climate change research and risk assessments studies, U.S. mitigation activities, and policy developments. They work both independently and in partnership with other agencies, NGOs, communities, and industry toward the common goal of increasing awareness, understanding, and preparedness for the potential environmental and societal challenges posed by climate change, as well as and opportunities for solutions. The Department of Labor supports the creation of clean energy jobs and training of 21st century workforce through targeted funding opportunities in apprenticeships programs and workforce re-training after job displacement from transition to clean energy. They also work closely with other agencies on their workforce programs, helping to form innovative partnerships across sectors.

In the summer of 2021, NOAA funded a federal inventory of existing and proposed ACE-related programs. Though this project is still ongoing, preliminary results identified 166 existing programs and 72 proposed ACE-related programs across 19 federal departments and independent agencies surveyed. This preliminary analysis included only program language in the President's Budget request or on Department websites; interviews with program directors and analysis of more federal departments will supplement these results in the future. These existing and proposed programs are summarized in Table 9-1 and Figure 9-2, below.

Table 9-1 **Existing and Proposed ACE-Related Programs**

	Total Programs		Number of Existing Programs Containing:						Number of Proposed Programs Containing:					
	Existing	Proposed	Education	Training	Public Awareness	Public Access	Public Participation	International Coordination	Education	Training	Public Awareness	Public Access	Public Participation	International Coordination
Department of Agriculture	17	5	9	8	5	10	10	1	3	5	3	4	3	0
Department of Commerce	20	17	11	12	8	15	8	1	9	12	5	9	6	0
Department of Education	1	1	1	0	1	1	1	0	1	1	2	2	1	0
Department of Energy	24	5	14	18	6	7	4	1	1	2	0	1	1	0
Department of Health and Human Services	4	2	2	2	1	4	1	0	0	1	2	2	0	0
Department of Homeland Security	3	6	2	2	1	2	1	0	2	5	3	3	2	0
Department of Housing and Urban Development	2	1	0	2	0	1	1	0	0	1	0	0	0	0
Department of the Interior	12	10	6	7	4	3	6	1	2	7	1	3	6	0
Department of Labor	1	2	0	1	0	0	0	0	1	2	0	0	1	0
Department of Transportation	4	4	1	1	2	3	1	0	0	2	0	3	0	0
Department of Veterans Affairs	0	1	0	0	0	0	0	0	1	1	0	0	0	0
AmeriCorps	3	0	1	3	0	0	2	0	0	0	0	0	0	0
Environmental Protection Agency	24	12	10	13	8	14	9	0	0	7	3	4	5	0
Institute of Library and Museum Services	3	0	3	3	1	0	2	0	0	0	0	0	0	0
National Aeronautics and Space Administration	20	1	8	9	1	12	9	6	0	0	0	1	1	0
National Endowment for the Humanities	3	0	3	0	1	3	2	0	0	0	0	0	0	1
National Science Foundation	8	1	5	3	0	1	4	2	1	1	0	0	0	1
Small Business Administration	0	2	0	0	0	0	0	0	2	0	2	0	0	0
Smithsonian Institution	9	2	7	5	5	4	4	4	1	0	0	0	0	1
U.S. Global Change Research Program (USGCRP)*	8	0	4	3	5	7	6	4	0	0	0	0	0	0
TOTALS	166	72	87	92	49	87	71	20	24	47	21	32	26	3

Figure 9-2 **ACE Elements Across Federal Departments and Agencies Climate Programs.**
A radar chart showing the number of programs in each identified federal department or agency (colored lines) that include a specific ACE element (labelled on the outside of the chart).



The analysis also included a look at which programs' budget and website language identified a focus on specific cross-cutting themes: gender-sensitive and intergenerational work, derived from the Doha Work Programme, and equity and justice, one of President Biden's priorities. These preliminary results suggest significant increase in focus on equity and justice in proposed programs, consistent with the Biden Administration's priorities for domestic efforts to address the climate crisis, and a less focus on gender-sensitive and intergenerational work in federal climate, education, training, and engagement programs.

Table 9-2 **CE Elements Across Federal Departments and Agencies Climate Programs.**

	Total Programs	Gender-sensitive Programs	Intergenerational Programs	Programs that focus on equity and justice	Percentage of programs that include at least one cross-cutting focus
Base	166	7	8	60	36%
Proposed	72	0	0	50	69%
Total	238	7	8	110	53%
Existing	166	7	8	60	36%
Proposed	72	0	0	50	69%
Total	238	7	8	110	53%

Sample Non-federal Climate Education, Engagement, Workforce Development and Training Initiatives Between 2014-2021

Non-Federal Spotlight

Community ACE Strategic Planning

Over the course of 2020 a community of stakeholders involved in ACE, including representatives from 120 different organizations, institutions, social movements, businesses, Tribes, federal agencies, and municipalities, worked to develop a (non-official) proposed ACE National Strategic Planning Framework for the United States.[273] This group found that one of the most effective ways to engage people with climate solutions and empower them to act is by incorporating the six ACE elements—education, training, public awareness, public access to information, public participation, and regional and international cooperation—into activities that are already taking place and integrating them into existing laws, regulations, investments and grants, and decision-making processes.

Implementing Next-Generation Science Standards

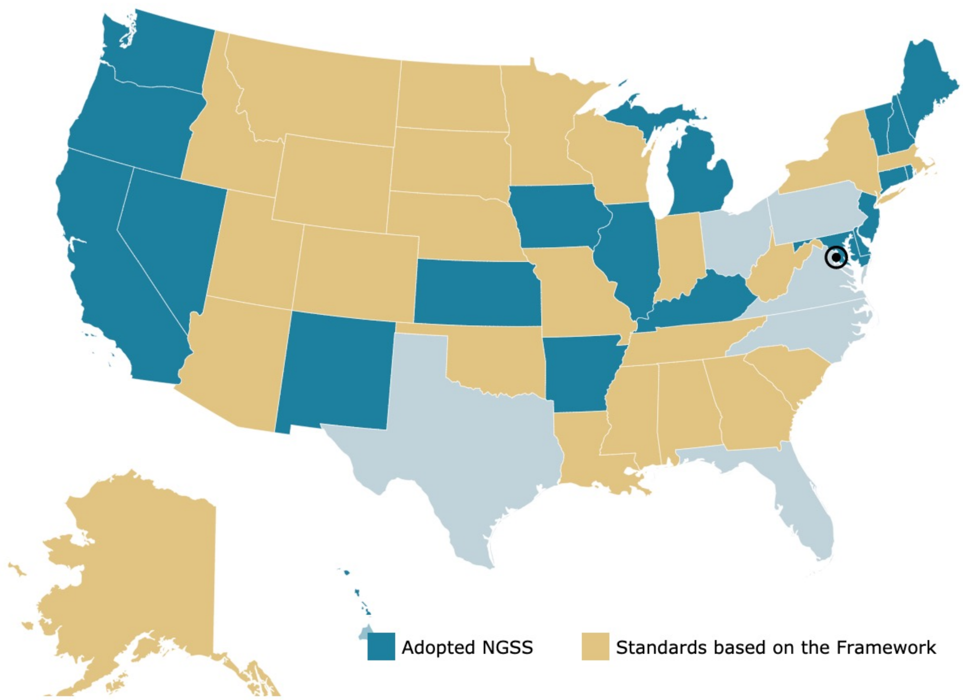
One of the most significant advances in K–12 climate change educational efforts remain the Next Generation Science Standards (NGSS) for teaching science in the United States. In 2013, the NGSS were released as the most current, research-based way of educating students in Science, Technology, Engineering and Math (STEM) and preparing them for STEM careers. The NGSS establishes high standards for delivering effective STEM education and includes a comprehensive and significant increase in climate change and solutions related education standards from kindergarten to twelfth grade.

In the United States, much responsibility for education policy, including science standards, lies at the state level. National educational policy on standards therefore remains limited. Whole Americans broadly recognize that educators should teach climate change, with 78 percent supporting teaching climate change in school,[275] an education gap exists. This 'education gap' represents a gap between scientific and societal understanding; that is, addressing climate change effectively will require transfer and use of knowledge (i.e., education) to enable informed decision-making at all levels in society. As a result, school districts have enacted NGSS in an uneven manner.

Several teams have conducted analysis of performance standards related to the topic of climate change. Science teachers have stated that standards like the NGSS are one of the main reasons for teaching climate change.[276] Thus, these detailed analyses can provide insights into where climate change is likely to be taught from grades K-12.[277]

K–12 Science Standards Adoption

Figure 9-3
As of August of 2021, forty-four states (representing 71 percent of U.S. students) have education standards influenced by the Framework for K-12 Science Education and/or the Next Generation Science Standards. (Source: NSTA@NGSS, https://ngss.nsta.org/)



Our Climate Our Future Project
Our Climate Our Future (OCOF)[278] is an interactive video series for young people about climate change produced by the nonprofit Alliance for Climate Education. The award-winning collection of videos and accompanying lesson plans on climate science, impacts and solutions was updated in 2019. This project provides resources students and educators need in order to take action on climate change in their community. Teachers use this resource independently in their classrooms. ACE already has a strong network of teachers across the country who repeatedly use Our Climate Our Future with their classes, year after year. Since 2009, Teachers have used OCOF videos to educate two million students and trained over 4,000 student leaders.

Empowering Youth with Youth Climate Summits

The Wild Center's Youth Climate Program[279] works to convene, engage, connect and empower young people around the world to take action on climate change. This program has become a global initiative that convenes, engages, and empowers young people to engage in climate change-related activities in their schools and communities through Youth Climate Summits. Each Youth Climate Summit is a one – or two-day event that brings youths–typically high school age–together to learn about climate science, impacts, and solutions. After a series of speakers, workshops, and activities, the Summit culminates with student participants writing a Climate Action Plan that can be implemented in their schools and communities. The solutions-focused education they receive at the summit often inspires students to begin a collaborative and productive dialogue with their respective civic and government leaders as they seek participation in their communities' climate change mitigation and adaptation plans. Additionally, students gain the knowledge, confidence, and skills necessary to communicate with decision-makers. The Wild Center's Youth Climate Summit model has been successfully replicated and scaled in science centers, museums, schools, community organizations, zoos, and aquariums. More than 90 Youth Climate Summits have taken place between 2015 and 2020 in 12 communities in New York State as well as Massachusetts, California, Maryland, Tennessee, Ohio, Colorado, Canada, Germany and Sri Lanka.

Figure 9-1

A three-day leadership retreat for youths, focusing on public speaking skills, problem-solving, project management, climate justice and sustainability. (Photo: Courtesy of Climate Initiatives, The Wild Center)[280]

Climate Literacy and Energy Awareness Network

CLEAN Network[281] is a growing community-based informal network of scientists, educators, policymakers, community leaders, students, and citizens who are engaged in fostering climate and energy literacy in the United States and abroad. CLEAN provides a forum for organizations, agencies, and individuals to collaborate towards more robust climate education. Members share ideas, coordinate efforts, promote policy reform, develop learning resources, and support integration of climate literacy into formal and informal education venues. Initiatives of CLEAN feature accurate, peer-reviewed scientific information, engaging learning experiences, and multiple formal and informal pathways to reach broad and diverse audiences.

Association of Climate Change Officers

Association of Climate Change Officers (ACCO)[282] was established in 2008 and incorporated in 2009 as a non-profit organization in order to build a community of practice serving the emerging occupation of climate leadership in the public and private sectors, as well as support other occupations whose professionals critically intersected with climate change. ACCO has already established a rich history of important convening, education and research synthesis. Amongst other accomplishments, ACCO established the first set of professional competencies for climate change officers; developed more than 20 courses covering a broad spectrum of disciplines and leveraging content contributions from nearly 400 federal and national experts and members; co-founded the U.S. EPA's Climate Leadership Awards program, including designing 3 of the program's awards categories and establishing evaluation criteria; and designed and launched Future CCOs, a post-graduate climate fellowship program.

National Network for Ocean and Climate Change Interpretation

The National Science Foundation funded National Network for Ocean and Climate Change Interpretation (NNOCCI)[283] is comprised of interpreters, educators, social scientists, climate scientists, and organizations working together in a thriving community of practice focused on creating social change through dialogue and public engagement in climate solutions. Since 2011, the community has grown training programs that employ emotionally aware facilitation, a cohort model of engagement, and skill-building for strategic framing for science communication. NNOCCI also includes a community of more than 180 informal science education institutions (ISEIs) and partnerships with academia throughout the United States. As of 2020, the community reports training more than 38,000 informal science educators who are now reaching more than 150 million visitors each year in informal science education institutions, as well as their colleagues in their community and their social networks. NNOCCI's consistent messaging about climate change across the country is changing public discourse to be positive, productive, solutions-focused, and supportive of community climate action.[284]

Climate Matters

Climate Matters[285] is an effective climate communication initiative. Early in the development process, the Climate Matters team came to recognize TV weathercasters as a community of practice, and they aimed to support this community as a strategy accelerating the use of localized climate science information and enhancing public understanding. Concurrent with the growth of the Climate Matters program, there has been a dramatic shift in how members of the broadcast meteorology community themselves view climate change, such that their views are now much more closely aligned with those of climate scientists.[286][287] The prior diversity of views about climate change—and the overt conflict in the meteorology community about those views—was itself a barrier to weathercasters reporting on climate change.[288] The program's rapid growth from a successful pilot-test in one media market to adoption in >90 percent of media markets nationwide provides evidence of the potential of a community of practice approach.[289]

Public Awareness on Climate

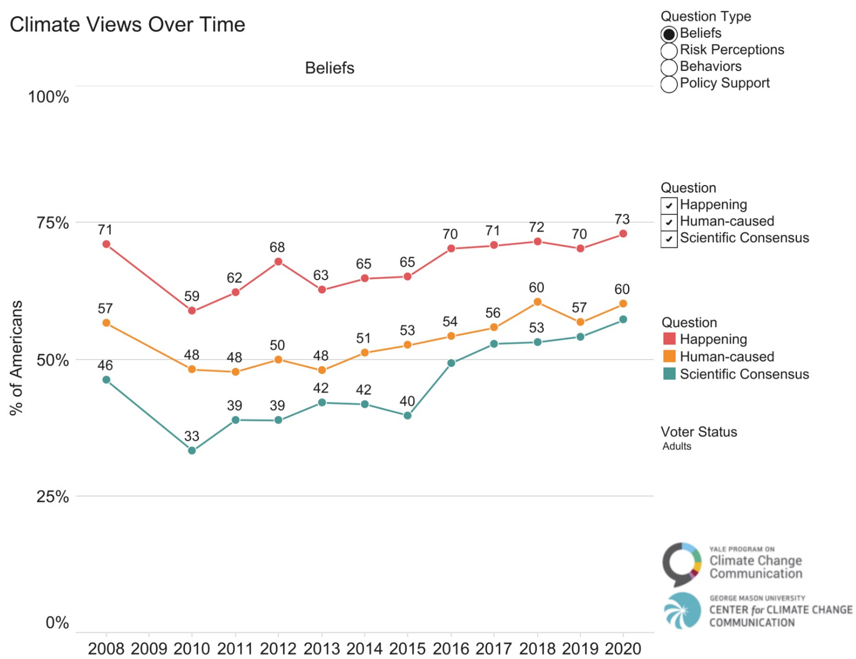
Capitalizing on Public Survey Research

During the past years, numerous organizations and federal programs have used public survey research on beliefs and attitudes from Yale University, George Mason University, and elsewhere to differentiate their climate and global change education and communication projects. The survey research underscores that people actively interpret information and construct their own mental models based on what they personally know, value, and feel. Using this research, the U.S. climate and global change communication and education community can be even more strategic in designing and implementing programs with limited resources.

Key findings for the latest research in 2020[290] include:

- A record-tying 73 percent of Americans think global warming is happening. Only one in ten Americans (10 percent) think global warming is not happening.
- A record-high 54 percent of Americans are "extremely" or "very" sure global warming is happening. By contrast, only 6 percent are "extremely" or "very" sure global warming is not happening.
- A record-tying 62 percent of Americans understand that global warming is mostly human-caused. By contrast, about three in ten (29 percent) think it is due mostly to natural changes in the environment.
- More than half of Americans (56 percent) understand that most scientists think global warming is happening. However, only about one in five (21 percent) understand how strong the level of consensus among scientists is (i.e., that more than 90 percent of climate scientists think human-caused global warming is happening).

Figure 9-4 **Trends in national public climate opinions over time**[291]



A graph showing trends in belief that climate change is happening (red), that it is human-caused (orange) and that there is scientific consensus around climate change (blue) among American adults. Graph reprinted courtesy of the Yale Program on Climate Change Communication and the George Mason University Center for Climate Change Communication.[292]

Emerging Regional Climate Literacy Networks

The climate change education and community engagement communities in the United States are increasingly developing strategies to accelerate local action on climate change through coordinated community-focused initiatives with education, youth leadership development, and workforce development outcomes. Through a series of innovative expert-stakeholder meetings, workshops, and summits in diverse parts of the country, a federal and non-governmental collaboration brought a unique spectrum of leaders together to promote a strategy to support local action on climate change education, youth and community engagement, and workforce development. Participants collaborated to diagnose gaps, challenges, and missed opportunities; identify effective practices and tools; and develop a shared strategy. These dialogs advanced efforts to apply tested strategies to identify knowledge, action, and coordination gaps and determine how expertise, institutions, networks, and resources can be brought together to create a more just, equitable, and resilient society. Some regional leading organization demonstrating the effectiveness of coordinating and coalition building efforts are Climate Generation: A Will Steger Legacy (St Paul, Minnesota), The CLEO Institute (Florida), Ten Strands (California), The Climate and Resilience Education Task Force (New York City), Communitopia (Pittsburgh, Pennsylvania), ClimeTime (Washington State), Renewable Energy Alaska Project (REAP) (Alaska), EcoRise (Texas)

Education-Focused Initiatives

The Aspen Institute launched the K-12 Climate Action[293] commission in 2020 to learn about the needs and opportunities for schools to move from climate education toward climate action. (Kindergarten ("K") refers to the first year of primary school for most children; grade 12 is the last year of secondary school.) The commission will develop an action plan that considers how the education sector can mitigate, adapt, educate, and advance equity to respond and address climate change. It is holding a listening tour, developing an action plan, and building a coalition to support our schools to be a force toward climate action, solutions, and environmental justice.

The commission has found Kindergarten-Grade 12 public schools can play a critical role in moving the United States towards environmental sustainability. If all the schools in the U.S. were to shift to clean energy, sustainable food use, and non-fossil fuel transportation over the next decade, the nation would have successfully transitioned one of the largest public sectors impacting the environment. This transition is especially impactful because of the potential for schools to transition to sustainability while educating their students about climate change and justice and helping prepare youth to confront the climate challenges of the future.

266 https://www.epa.gov/climate-indicators

267 Leiserowitz, A., Maibach, E., Roser-Reneuf, C., Rosenthal, S., Cutler, M., & Kotcher, J. (2018) Climate Change in the American Mind: March 2018 [Online]. Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication. Available at https://climatecommunication.yale.edu/publications/climate-change-ameri- can-mind-march-2018

268 https://www.pewresearch.org/science/2021/05/26/gen-z-millennials-stand-out-for-climate-change-activism-social-media-engagement-with-issue/

269 https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/climateed-dec-3-2014.pdf).

270 https://obamawhitehouse.archives.gov/blog/2015/12/03/one-year-progress-climate-education-and-literacy

271 Gardiner, E.P., Herring, D.D. & Fox, J.F. The U.S. Climate Resilience Toolkit: evidence of progress. Climatic Change 153, 477–490 (2019). https://doi.org/10.1007/s10584-018-2216-0

272 Yamineva, Y., 2017: Lessons from the intergovernmental panel on climate change on inclusiveness across geographies and stakeholders. Environ. Sci. Policy, 77, 244–251, https://doi.org/10.1016/j.envsci.2017.04.005.

273 Bowman, T., Morrison, D. (2020) An ACE National Strategic Planning Framework for the United States [Online]. Created in collaborative reflection with the U.S. ACE Community. Available at http://aceframework.us.

274 https://aceframework.us/the-framework

275 Cheskis, A., Marlon, A., Wang, X., and Leiserowitz, A. (2018). Americans support teaching children about global warming. New Haven, CT: Yale University–Yale Program on Climate Change Communication. Retrieved from: http://climatecommunication.yale.edu/publications/ americans-support-teaching-children-global-warming/

276 Wise, S. B. (2010). Climate change in the classroom: Patterns, motivations, and barriers to instruction among Colorado science teachers. Journal of Geoscience Education, 58(5), 297-309.

277 https://d32ogoqmya1dw8.cloudfront.net/files/clean/educational_resources/clean-ngss/how_learning_about_climate_change_p.pdf

278 https://ourclimateourfuture.org/

279 https://www.wildcenter.org/our-work/youth-climate-program/

280 https://i2.wp.com/yaleclimateconnections.org/wp-content/uploads/2021/04/0321_NYC_SummitActionPlanning.jpg?w=974&ssl=1

281 https://cleanet.org/clean/community/

282 https://climateofficers.org/

283 https://climateinterpreter.org/about/projects/NNOCCI

284 Henderson, J., & Drewes, A. (Eds.). (2020). Teaching Climate Change in the United States (1st ed.). Chapter 9. Routledge. https://doi.org/10.4324/9780367179496

285 https://medialibrary.climatecentral.org/about-us

286 E Maibach 2021 Environ. Res. Lett. 16 025004

287 Perkins D, Timm K, Myers T and Maibach E 2020 Broadcast meteorologists' view on climate change: a state-of-the-community review Weather Clim. Soc. 12 249–62

288 Stenhouse N, Harper A, Cai X, Cobb S, Nicotera A and Maibach E 2016 Conflict about climate change at the American Meteorological Society: meteorologists' views on a scientific and organizational controversy Bull. Am. Meteorol. Soc. 98 219–23

289 Supporting communities of practice as a strategy to accelerate uptake of environmental science for climate action: TV weathercasters as a case study, E Maibach1, Published 27 January 2021 • © 2021 The Author(s). Published by IOP Publishing Ltd, Environmental Research Letters, Volume 16, Number 2

Citation E Maibach 2021 Environ. Res. Lett. 16 025004

290 https://climatecommunication.yale.edu/publications/climate-change-in-the-american-mind-april-2020/2/

291 https://climatecommunication.yale.edu/visualizations-data/americans-climate-views/

292 Ibid.

293 https://www.k12climateaction.org/

Annex 1

3RD AND 4TH BIENNIAL REPORTS[294]

Endnotes

294 The 3rd and 4th Biennial Reports of the United States are being submitted jointly, as an annex to the 7th National Communication of the United States

1 SUMMARY OF GREENHOUSE GAS EMISSIONS AND REMOVALS

Please see Chapter 2 of the attached 7th National Communication, which incorporates biennial report-related requirements.

2 DESCRIPTION OF TARGETS

QUANTIFIED ECONOMY-WIDE EMISSION REDUCTION TARGET

The United States communicated in 2010 a target of achieving economy-wide emissions reductions in the range of 17 percent below 2005 levels in 2020 (Table 1).[295] The United States reports on progress towards this target annually using its Inventory of U.S. Greenhouse Gas Emissions and Sinks,[296] which provides information on all of the sectors and gases covered in our economy-wide emissions target. Specifically, to determine whether the United States meets its 2020 quantified economy-wide emissions reduction target, we compare total net greenhouse gas emissions for 2020 with total net greenhouse gas emissions for 2005. This inventory-based accounting approach means that the U.S. target covers the full scope of emissions and removals under the UNFCCC inventory reporting guidelines, and the relevant data and methodologies are published in the annual inventory report.

Table A-1 **Key parameters for the U.S. 2020 quantified economy-wide emissions reduction target**

Parameter	Information
Base Year	2005
Target Year	2020
Emissions Reduction Target	In the range of 17 percent below 2005 levels
Gases Covered	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3
Global Warming Potential	100-year values from the IPCC Fourth Assessment Report (IPCC 2007)
Sectors Covered	All IPCC sector sources and sinks, as measured by the full annual inventory (i.e., energy, transport, industrial processes, agriculture, LULUCF, and waste)
Accounting for Land Use, Land-Use Change, and Forestry (LULUCF)	Emissions and removals from the LULUCF sector are accounted using a net-net approach and a 2005 base year, including a production approach to account for harvested wood products. The United States is considering approaches for identifying the impact of natural disturbances on emissions and removals.
Use of international market-based mechanisms	International market-based mechanisms will not be used in meeting the 2020 quantified economy-wide emissions reduction target.

Parameter	Information
Other	The United States uses a net-net accounting approach to determine whether it has achieved its 2020 target. Net emissions in the target year will be compared against net emissions in the base year to calculate the percentage emissions reductions achieved.

Table 1 Notes:

- The range specified in our 2020 target recognizes the important effect of external factors in determining emissions in a single year. We have not ascribed a specific margin to the range on one side or the other. The range is not conditional, and there are no underlying assumptions.
- The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* coverage of sectors and use of global warming potential values is consistent with the formal United Nations Framework Convention on Climate Change inventory reporting guidelines for developed countries (UNFCCC 2013). Values are those reported in the most recent report.
- CH_4 = methane; CO_2 = carbon dioxide; HFCs = hydrofluorocarbons; IPCC = Intergovernmental Panel on Climate Change; N2O = nitrous oxide; NF_3 = nitrogen trifluoride; PFCs = perfluorocarbons; SF_6 = sulfur hexafluoride.

NOTE: The full version of common tabular format 2(a-f) can be found in the electronic common tabular format submissions for Biennial Report 3 and Biennial Report 4.

Based on preliminary estimates of energy sector emissions and other activity data, the United States expects to achieve its 2020 target.

NATIONALLY DETERMINED CONTRIBUTION

In April 2021 the United States communicated its Nationally Determined Contribution (NDC): to achieve an economy-wide target of reducing its net greenhouse gas emissions by 50-52 percent below 2005 levels in 2030. As with the 2020 target, the NDC is absolute and economy-wide, covering all sectors and gases. It will be accounted for using a net-net accounting approach. Net emissions in the target year, as reported in the most recent *Inventory of U.S. Greenhouse Gas Emissions and Sinks* will be compared against net emissions in the base year from the same inventory to calculate the percentage emissions reductions achieved. Full details on the NDC are included in the information for clarity, transparency, and understanding accompanying the NDC communication, and found on the Interim NDC Registry.[297]

This 2030 NDC represents increased ambition compared to the NDC previously submitted in relation to 2025. This increased ambition is made possible in part through advances in technology and resulting market responses.

295 https://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/unitedstatescphaccord_app.1.pdf

296 The most recent Inventory of U.S. Greenhouse Gas Emissions and Sinks can be found here: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

297 https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf

298 Full text available at: https://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/

3
PROGRESS TOWARDS TARGETS

PROGRESS TOWARDS 2020, NDC TARGETS

As reported in Chapter 2 of this Biennial Report, the United States communicated a target of achieving economy-wide emissions reductions in the range of 17 percent below 2005 levels in 2020.[298] The United States NDC is to achieve an economy-wide target of reducing its net greenhouse gas emissions by 50-52 percent below 2005 levels in 2030.[299]

The United States applies a net-net accounting approach for both its 2020 target and its 2030 NDC, using net greenhouse gas emission estimates reported in the most recent Inventory of U.S. Greenhouse Gas Emissions and Sinks. [300]Net greenhouse gas emissions declined to 13 percent below 2005 levels in 2019, as reported in *the Inventory of U.S. Greenhouse Gas Emissions and Sinks* submitted in April 2021.[301] Based on preliminary estimates of energy sector emissions and other activity data, the United States expects to achieve its 2020 target.

Estimates of net greenhouse gas emissions reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* will also be used to assess progress towards the U.S. 2030 NDC.

MITIGATION ACTIONS AND THEIR EFFECTS

The United States has made continual progress toward its greenhouse gas emissions reduction targets. The success of these emission reductions can be attributed to, in part, by market transformations and energy use changes driven by both federal and nonfederal policy and measures, primarily across the electricity and transportation sectors. Since that 2020 goal was set, the United States has increased its ambition and put into place new policies and measure to drive down emissions and put the country on a path to achieve these goals. The policies and measure help modify long-term trends by locking in clean infrastructure, avoiding the lock-in of fossil fuel infrastructure, speeding the turnover of fossil fuel vehicle and appliance stock, influencing land use decisions and agricultural production practices, and shifting behaviors and culture in support of a clean energy future.

Chapter 4 of the National Communication describes the federal and nonfederal policies through 2020 that contribute to the United States' progress its commitments to reduce emissions. Annex 2 includes a detailed list of relevant policy and measures. The United States has also developed a National Climate Strategy that lays out priority policies and measures to take this decade to put the country on a path toward net-zero emissions no later than 2050, in line with its commitment under the Paris Agreement to pursue efforts to limit warming to 1.5°C.

There have not been significant changes since the previous report to the domestic institutional arrangements for domestic compliance, monitoring, reporting, archiving of information and evaluation of progress towards U.S. emissions reduction targets. Chapter 3 of the attached National Communication, and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, describe these in detail.

The United States supports partners around the world in developing stronger economies that are consistent with a global trajectory to net zero emissions by 2050. These efforts include programs to develop economic development paradigms that are consistent with ambitious global climate action, and measures to enhance the resilience of communities and economies in response to changes in global climate, trade patterns, and consumer preferences. This holistic, country-driven approach to supporting development efforts, including to capture the positive effects arising from the implementation of mitigation policies, programs and actions and enhance resilience against any negative impacts is at the heart of assistance provided by USAID and other U.S. technical agencies.

ESTIMATES OF EMISSION REDUCTIONS AND REMOVALS FROM LAND USE, LAND-USE CHANGE AND FORESTRY ACTIVITIES

A summary of inventory data for the 2005 base year and every subsequent reported year, is included in in Chapter 3 of the attached 7th National Communication. This information includes the total greenhouse gas emissions excluding emissions and removals from the LULUCF sector; emissions and removals from the LULUCF sector; and total greenhouse gas emissions, including emissions and removals from the LULUCF sector. In 2019, removals from the LULUCF sector were equivalent to 12 percent of total economy-wide greenhouse gas emissions.

USE OF UNITS FROM THE MARKET-BASED MECHANISMS

International market-based mechanisms will not be used in meeting the 2020 quantified economy-wide emissions reduction target.

At this time, the United States does not intend to use voluntary cooperation using cooperative approaches referred to in Article 6.2 or the mechanism referred to in Article 6.4 in order to achieve its NDC target.

unitedstatescphaccord_app.1.pdf

299 Full text available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf

300 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

301 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

4 PROJECTIONS

Please see Chapter 5 of the attached 7th National Communication, which incorporates biennial report-related requirements.

5
SUPPORTING THE GLOBAL COMMUNITY: CLIMATE FINANCE, TECHNOLOGY TRANSFER, AND CAPACITY BUILDING

Please see Chapter 7 of the attached 7th National Communication, which incorporates biennial report-related requirements.

Annex 2

SUMMARY TABLE OF POLICIES AND MEASURES

Table A-2 **Summary Table of Policiies and Measures Through 2020**

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Transport								
National Progwram for Light-Duty Vehicle GHG Emis-sions and CAFE Standards	Reduce GHG emissions from the light-duty vehicle sector	Establishes corporate emissions fuel economy and GHG emission standards for new light-duty vehicles (LDVs) produced for sale in the U.S.	CO2, CH4, N2O, HFCs	Implemented and Ongoing	Regula-tory	Model year 2012	Environmental Protection Agency, Department of Transportation	236,000
National Program for Heavy-Duty Vehicle GHG Emissions and Standards	Reduce GHG emissions from the heavy-duty vehicle sector	"Establishes fuel efficiency and GHG emission standards for work trucks, buses, and	CO2, CH4, N2O	Implemented and Ongoing	Regula-tory	2011	Environmental Protection Agency, Department of Transportation	37,700
Renewable Fuel Standard	Increase use of renew-able transportation fuels	Increases the share of renewable fuels used in transporta-tion via implementation of the Renewable Fuel Standard Program.	CO2	Implemented and Ongoing	Regula-tory	2011	Environmental Protection Agency	138,400

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Advanced Technology Vehicle Manufacturing Loan Program	Provide loans to advanced vehicle tech-nology manufacturers	Provides direct loans to qualifying U.S. advanced technol-ogy vehicles or component and engineering integration projects.	CO2	Implemented and Ongoing	Eco-nomic	2008	Department of Energy	26,179
SmartWay Transport Part-nership	Reduce GHG emissions from movement of goods.	Promotes collaboration with businesses and other stake-holders to decrease climate-related and other emissions from movement of goods.	CO2, BC	Implemented and Ongoing	Volun-tary	2004	Environmental Protection Agency	12,000
Control of Air Pollution from Airplanes and Airplane Engines: GHG Emission Stan-dards and Test Procedures	Reduce GHG emissions from certain classes of aircraft	Establishes greenhouse gas emission standards for air-planes used in commercial aviation and for large business jets. This action aligns U.S. standards with the internation-al carbon dioxide (CO2) emissions standards set by the International Civil Aviation Organization (ICAO).	CO2	Implemented and Ongoing	Regula-tory	2021	Environmental Protection Agency, Fed-eral Aviation Administration	n/a
National Clean Diesel Cam-paign	Reduce diesel emis-sions.	Reduces diesel emissions through the implementation of proven emission control technologies.	CO2	Implemented and Ongoing	Volun-tary	2008	Environmental Protection Agency	n/a
Light-Duty Vehicle Fuel Econ-omy and Environment Label	Provide information to vehicle buyers	Provides comparable information on new LDVs' fuel econ-omy, energy use, fuel costs, and environmental impacts.	CO2	Implemented and Ongoing	Regula-tory	2011	Environmental Protection Agency, Department of Transportation, Department of Energy	n/a
Federal Fleet Program	Reduce GHG emissions from the federal vehicle fleet	Requires federal agencies to acquire low greenhouse gas emitting (light-duty and medium-duty passenger) vehicles.	CO2	Implemented and Ongoing	Regula-tory	2010	Environmental Protection Agency	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
EPA Ports Initiative	Emissions reductions from ports	Program to reduce emissions from ports and other goods movement hubs through use of community engagement, data and analysis, funding, and information sharing.	All	Implemented and Ongoing	Volun-tary	2016	Environmental Protection Agency	n/a
State and Alternative Fuel Provider Fleet Program	Require fleets to pur-chase alternative fuel vehicles	Requires covered fleets either to acquire alternative fuel vehicles as a percentage of their annual LDV acquisitions or to employ other petroleum-reduction methods.	CO2	Implemented and Ongoing	Regula-tory	1992	Department of Energy	n/a
Vehicle Technology Deploy-ment (Clean Cities)	Support the use of alternative fuel vehicles and other petro-leum-reducing vehicle technologies	Provides technical assistance, consumer information, industry coordination, tools, knowledge-sharing, and cost-shared funding for local/regional projects that mitigate GHG emissions and reduce reliance on petroleum in the transportation sector.	CO2, CH4, NO2	Implemented and Ongoing	Eco-nomic	1993	Department of Energy	8,300
Anti-Idling Programs	Reduce GHG from com-mercial motor vehicles.	Decreased fuel consumption and greenhouse gas emis-sions due to reduced wait times and engine idling at the U.S.-Canada border and at U.S. inspection stations.	all	Implemented and Ongoing	Eco-nomic	2011-2015	Department of Transportation	n/a
Maritime Environmental and Technical Assistance Program	Reduce GHG emissions from the maritime sector.	Supports technology and innovation projects within the maritime sector to provide needed (and often lacking) information on applications to reduce and mitigate envi-ronmental impacts related to air and water quality.	GHGs, NOx, SOx, PM, BC	Implemented and Ongoing	Informa-tional	2010	Department of Transportation	n/a
On-Road GHG Assessment Tools	Support State and local strategies to reduce greenhouse gas (GHG) emissions from the transportation sector.	Supports and encourages State and local governments to estimate future GHG emissions from the on-road portion of the transportation sector and find strategies to mitigate these effects.	CO2	Implemented and Ongoing	Informa-tional	2011	Department of Transportation	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Alternative Fuel Corridors Program	Establish a national network of alternative fuel corridors.	Designates Alternative Fuel Corridors in collaboration with State and local partners for electric, hydrogen, natural gas and propane. Publishes corridor maps, information and technical guidance and supports mapping tools in cooperation with the Department of Energy.	All	Implemented and Ongoing	Volun-tary	2016	Department of Transportation	n/a
Continuous Lower Energy, Emissions and Noise Program	Reduce GHG emissions from the aviation sector.	The Continuous Lower Energy, Emissions and Noise (CLEEN) Program is the FAA's principal environmental effort to accelerate the development of new aircraft and engine technologies.	All	Implemented and Ongoing	Eco-nomic	2010	Department of Transportation	n/a
Carbon Offsetting and Reduc-tion Scheme for International Aviation	Reduce GHG emissions from the aviation sector.	Supports the monitoring, reporting, and verification of CO2 emissions from international flights pursuant to Annex 16, Volume IV–Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), of the Chica-go Convention.	CO2	Implemented and Ongoing	Volun-tary	2019	Department of Transportation	n/a
Next Generation Air Transpor-tation System	Reduce GHG emissions from the aviation sector.	Achieves more efficient aircraft operations and reduced GHG emissions through airspace, operational, and infra-structure improvements	All	Implemented and Ongoing	Eco-nomic	2004	Department of Transportation	n/a
Federal Transit, Highway, and Railway Programs	Reduce GHG emissions from the transit, highway, and railway sectors.	Helps public transportation providers, railways, and other key stakeholders to implement strategies that reduce GHGs.	All	Implemented and Ongoing	Eco-nomic	1991-2015	Department of Transportation	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Transit GHG Assessment Tools	Assist transit agencies with estimating the GHG emissions from transit projects.	The tool provides a resource to generate coarse but informative estimates of GHG emissions using limited project information and can be used for a broad range of transit projects.	All	Implemented and Ongoing	Volun-tary	2017	Department of Transportation	n/a
Low and No-Emission Com-ponent Assessment Program	Reduce GHG and reg-ulated emissions from transit buses.	Supports research for the testing, evaluation, and analysis of low or no emission components intended for use in “LoNo” transit buses to provide public transportation.	All	Implemented and Ongoing	Volun-tary	2017	Department of Transportation	n/a
Bus Testing Program	Reduce GHG and reg-ulated emissions from transit buses.	Provides information on transit bus GHG and regulated emissions to support FTA-funded transit operators in selecting cleaner and more efficient bus models for their fleets.	CO2, CH4, NOx	Implemented and Ongoing	Regula-tory	1989	Department of Transportation	n/a
Energy: Supply								
EPA Green Power Partnership	Reduce GHG emissions through green power purchases and use.	Supports U.S. organizations to voluntarily purchase green power to reduce the emissions, air pollution, and health impacts associated with the electricity consumption.	CO2	Implemented and Ongoing	Volun-tary	2001	Environmental Protection Agency	68,000
Enhanced Geothermal Sys-tems Demonstration Projects	Market development for geothermal generation.	Support the development and deployment of enhanced geothermal systems through demonstration project funding	CO2	Implemented and Ongoing	Eco-nomic	2009	Department of Energy	14,742
21st Century Power FEED Studies	Support the develop-ment of the generation plant of the future to provide secure, stable, and reliable power	Partnered with industry to develop Front End Engineering and Design studies for new generation facilities	CO2	Implemented and Ongoing	Eco-nomic	2019	Department of Energy	10,000

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru- ment	Imple- mentation Start Year	Implement- ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Onshore Renewable Energy Development Program	Encourage renewable energy development onshore	Provides opportunities for and encourages use of federal public lands for the development of wind, solar, and geothermal energy.	CO2	Implemented and Ongoing	Eco- nomic	Around 1980	Department of Interior	8,300
Modernize and Expand Rural Electricity Infrastructure	Expands electricity to rural communities	Provides loans to finance electricity infrastructure to ensure reliable and affordable electricity to rural commu- nities	CO2, N2O, SO2	Implemented and Ongoing	Eco- nomic	1936	Department of Agriculture	2,745
Rural Energy for America Program (REAP)	Fund energy efficiency and renewable energy systems	Provides grants and loan guarantees to various rural residents, agricultural producers, and rural businesses for energy efficiency and renewable energy systems.	CO2, CH4	Implemented and Ongoing	Eco- nomic	2008	Department of Agriculture	800
Rural Development Biofuels Programs	Fund expansion of biofuels and biobased products	Supports expansion of biofuels by providing incentives, funding and support to biorefineries and biofuel pro- ducers, and providing loan guarantees for biorefineries. Includes Biorefinery Assistance Program, Advance Biofuel Payment Program, and High Biofuels Infrastructure Incen- tive Program.	CO2, CH4	Implemented and Ongoing	Eco- nomic	2010	Department of Agricul- ture–Rural Development	5,674
EPA Combined Heat & Power Partnership	Reduce GHG emissions by encouraging energy efficiency	Encourages industry to engage and collaborate through EPA's Partner network. The Partnership serves as a resource center for assessing the environmental impact of thermal and electrical energy use through CHP project development.	CO2	Implemented and Ongoing	Informa- tional	2001	Environmental Protection Agency	n/a
Microgrid R&D	Research to advance distributed energy resources	Conducts applied R&D to make microgrid integral to transforming the nation's grid to a more resilient, reliable, and decentralized electricity delivery infrastructure	CO2	Implemented and Ongoing	Eco- nomic	2017	Department of Energy	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
RE-Powering America's Land Initiative	Promote renewable energy on formerly contaminated lands.	Encourages development of renewable energy on current and formerly contaminated lands, landfills, and mine sites by identifying contaminated lands that might be suitable for renewable energy development and providing technical assistance to communities.	CO2	Implemented and Ongoing	Eco-nomic	2006	Environmental Protection Agency	n/a
Advanced Reactor Demonstration Program	Demonstrate technology capable of decarbonizing the electricity sector and industrial process heat	Supports the design, development, licensing, construction and operation of two advanced nuclear reactor projects, resulting in the introduction of clean, resilient baseload power generation to the domestic power portfolio.	CO2	Implemented and Ongoing	Eco-nomic	2020	Department of Energy	n/a
Offshore Renewable Energy Program	Encourage renewable energy development offshore	Advances a sustainable Outer Continental Shelf renewable energy future through site planning and environmentally responsible operations and energy generation.	CO2	Implemented and Ongoing	Eco-nomic	2009	Department of Interior	n/a
Offshore Wind Demonstration Projects	Expand clean energy from offshore wind generation.	Support the development and deployment of offshore wind energy systems through demonstration project funding.	CO2	Implemented and Ongoing	Eco-nomic	2012	Department of Energy	n/a
Hydroelectric Production Incentive program	Expand clean energy from hydroelectric generation.	Supports the expansion of hydropower energy development at existing dams through an incentive payment procedure.	CO2	Implemented and Ongoing	Regula-tory	2005	Department of Energy	n/a
Methane Mitigation	Reduce methane emissions from the entirety of the natural gas supply chain.	Continue and expand upon existing RD&D efforts on technologies capable of embedded sensing and reduction of methane emissions within the natural gas infrastructure.	CH4	Implemented and Ongoing	Eco-nomic	2016	Department of Energy	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Energy: Residential and Commercial Energy End-Use								
ENERGY STAR Labeled Products	Reduce GHG emissions through energy effi-cient products.	Labels distinguish energy-efficient products in the mar-ketplace.	CO2	Implemented and Ongoing	Volun-tary	1992	Environmental Protection Agency, Department of Energy	266,000
Appliance, Equipment, and Lighting Energy Efficiency Standards	Establish minimum energy conservation requirements	Establish minimum energy conservation standards for more than 60 categories of appliances, equipment, and lighting.	CO2	Implemented and Ongoing	Regula-tory	1987	Department of Energy	232,000
ENERGY STAR Commercial Buildings	Reduce GHG emissions from US commercial building operations.	Partners with owners, managers, and occupants of all commercial buildings, as well as policymakers, to reduce GHG emissions through improved energy efficiency and increased use of renewable energy.	CO2	Implemented and Ongoing	Volun-tary	1995	Environmental Protection Agency	141,000
Home Performance with ENERGY STAR	Encourage energy-effi-ciency improvements in existing homes	Provides homeowners with resources to identify trusted contractors for high-quality, comprehensive energy audits and residential retrofits.	CO2	Implemented and Ongoing	Volun-tary	2002	Department of Energy	61,800
Building Energy Codes	Support energy-effi-cient building codes	Develops cost-effective building energy codes with adop-tion and compliance strategies.	CO2	Implemented and Ongoing	Regula-tory	1992	Department of Energy	39,700
Better Buildings Initiative	Support energy effi-ciency in buildings and facilities.	Catalyze change and investment in energy efficiency by developing innovative, replicable solutions with market leaders, making energy efficiency investment easier, developing a skilled clean energy workforce, and leading by example in federal government.	CO2	Implemented and Ongoing	Volun-tary	2011	Department of Energy	16,500

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
ENERGY STAR Residential New Construction	Reduce GHG emissions through energy effi-cient new homes and apartments.	Promotes improvement in energy performance in residen-tial buildings beyond the labeling of products.	CO2	Implemented and Ongoing	Volun-tary	1995	Environmental Protection Agency	6,700
Weatherization Assistance Program	Fund weatherization services for low-income households	Provides funding and technical support to states, U.S. territories, and tribes, which in turn work with a network of about 900 local agencies to provide trained crews to perform residential weatherization services for income-el-igible households.	CO2	Implemented and Ongoing	Eco-nomic	1977	Department of Energy	1,700
Grid Interactive Efficient Buildings (GEB) Initiative	Remake buildings into a clean and flexible energy resources.	Advance clean and flexible energy resources in buildings by combining energy efficiency and demand flexibility with smart technologies and communications to inexpen-sively deliver greater affordability, comfort, productivity, and performance to America's homes and buildings.	All	Implemented and Ongoing	Eco-nomic	2019	Department of Energy	n/a
Rural Energy Savings Pro-gram (RESP)	Fund energy efficiency and renewable energy for rural communities	Provides loan funds to eligible energy providers to relend to its customers for energy efficiency measures and customer owned renewable systems	CO2, N2O, SO2	Implemented and Ongoing	Eco-nomic	2016	Department of Agriculture	n/a
Federal Energy Management Program	Promote energy effi-ciency and renewable energy in federal facilities	Promotes energy efficiency and renewable energy use in federal buildings, facilities, and operations.	CO2	Implemented and Ongoing	Regula-tory	2008	Department of Energy	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instrument	Implementation Start Year	Implementing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Advanced Building Construction (ABC) Initiative	Integrate energy-efficiency solutions into construction practices for new buildings and retrofits.	Integrates energy-efficiency solutions into highly productive U.S. construction practices for new buildings and retrofits.	All	Implemented and Ongoing	Economic	2020	Department of Energy	n/a
Update energy efficient building codes and standards	Support energy-efficient investment in federally assisted affordable housing	Provides incentives for investing public – and private-sector funds in energy-efficient upgrades in 1.1 million housing units, and meets statutory requirements to update building codes and provide incentives for ENERGY STAR and other above-code green building standards in new federally assisted housing.	CO2	Implemented and Ongoing	Regulatory	2010	Housing and Urban Development, Department of Agriculture	n/a
Energy: Industrial Energy End-Use								
ENERGY STAR for Industry	Reduce GHG emissions from US manufacturing.	Partners with all manufacturing to reduce CO2 emissions, develop long-term decarbonization strategies, and provide performance measurement tools.	CO2	Implemented and Ongoing	Voluntary	2000	Environmental Protection Agency	43,000
Better Plants Initiative	Reduce energy consumption, carbon emissions, water consumption, and waste in the manufacturing sector	Provides guidance, tools and protocols to facilitate energy efficiency savings and improved energy performance	All	Implemented and Ongoing	Voluntary	2011	Department of Energy	40,000
Industrial Assessment Centers (IACs)	Encourage energy efficiency in industrial plants	Provide energy assessments to small and medium sized manufacturers and make energy efficiency, carbon reduction, water efficiency, and waste reduction recommendations.	All	Implemented and Ongoing	Economic	1976	Department of Energy	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Superior Energy Perfor-mance/ISO 50001	Reduce energy consumption in the manufacturing sector	Encourages the implementation of strategic energy man-agement systems that align to the ISO 50001 standard. Provides guidance, tools and protocols to facilitate energy efficiency savings and improved energy performance	All	Implemented and Ongoing	Volun-tary	2011	Department of Energy	n/a
Industrial Processes and Product Use								
Carbon Capture FEED Studies	Develop the next generation of advanced carbon dioxide (CO2) capture concepts	Partnered with industry to develop Front End Engineer-ing and Design studies to capture CO2 from generating facilities	CO2	Implemented and Ongoing	Eco-nomic	2019	Department of Energy	38,000
Carbon Dioxide Removal Program	Research, develop, and demonstrate CDR technologies and ap-proaches by investing in Direct Air Capture and mineral carbonation projects	Advance activities including DAC, bioenergy with carbon capture and storage (BECCS), mineralization, terrestrial carbon removal and sequestration (e.g., improved forest management, afforestation, reforestation), and coastal blue carbon (e.g., CO2 storage in wetlands).	CO2	Implemented and Ongoing	Eco-nomic	2020	Department of Energy	1,000
Methane Quantification	Support research for reducing methane emissions	Support large-scale tests to assess combined top-down and bottoms-up methane quantification processes to determine the most accurate and efficient mechanisms for methane emissions measurement and verification.	CH4	Under Develop-ment	Informa-tional	2016	Department of Energy	n/a
Carbon Capture Program	Research for carbon emissions capture.	Research, development, demonstration, and deployment (RDD&D) is focused on adapting technologies or making them robust enough to capture greater than 95% of the CO2 emissions from these wide variety of sources such as power plants, cement and steel facilities, refineries, petrochemical facilities, and other sources.	CO2	Implemented and Ongoing	Eco-nomic	2002	Department of Energy	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Carbon Storage Assurance Facility Enterprise (Carbon-SAFE)	Development of geo-logic storage sites for the storage of 50+ mil-lion metric tons (MMT) of carbon dioxide (CO2) from industrial sources	Works to address the technical and non-technical challenges specific to a CO2 storage project of this scale; develop a plan that encompasses technical requirements, economic feasibility, and public acceptance of an eventual storage project; and conduct high-level technical evalua-tions of the sub-basin and potential CO2 sources.	CO2	Implemented and Ongoing	Eco-nomic	2016	Department of Energy	10,000
Regional Carbon Sequestra-tion Partnerships	Support large-scale research for geologic carbon storage	Work to determine the best geologic storage approaches and apply technologies to safely and permanently store CO2 for their specific regions.	CO2	Implemented and Ongoing	Eco-nomic	2008	Department of Energy	n/a
Carbon Storage Program	Address the perfor-mance challenges of operating and monitor-ing commercial scale CO2 storage sites.	Assess and monitor long-term storage of CO2 at com-mercial volumes and timeframes and ensure the viability of geologic carbon storage as an effective CO2 emission reduction solution that can be widely implemented.	CO2	Implemented and Ongoing	Eco-nomic	2002	Department of Energy	n/a
Natural Gas STAR Program & Methane Challenge	Reduce GHG emissions from oil and natural gas companies.	Works with oil and natural gas companies to promote proven, cost-effective technologies and practices that improve operational efficiency and reduce methane (i.e., natural gas) emissions	CH4	Implemented and Ongoing	Volun-tary	1993 / 2016	Environmental Protection Agency	17,800
Coalbed Methane Outreach Program	Reduce GHG emissions from coal mining.	Voluntary program with the goal of reducing methane emissions from coal mining activities.	CH4	Implemented and Ongoing	Volun-tary	1994	Environmental Protection Agency	7,110
SF6 Emission Reduction Partnership for Electric Power Systems	Reduce GHG emissions from electric transmission and distribution.	Collaborative effort between EPA and the electric power industry to identify, recommend, and implement cost-ef-fective solutions to reduce sulfur hexafluoride (SF6) emissions.	SF6	Implemented and Ongoing	Volun-tary	1999	Environmental Protection Agency	1,090

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instrument	Implementation Start Year	Implementing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
CO2 Utilization	CO2 utilization technologies that have the potential to develop additional markets for CO2 based-products.	Partners with industry, Labs and academia for CO2 conversion to fuels, organic and inorganic chemicals, food and feeds, construction materials, energy storage, wastewater treatment, and others	CO2	Implemented and Ongoing	Economic	2015	Department of Energy	200
Methane and Waste Prevention Rule	Establish natural gas flaring and venting criteria during offshore oil & gas development activities.	Clarifies limits on the volume or length of time natural gas can be flared or vented during specific operational conditions and implements methods for accounting for flared and vented gas volumes.	CO2, CH4, N2O	Implemented and Ongoing	Regulatory	2010	Department of Interior	n/a
Fugitive Emissions	Reduce fugitive emissions from offshore oil and gas facilities.	Perform fugitive emission monitoring of offshore oil and gas facilities utilizing portable infrared cameras during risk-based air quality compliance inspections. The program helps identify fugitive sources and facilitate quick remediation.	CH4	Implemented and Ongoing	Regulatory	2010	Department of Interior	n/a
Significant New Alternatives Policy Program	Transition away from ozone-depleting chemicals.	Facilitates smooth transition away from ozone-depleting chemicals in industrial and consumer sectors.	HFCs, PFCs, SF6	Implemented and Ongoing	Regulatory	1990	Environmental Protection Agency	469,294
Federal Air Standards for Oil and Natural Gas Sector	Reduce volatile organic compound emissions from oil and natural gas sectors.	The new source performance standards control volatile organic compound emissions from various sources, substantially reducing methane emissions as a cobenefit.	CH4	Adopted	Regulatory	2012	Environmental Protection Agency	n/a
Chill Advanced Refrigeration Partnership	Reduce ozone-depleting and GHG emissions from supermarkets.	Reduces ozone-depleting and GHG refrigerant emissions from supermarkets through data collection, benchmarking, collaboration, and information sharing on technologies and practices to reduce emissions.	HFCs	Implemented and Ongoing	Voluntary	2007	Environmental Protection Agency	16,055

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO_2e) in 2030
Responsible Appliance Dis-posal Program	Reduces emissions from end-of-life appliances.	Reduces emissions of refrigerant and foam-blowing agents from end-of-life appliances.	HFCs	Implemented and Ongoing	Volun-tary	2006	Environmental Protection Agency	1,291
Voluntary Code of Practice for the Reduction of Emissions of HFC and PFC Fire Protection Agents	Reduces GHG emissions from fire protection agents.	Minimizes non-fire emissions of HFCs and PFCs used as fire-suppression alternatives, and protects people and property from the threat of fire using proven, effective products and systems.	HFCs, PFCs	Implemented and Ongoing	Volun-tary	2002	Environmental Protection Agency	n/a
Forestry and Land Management								
Forest Service Programs	Promote forest preser-vation and restoration	Restores the health of the nation's forests, woodlands, and rangelands.	CO_2	Implemented and Ongoing	Eco-nomic	1978-2020	Department of Agriculture–Forest Service	n/a
Agriculture								
Natural Resource Conserva-tion Service Programs	Promote sustainable development.	Helps landowners to implement practices or measures that address natural resource concerns	CO_2, N_2O, CH_4	Implemented and Ongoing	Eco-nomic, Informa-tional	1935-2014	Department of Agriculture	81,870
Conservation Reserve Program	Promote sustainable development.	Encourages farmers to convert highly erodible cropland or other environmentally sensitive acreage.	CO_2, N_2O	Implemented and Ongoing	Eco-nomic	1985	Department of Agriculture	17,500
AgSTAR	Reduce GHG emissions using biogas recovery.	Encourages the use of methane recovery technologies at confined animal feeding operations that manage manure as liquids or slurries.	CH_4	Implemented and Ongoing	Volun-tary	1994	Environmental Protection Agency, Department of Agriculture	10,770

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Waste								
Standards for New Sources and Emission Guidelines for Existing Sources–Landfills	Reduce GHG emissions at landfills	Requires owner and operators of new landfills to capture and control emissions from landfills including methane and requires states to develop rules updating require-ments for existing and fills to capture and control emis-sions from landfills including methane.	CH4	Implemented and Ongoing	Regula-tory	2016	Environmental Protection Agency	283,700
Landfill Methane Outreach Program	Reduce GHG emissions at landfills.	Reduces GHG emissions at landfills by supporting the recovery and use of landfill gas for energy.	CH4	Implemented and Ongoing	Volun-tary	1994	Environmental Protection Agency, Department of Agriculture	1,915
Cross-cutting								
Section 1703/1705 Loan Guarantee Program	Mitigate risks related to innovative advanced technology investments	Mitigates the financing risks associated with innovative and, in the case of the Section 1705 Program, some com-mercial energy projects	CO2	Implemented and Ongoing	Eco-nomic	2009	Department of Energy	52,780
Center for Corporate Climate Leadership	Support organi-zation-wide GHG measurement and management.	Serves as a resource center for organizations interested in GHG measurement and management, to reduce the business risks and environmental impacts associated with climate change.	All	Implemented and Ongoing	Informa-tional	2012	Environmental Protection Agency	n/a
Sustainable Materials Management and Circular Economy	Encourage sustainable materials management.	Provides a systemic approach to reduce the use of materi-als and their associated environmental impacts over their entire lifecycle.	All	Implemented and Ongoing	Volun-tary	2009	Environmental Protection Agency	n/a
National Energy Information Surveys and Analysis	Provide information and analysis critical to understanding energy	The U.S. Energy Information Administration collects, ana-lyzes, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy.	CO2	Implemented and Ongoing	Informa-tional	1977	Department of Energy	n/a

Name of policy or program	Objective of policy or program	Brief Description	Affected Gases	Status	Type of Instru-ment	Imple-mentation Start Year	Implement-ing Entities	Estimate of Mitigation Impact (kt CO2e) in 2030
Indian Energy Policy and Programs/Tribal Energy Program	Fund energy efficiency and renewable energy by tribes	Provides financial and technical assistance that enables American Indian and Alaska Native tribes to deploy renewable energy resources, reduce their energy costs through efficiency and weatherization, and increase energy security for tribes and villages.	CO2	Implemented and Ongoing	Eco-nomic	2010	Department of Energy	116
State Energy Program	Fund energy efficiency and renewable energy state programs	Provides funding to state energy offices to reduce market barriers to the cost-effective adoption of renewable energy and energy efficiency technologies.	CO2	Implemented and Ongoing	Eco-nomic	1977	Department of Energy	50
Mandatory Greenhouse Gas Reporting Program	Collect annual, accurate and timely GHG emissions data at the facility level.	Requires reporting of GHG emissions from 41 U.S. industry groups that, in general, emit 25,000 metric tons or more of CO2e per year. The reporting program covers 85–90% of total U.S. emissions from more than 8,100 facilities.	All	Implemented and Ongoing	Regula-tory	2009	Environmental Protection Agency, Department of Agriculture	n/a

Annex 3

PROVISION OF PUBLIC FINANCIAL SUPPORT TABLES

Table A3 **Provision of Public Financial Support: Contribution Through Multilateral Channels FY15-FY16**

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
2015									
Total contributions through multi-lateral channels									
Multilateral climate change funds									
1. Global Environment Facility	136,563,000.00	136,563,000.00	84,660,000.00	84,660,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
2. Least Developed Countries Fund			25,000,000.00	25,000,000.00	Committed	ODA	Grant	Adaptation	Cross-cutting
3. Special Climate Change Fund									
4. Adaptation Fund									
5. Green Climate Fund									

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
6. UNFCCC Trust Fund for Supplementary Activities			2,264,520.00	2,264,520.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
7. Other multilateral climate change funds									
Clean Technology Fund			185,000,000.00	185,000,000.00	Committed	ODA	Grant	Mitigation	Energy
Forest Investment Program			50,000,000.00	50,000,000.00	Committed	ODA	Grant	Mitigation	Forestry
Initiative for Sustainable Forest Landscapes			10,000,000.00	10,000,000.00	Committed	ODA	Grant	Mitigation	Forestry
Pacific Catastrophe Risk Assessment and Financing Initative			8,000,000.00	8,000,000.00	Committed	ODA	Grant	Adaptation	Cross-cutting
Capacity Building and Transparency Initiative			5,000,000.00	5,000,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
The Forest Carbon Partnership Facility			4,500,000.00	4,500,000.00	Committed	ODA	Grant	Mitigation	Forestry
Climate Technology Center and Network			1,000,000.00	1,000,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
Climate and Clean Air Coalition			2,540,000.00	2,540,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Pilot Auction Facility for Methane			7,500,000.00	7,500,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Multilateral financial institutions, including regional development banks									
1. World Bank	1,474,757,000.00	1,474,757,000.00			Committed	ODA	Grant		
2. International Finance Corporation									
3. African Development Bank	208,086,000.00	208,086,000.00			Committed	ODA	Grant		

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
4. Asian Development Bank	211,583,000.00	211,583,000.00			Committed	ODA	Grant		
5. European Bank for Reconstruction and Development									
6. Inter-American Development Bank	105,398,448.00	105,398,448.00			Committed	ODA	Grant		
7. Other									
Specialized United Nations bodies									
1. United Nations Development Programme	80,000,000.00	80,000,000.00			Committed	ODA	Grant		
2. United Nations Environment Programme	7,550,000.00	7,550,000.00			Committed	ODA	Grant		
3. Other									
Montreal Protocol Multilateral Fund			34,410,000.00	34,410,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Intergovernmental Panel on Climate Change / UN Framework Convention on Climate Change			7,735,480.00	7,735,480.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
2016									
Total contributions through multilateral channels									
Multilateral climate change funds									
1. Global Environment Facility	168,263,000.00	168,263,000.00	114,440,000.00	114,440,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
2. Least Developed Countries Fund									

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
3. Special Climate Change Fund									
4. Adaptation Fund									
5. Green Climate Fund			1,000,000,000.00	1,000,000,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
6. UNFCCC Trust Fund for Supplementary Activities			1,724,138.00	1,724,138.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
7. Other multilateral climate change funds									
Clean Technology Fund			170,680,000.00	170,680,000.00	Committed	ODA	Grant	Mitigation	Energy
Forest Investment Program			50,000,000.00	50,000,000.00	Committed	ODA	Grant	Mitigation	Forestry
Capacity Building and Transparency Initiative			5,000,000.00	5,000,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Multilateral financial institutions, including regional development banks									
1. World Bank	1,384,085,000.00	1,384,085,000.00			Committed	ODA	Grant		
2. International Finance Corporation									
3. African Development Bank	248,450,000.00	248,450,000.00			Committed	ODA	Grant		
4. Asian Development Bank	110,605,435.00	110,605,435.00			Committed	ODA	Grant		
5. European Bank for Reconstruction and Development									
6. Inter-American Development Bank	102,020,448.00	102,020,448.00			Committed	ODA	Grant		

Donor funding	Total Amount				Status	Funding ource	Financial instrument	Type of support	Sector
	Core/general		Climate-specific						
	Domestic Currency	USD	Domestic Currency	USD					
7. Other									
Specialized United Nations bodies									
1. United Nations Development Programme	80,000,000.00	80,000,000.00			Committed	ODA	Grant		
2. United Nations Environment Programme	7,000,000.00	7,000,000.00			Committed	ODA	Grant		
3. Other									
Montreal Protocol Multilateral Fund			34,250,000.00	34,250,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Intergovernmental Panel on Climate Change / UN Framework Conven-tion on Climate Change			8,275,862.00	8,275,862.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting

Table A4 **Provision of Public Financial Support: Contribution Through Multilateral Channels (FY17-FY18)**

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
2017									
Total contributions through multilateral channels									
Multilateral climate change funds									
1. Global Environment Facility	146,563,000.00	146,563,000.00	97,000,000.00	97,000,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
2. Least Developed Countries Fund									
3. Special Climate Change Fund									
4. Adaptation Fund									
5. Green Climate Fund									
6. UNFCCC Trust Fund for Supplementary Activities									
7. Other multilateral climate change funds									
Capacity Building Initiative for Transparency			5,000,000.00	5,000,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Initiative for Sustainable Forest Landscapes BioCar-bon Fund+			2,850,000.00	2,850,000.00	Committed	ODA	Grant	Mitigation	Forestry
Climate Technology Center and Network			990,000.00	990,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
Climate and Clean Air Coalition			490,000.00	490,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Multilateral financial institutions, including regional development banks									

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
1. World Bank	1,296,563,000.00	1,296,563,000.00			Committed	ODA	Grant		
2. International Finance Corporation									
3. African Development Bank	203,718,000.00	203,718,000.00			Committed	ODA	Grant		
4. Asian Development Bank	99,233,000.00	99,233,000.00			Committed	ODA	Grant		
5. European Bank for Reconstruction and Development									
6. Inter-American Development Bank	21,939,727.00	21,939,727.00			Committed	ODA	Grant		
7. Other									
Specialized United Nations bodies									
1. United Nations Development Programme	80,000,000.00	80,000,000.00			Committed	ODA	Grant		
2. United Nations Environment Programme	7,000,000.00	7,000,000.00			Committed	ODA	Grant		
3. Other									
Montreal Protocol Multilateral Fund			40,330,000.00	40,330,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
2018									
Total contributions through multilateral channels									
Multilateral climate change funds									
1. Global Environment Facility	171,855,000.00	171,855,000.00	113,424,300.00	113,424,300.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting
2. Least Developed Countries Fund									
3. Special Climate Change Fund									

	Total Amount								
	Core/general		Climate-specific						
Donor funding	Domestic Currency	USD	Domestic Currency	USD	Status	Funding ource	Financial instrument	Type of support	Sector
4. Adaptation Fund									
5. Green Climate Fund									
6. UNFCCC Trust Fund for Supplementary Activities									
7. Other multilateral climate change funds									
Multilateral financial institutions, including regional development banks									
1. World Bank	1,232,280,000.00	1,232,280,000.00			Committed	ODA	Grant		
2. International Finance Corporation									
3. African Development Bank	226,231,000.00	226,231,000.00			Committed	ODA	Grant		
4. Asian Development Bank	47,396,000.00	47,396,000.00							
5. European Bank for Reconstruction and Development									
6. Inter-American Development Bank									
7. Other									
Specialized United Nations bodies									
1. United Nations Development Programme	80,000,000.00	80,000,000.00			Committed	ODA	Grant		
2. United Nations Environment Programme	10,000,000.00	10,000,000.00			Committed	ODA	Grant		
3. Other									
Montreal Protocol Multilateral Fund			39,330,000.00	39,330,000.00	Committed	ODA	Grant	Mitigation	Cross-cutting
Intergovernmental Panel on Climate Change / UN Framework Convention on Climate Change			3,000,000.00	3,000,000.00	Committed	ODA	Grant	Cross-cutting	Cross-cutting

Table A-5 **Summary of provision of bilateral financial support FY2015-2018**

	CE	AD	SL	Total
Total Bilateral Climate Finance	**4828.296**	**1174.166**	**662.8439**	**6665.306**
Multiple Countries and Regions	**182.8702**	**202.272**	**141.4359**	**526.578**
Africa				
Benin	234	0	0	234
Burkina Faso	1.019031	0	0	1.019031
Burundi	10.597	0	0	10.597
Cameroon	0	0.703224	0	0.703224
Cote d'Ivoire	2.759153	0	0	2.759153
Ethiopia	7.617153	85.19355	0	92.8107
Ghana	8.884374	2.7	2.7	14.28437
Kenya	436.0801	5.317316	0	441.3975
Lesotho	0.475637	0	0	0.475637
Liberia	201.6	0.97	3.003	205.573
Madagascar	0.80433	0.73	0.73	2.26433
Malawi	1.382394	10.49569	14.418	26.29608
Mali	0	15.6266	0	15.6266
Morocco	0	52	0	52
Mozambique	2.25344	8.375	0	10.62844
Multiple	205.8762	30.79808	64.132	300.8062
Niger	0	198	10	208
Nigeria	53.05232	2	0	55.05232
Rwanda	0	4	0	4
Senegal	275.298	4	0	279.298
Sierra Leone	13.72184	16	0	29.72184
Somalia	1.33	0.5	0	1.83
South Africa	537.2459	0	0	537.2459
Tanzania	23.29583	17.37	0.65	41.31583
Uganda	31.04	9.95	2	42.99
Zambia	24.84235	0	18.2515	43.09385
No regional total is provided because "multiple region" funds also go to this region.				
Asia				
Afghanistan	1.769073	0	0	1.769073
Bangladesh	6.5	12.977	18.13	37.607
Burma	1.260031	0	0	1.260031
Cambodia	0	7.085	19.21435	26.29935

China	7.30635	1.073852	0.075	8.455202
India	433.7807	9.674822	27.076	470.5316
Indonesia	128.25	8.042448	68.092	204.3844
Kazakhstan	7.634	0	0	7.634
Laos	0.444784	0.272	0	0.716784
Maldives	0	4.7	0	4.7
Mongolia	0	303.13	0	303.13
Multiple	54.70006	15.75	31.886	102.3361
Nepal	341.775	7.57	0	349.345
Pacific Islands	0	9.5	0	9.5
Pakistan	200.688	0	0	200.688
Papua New Guinea	0	0.45	0	0.45
Philippines	9.143205	17.92678	14.9	41.96999
Sri Lanka	0	2.229	0	2.229
Tajikistan	2.5	0	0	2.5
Thailand	0	0.094089	0	0.094089
Timor-Leste	0	5.05	0	5.05
Uzbekistan	0.5	0	0	0.5
Vietnam	102.45	9.88	21.89	134.22
No regional total is provided because "multiple region" funds also go to this region.				
Europe & Eurasia				
Armenia	4.642	1.806	0	6.448
Bosnia and Herzegovina	3.218921	0.2	0	3.418921
Georgia	12.87	0	0	12.87
Kosovo	38	3.7	0	41.7
Moldova	1.9	0	3.5	5.4
Multiple	21.61609	0	0	21.61609
North Macedonia	0.2352	0	0	0.2352
Serbia	1.068	0.2	0	1.268
Ukraine	496.2	0	0	496.2
No regional total is provided because "multiple region" funds also go to this region.				
Latin America & Caribbean				
Antigua and Barbuda	0	0.8	0	0.8
Argentina	0.453667	0	0	0.453667
Bahamas	0	2.1	0	2.1
Barbados	0	0.12418	0	0.12418
Barbados and Eastern Caribbean	0	3	0	3
Belize	1.365057	1.06	0	2.425057
Brazil	3.906556	3.78635	7.633783	15.32669

Caribbean Islands	0	5.2	0	5.2
Chile	5	0	0	5
Colombia	11.25026	5	32.69	48.94026
Costa Rica	6.90455	0	0	6.90455
Dominican Republic	0.885071	6.78027	0.035	7.700341
El Salvador	188.4924	2.657	2.119505	193.2689
Guatemala	0.825319	9.619525	17.8	28.24484
Haiti	0.484999	1.695	17	19.18
Honduras	138.3095	10.9816	0	149.2911
Jamaica	142.0936	6.5	0	148.5936
Mexico	27.42481	6.8	30.25	64.47481
Multiple	41.61199	9.194	45.62484	96.43082
Panama	48.22971	0	0	48.22971
Paraguay	0	0.53	0	0.53
Peru	0.05	9.158	45.80705	55.01505
No regional total is provided because "multiple region" funds also go to this region.				
Middle East				
Jordan	65.97302	0.855668	0	66.82869
Lebanon	0	0	1.8	1.8
West Bank and Gaza	10.539	0.012	0	10.551
No regional total is provided because "multiple region" funds also go to this region.				

Values in millions of USD; CE = Clean Energy; AD = Adaptation; SL = Sustainable Landscapes

Annex 4

METHODOLOGIES USED IN THE REPORTING OF FINANCIAL INFORMATION

The UNFCCC reporting guidelines for national communications and biennial reports also specify that Parties are to provide the underlying methodology for all financial assistance provided (UNFCCC 2013a). Specifically, the guidelines state: "Parties shall report in a rigorous, robust and transparent manner the underlying assumptions and methodologies used to produce information on finance."

The United States conducted an interagency process to compile methodology documents for all figures for financial assistance provided in the BR, particularly those figures listed in table 7, 7(a) and 7(b) of the BR.

Pursuant to paragraph 15 of the 2011 UNFCCC biennial reporting guidelines for developed country Parties, this appendix provides background information on the underlying assumptions and methodologies used to produce information on finance for the 2016 BR. Specifically, this appendix describes:

- The overall methodology used for producing information on finance for the BR,
- The methodology for determining which funds are "climate-specific,"
- The methodology used to specify funds as "committed,"
- The methodology used for reporting core/general contributions through multilateral channels, and
- Other methodological issues.

OVERALL METHODOLOGY FOR PRODUCING INFORMATION ON CLIMATE FINANCE

The 2016 BR covers U.S. international climate finance for FY 2015-2018 (October 1, 2014, through September 30, 2018)). U.S. international climate finance is provided through the following channels:

- Grant-based finance, which is delivered through both bilateral and multilateral channels, and includes foreign assistance funding for international development through USAID, the Departments of State and Treasury, and MCC;
- Development finance through DFC; and
- Export credit finance through Ex-Im.

To ensure accurate and comprehensive reporting, interagency data requests were issued government-wide in 2015, 2016, 2017, 2018 to request information on climate-related international programs or activities supported with FY 2015-18 resources. In addition, DOS and USAID issued internal data calls for climate-related finance as part of their annual Operational Plan process.

Methodology for Determining Which Funds Are "Climate-Specific"

Climate-specific funds reported in the 2021 national communication and biennial reports are those assessed to support climate adaptation or mitigation. This includes activities that were conceived and funded specifically to achieve climate-related objectives, as well as activities that provide climate co-benefits. In cases where only a portion of a program's budget supports climate benefits, only that relevant fraction was counted—not the entire program budget.

U.S. international climate finance is categorized under the three thematic pillars :

- *Adaptation*—increasing resilience to the impacts of climate change;
- *Clean Energy*—reducing greenhouse gas emissions from energy, industry, and transportation by greater use of renewable energy, increased energy efficiency, and other means; and
- *Sustainable Landscapes*—reducing greenhouse gas emissions from forests, agriculture and land use.

Further details on each pillar follow. These details are specific to the data in the 2021 national communication and biennial reports (i.e., data for FYs 2015-18) and are subject to change in future reporting.

Adaptation

Adaptation programming seeks to reduce the vulnerability of people, places, and livelihoods to negative impacts of climate change by integrating effective adaptive strategies into key development sectors, including agriculture and food security, infrastructure, health, water, disaster preparedness, and conflict prevention. Types of activities include, but are not limited to:

- Developing tools for information dissemination or building new capacity among hydrometeorological information providers to deliver climate information and services.
- Providing support for modeling, mapping, and research to better understand climate impacts in specific regions or sectors.
- Strengthening government and local community response and communications capacity for climate change-related disasters, such as floods.
- Increasing public, civil society, and private sectors' awareness of and participation in climate change adaptation policy and action; strengthening the capacity of public institutions to integrate climate change adaptation into policy and administration; and improving coordination by government institutions on climate change adaptation policy.
- Increasing water storage and water use efficiency to deal with increased variability in water supply.
- Distributing drought-resistant seeds or promoting management practices that increase the ability of farmers to cope with reduced rainfall.
- Introducing and enforcing flood management plans and zoning and building codes, or coastal zone management activities, to reduce vulnerability to rising sea levels and storm surges.
- Reducing risk through such activities as implementing flood and famine early warning systems, negotiating transboundary water issues, and meeting critical infrastructure needs.

Clean Energy

Clean energy programming seeks to enable countries to accelerate their transition to climate resilience, lower greenhouse gas emissions, and sustainable economic development through assistance for clean, low-emission energy systems in the energy, industry, transportation, and buildings sectors. Types of activities include, but are not limited to:

- Promoting and deploying clean energy, including renewable energy technologies, energy-efficient end-use technologies, and carbon accounting.
- Assisting with the creation and implementation of national and sub-national low-emission development plans and actions, and nationally determined contributions (NDCs).
- Supporting and demonstrating clean energy technologies, such as development of agricultural biodigesters, improved cookstoves, solar water heaters, and electricity generation from landfill methane.
- Strengthening monitoring, reporting and verification (MRV) including actions to promote emissions inventories, carbon accounting, and carbon market readiness.
- Supporting an improved enabling environment (law, regulations, policies) for integrating renewable energy into national grids; enhancing cost recovery in the energy sector; and improving the financial and regulatory capacities of energy utilities.
- Supporting actions that enhance government and private sector capacity to promote low-emission development through institutional, policy, regulatory and market reforms.
- Supporting efforts to reduce gas flaring through the creation of domestic markets and productive uses for the previously flared gas.
- Supporting enhanced transmission, distribution, and operating systems, such as working to reduce technical losses in an energy distribution system, thereby reducing greenhouse gas emissions; or upgrading transmission and operating systems that carry clean energy, in whole or in part (if in part, only that share should be attributed).

Sustainable Landscapes

Sustainable Landscapes programming promotes greenhouse gas emission mitigation through sustainable land use practices. Types of activities include, but are not limited to:

- Developing national strategic plans on climate change mitigation, such as low emissions development strategies and REDD+ strategies, and building the capacity of institutions to implement low emission development.

- Building capacity to estimate, report, and monitor greenhouse gases from forest and land use at the national and/or subnational level, such as strengthening forest carbon inventory and monitoring systems.
- Supporting REDD+ projects intended to generate verified emissions reductions.
- Supporting enabling laws and policies, effective implementing institutions, climate smart agriculture, and social and environmental safeguards that enhance the development of low emissions development plans and/or REDD+ strategies.
- Establishing economic incentives for land use practices that reduce greenhouse gases, reduce conversion of ecosystems in order to protect biodiversity, watersheds, or other ecosystem services that will also result in reduced greenhouse gas emissions.
- Assistance with implementing land-use strategies that affect forests, for example, by addressing the most influential drivers of deforestation and forest degradation or by restoring degraded lands through enhanced tree cover.
- Forest conservation projects leading to reduced-impact logging and reduced deforestation.
- Forest conservation projects improving governance in indigenous reserves and protected areas that are under threat of deforestation.
- Improving land tenure systems that create incentives for communities to manage and restore forested areas, resulting in increased carbon sequestration in tree biomass.

METHODOLOGY USED TO SPECIFY FUNDS AS "COMMITTED"

The common tabular format for UNFCCC biennial reporting includes three options for the status of financial support: "provided," "committed," and "pledged." All public financial support reported in the 2021 national communication and biennial reports is considered to be "committed." Details regarding the meaning of "committed" across each of the channels of international climate finance follow:

For *grant-based finance*, funds reported as committed are those that have been appropriated by Congress and allocated by the funding agency for a specific fund, country, project, or program.

For *development finance*, funds reported as committed are those for which a commitment letter is signed and executed by all parties.

For *export credit*, funds reported as committed are those authorized by the Ex-Im for that particular purpose.

Methodology Used for Reporting Core/General Contributions through Multilateral Channels

For core/general contributions to multilateral channels that do not include a climate-specific component, data shown in the 2021 BR reflect total U.S. contributions to covered institutions, as collected as part of the U.S. government's reporting to the OECD Development Assistance Committee. While a portion of these funds is used by the recipient institutions to finance climate change activities in developing countries, the United States does not include these non-climate-specific contributions in topline numbers presented in the 2021 BR.

Other Methodological Issues

Tables 7, 7(a), and 7(b) include four categories for “type of support”: Mitigation, Adaptation, Cross-cutting, and Other. With the exception of some multilateral funds that are listed as Cross-cutting, U.S. data are presented as follows:

- All U.S. “clean energy” funds, projects, programs, and activities are listed as Mitigation.
- All U.S. “sustainable landscapes” funds, projects, programs, and activities are listed as Mitigation.
- All U.S. “adaptation” funds, projects, programs, and activities are listed as Adaptation.
- Tables 7(a) and 7(b) also include several options for “sector”: Energy, Transport, Industry, Agriculture, Forestry, Water and Sanitation, Cross-cutting, Other, and Not Applicable (7(a) only). To ensure consistency across the data set, information on sectors is tied directly to the three thematic pillars noted earlier. Specifically, U.S. data are presented as follows:
- All U.S. “clean energy” funds are listed as Energy.
- All U.S. “sustainable landscapes” funds are listed as Forestry and Agriculture.
- All U.S. “adaptation” funds are listed as Cross-cutting.

Annex 5

METHODOLOGY UPDATES—NON – CO_2 AND NON-ENERGY CO_2 PROJECTIONS

Methodology Updates

This appendix describes changes in non-CO_2 and non-energy CO_2 projections methodologies used for projections in this report in comparison to methodologies described in *Methodologies for U.S. Greenhouse Gas Emissions Projections: Non-CO_2 and Non-Energy CO_2 Sources*. Sources are only included here where a methodology change has been made. Use of an updated version of the same data sources are not included here.

Aluminum Production

Methodology

Activity Data

For this projection, existing aluminum production was assumed to remain constant at the production rate at the end of the most recent year. Aluminum production changes as a result of broader economic trends. Year-to-year changes in production levels are due to variations in utilization rate of plants, and this projection assumes that no new plants are built and no currently operating plants are shut down.

Emissions Factor

The global aluminum industry has agreed to a goal to reduce the average PFC emissions factor globally to the rate of the median plant by technology type (Marks and Bayliss 2010). Although the goal is stated on a global basis, the U.S. industry met this goal in 2018. As such, the emissions factor for PFC was assumed to be the constant at the base year 2018 level.

HCFC-22 Production

In the past, EPA separately projected feedstock and non-feedstock production of HCFC-22 based on historical production from the Greenhouse Gas Inventory, phase-down schedules for emissive uses, and projected global production growth for feedstock uses. However, due to the small number of producers, HCFC-22 production has been withheld from the GHGI for several years, and current estimates for U.S. production growth are not available. Previously, to project HCFC-22 production for feedstock uses, EPA assumed that feedstock production increases 5 percent each year in accordance with the global production estimate outlined by Montzka et al. (2010). For the current projections, emissions are projected based on the historical emissions trend.

Electrical Transmission and Distribution

Now using default extrapolation approach due to the lack of transmission miles data.

Electronics Industry

Methodology

Semiconductor manufacturing is an expanding industry in the United States, both in terms of the number of facilities and the production levels achieved by the current facilities. Over time, semiconductor devices have gradually become more complex, requiring more layers and more complex processes to manufacture. Complex devices with many layers require more steps involving fluorinated gases. Semiconductor manufacturing of wafers 200 mm or less have different emissions factors from the manufacturing of wafers 300 mm or more due to multiple factors, including greater complexity of devices manufactured using 300 mm wafers and different gas usage patterns. Facility-level data from the Greenhouse Gas Reporting Program (GHGRP) and World Fab Watch (WFF) indicate that emissions factors from facilities that produce 200 mm or less have been decreasing between 2014 and 2019, partially due to the continued transition away from using C2F6 in chamber cleaning processes in 200 mm facilities, while EFs from facilities that produce wafers 300 mm or more have been increasing due to increasing device complexity. For this reason, EPA projected emissions from semiconductor manufacturing by estimating future changes in emissions based on two wafer sizes: 200 mm or less and 300 mm or more.

Meanwhile, for both PV and MEMS manufacturing, based on the historical 10-year trend, emissions were projected to remain constant at the base year level through the projection period.

Projections of Emissions from Semiconductor Manufacturing

To estimate the emissions from semiconductor manufacturing of wafers 200 mm or less versus 300 mm or more, the total historical semiconductor emissions from the GHGI was separated into emissions by wafer size using the GHGRP. Specifically, the GHGRP provides emissions data from all reporting facilities as well as the wafer sizes produced in each facility.

The fraction of emissions by wafer size was then projected to the out year by interpolating the trends from the change in emissions factors by wafer size. Emissions factors by wafer size were calculated as total emissions per total manufactured layer area (TMLA), which represents the total area of all layers produced or the silicon area multiplied by the number of layers of the devices manufactured. TMLA data is provided by the WFF.

Activity growth, in terms of TMLA, can occur without a new fab being built. The capacity of a fab is measured in terms of the number of chips it can produce, which is a function of both number of wafers processed (i.e., the silicon consumed) and the number of die pieces produced per wafer (i.e., the number of individualized chips cut, or diced, out of a wafer). Growing demand for a product can be met by shrinking die size (which is accomplished by growing circuits vertically, or increasing the number of layers), which also improves performance and functionality.

CH_4 and N_2O Emissions from Forest Fires

Source Description

GHG fluxes occur due to changes within and conversions between certain land-use types, such as forest land, cropland, grassland, settlements, and wetlands.

The GHG flux from *Forest Land Remaining Forest Land* is reported under the 2006 IPCC Guidelines (IPCC 2006) using estimates of changes in forest carbon stocks, non-CO_2 emissions from forest fires (CH_4 and N_2O), and the application of synthetic fertilizers to forest soils. This section focuses on the non-CO_2 GHG emissions associated with forest fires (both wildfires and prescribed fires). Changes in forest C stock are beyond the scope of this appendix.

Methodology

EPA projected CH_4 and N_2O emissions from forest fires by multiplying projected forest hectares burned by historical average carbon density factors, default IPCC combustion rates, and ratios of CH_4 and N_2O emissions to CO_2 emissions. Projections of area burned are drawn from an average of several model estimates from published research (EPA, 2017).

Projections of Forest Fires

Wildfire projections for the lower 48 states were estimated using modeling results from the MC2 dynamic global vegetation model run by the U.S. Forest Service's Pacific Northwest Research Station (EPA, 2017). This analysis used ensemble averages of MC2 climate projection data from five general circulation models (GCMs) and the IPCC greenhouse gas concentration trajectory RCP 4.5 to provide gridded results at varying spatial and temporal scales that can inform plant and leaf types, nutrient movement, and vegetation disturbance by wildfire. MC2's fire model simulates wildfire occurrence, behavior, and various ecosystem effects. The fire model calculates the fraction of a 1/24° (~4 km) grid cell area that is burned over different lengths of time (e.g., annually, multi-year periods) as a function of the simulated rate of fire spread and the amount of time since the last fire event. The corresponding area burned in a cell is then calculated by multiplying the fraction burned by the cell area. The burned area per cell output was then adjusted to include only the proportion of any cell assumed to be forest land (EPA, 2017). The gridded forest area burned were aggregated to state and national totals for projecting the CH_4 and N_2O emissions from forest fires. This projection uses MC2 results from the RCP 4.5 climate scenario.

Wildfires in Alaska were estimated using modeling results from the Alaska Frame-Based Ecosystem Code (ALFRESCO) model (EPA, 2017). ALFRESCO simulates spatial processes of fire and recruitment across the circumpolar arctic/boreal zone by combining disturbance events, seed dispersal, and succession on a landscape. This analysis applied the ensemble average of ALFRESCO's climate projection data from five GCMs under the RCP 4.5 scenario. Area burned results from ALFRESCO were not adjusted to include only forest land nor to exclude developed and agricultural land use types.

The acreage burned from prescribed fires through in the lower 48 states and Alaska was not available. Therefore, the average acreage burned from prescribed fires in all 49 states for the five most recent inventory years was determined and assumed to remain constant through 2040.

Carbon Emitted

Estimates for carbon emitted include emissions from wildfires in both Alaska and the lower 48 states, as well as emissions from prescribed fires in all 49 states. ALFRESCO provided total area burned rather than forest area burned, so the average ratio of forest area to total area in all 50 states from the U.S. GHG Inventory (EPA, 2020) over the previous five years was applied, resulting in projections of forest area burned in Alaska.

As stated in the U.S. GHG Inventory (EPA, 2020), the emissions factors for the three categories of forest fires are:

- Wildfires in the lower 48 states: 31.7 to 34.4 megagrams carbon per hectare
- Wildfires in Alaska: 63.3 to 64.4 megagrams carbon per hectare
- Prescribed fires in lower 48 states: 11.4 to 11.7 megagrams carbon per hectare

For the projections, the average of each emissions factor was used. It was assumed that these emissions factors remain constant through the end of the projection period.

Conversion Factors

To estimate CO_2 emissions, EPA multiplied total carbon emitted by the C to CO_2 conversion factor of 44/12 and by 92.8 percent, which is the estimated proportion of carbon emitted as CO_2.

Equation 38

$$\boldsymbol{E_{ind,y} = E_{paper,y} + E_{food,y} + E_{others,y}}$$

Where:

$E_{CH4,y}$	=	Total annual CH_4 emissions from forest fires for year ***y***
$E_{C,y}$	=	Total annual C emissions from forest fires for year ***y***
92.8 %	=	Estimated proportion of C emitted as CO_2
44/12	=	Molecular weight ratio of CO_2 to C
$ER_{CH4,y}$	=	Emissions ratio of CH_4 to CO_2 for year ***y***

Equation 39

$$\boldsymbol{E_{i,y} = E_{i,b} \times \left(\frac{CO2Emissions_{i,y}}{CO2Emissions_{i,b}}\right)}$$

Where:

$E_{N2O,y}$	=	*Total annual N_2O emissions from forest fires for year y*
$E_{C,y}$	=	Total annual C emissions from forest fires for year ***y***
92.8 %	=	Estimated proportion of C emitted as CO_2
44/12	=	Molecular weight ration of CO_2 to C
$ER_{N2O,y}$	=	Emissions ratio of N_2O to CO_2 for year ***y***

Default emissions ratios between CH_4, N_2O, and CO_2 are calculated based on emissions factors for burning of forests. Default emissions rates for forests other than tropical forests are 1,569 grams of CO_2, 4.7 grams of CH_4, and 0.26 grams of N_2O per kilogram of dry matter.

LANDFILLS

Recovered CH_4 from Gas-to-Energy and Flaring

The U.S. GHG Inventory accounts for CH_4 emissions avoided (i.e., recovered) due to landfill-gas-to-energy (LFGTE) projects and flaring. Recovered CH_4 emissions was projected by using Greenhouse Gas Reporting Program (GHGRP) historical data which reports on the percent of landfills with collection systems and landfills without collection systems.

For landfills with collection systems, EPA used GHGRP data on the percent of landfills with collection systems, average gas collection efficiency, and destruction efficiency (GHGRP 2020). GHGRP data indicates that both the percent of landfills with collection systems and the average gas collection efficiency are nonlinear through time, likely because both variables have upper limits on technology improvement. EPA extrapolated the historical nonlinear trends through the end of the projection period. For GHGRP landfills without collection systems, EPA did not apply the gas collection efficiency or destruction efficiency.

Recovered CH_4 emissions from all GHGRP landfills was adjusted by a 9 percent scale-up factor per the GHG Inventory (2020) because not all landfills are covered under GHGRP. EPA then subtracted these recovered CH_4 emissions from the total annual CH_4 emissions projected from MSW landfills. The projected recovery and flaring ratio will be cross-checked against more detailed landfill-level modeling to ensure that it properly reflects industry practices and regulatory requirements.

Oxidized CH_4 from Landfills Prior to Release to Atmosphere

A portion of the CH_4 escaping from a landfill oxidizes to CO_2 in the top layer of the soil. The amount of oxidation depends upon the characteristics of the soil and the environment. For MSW, it was assumed that 19.5 percent of the CH_4 generated (minus the amount of gas recovered for flaring or LFGTE projects) was oxidized in the soil (EPA 2020). This percent is based on the 2011-2017 average from GHGRP reported facilities. For industrial landfills, an oxidation factor of 10 percent was applied to the estimates of CH_4 generation minus recovery (EPA 2020). The factor of 10 percent is consistent with the value recommended in the IPCC (2006) revised guidelines for managed and covered landfills.

INDUSTRIAL WASTEWATER TREATMENT

Source Description

Industrial wastewater CH_4 emissions originate from on-site treatment systems, typically comprised of biological treatment operations. The collection systems at an industrial plant are not as extensive as domestic wastewater sewer systems; therefore, it is not expected that dissolved CH_4 will form during collection. However, some treatment systems are designed to have anaerobic activity (e.g., anaerobic reactors or lagoons), or may periodically have anaerobic conditions form (facultative lagoons or large stabilization basins). Emissions will also result from discharge of treated effluent to waterbodies where carbon accumulates in sediments (typically slow-moving systems, such as lakes, reservoirs, and estuaries).

Industry categories that are likely to produce significant CH_4 emissions from wastewater treatment include those that generate high volumes of wastewater, those with high organic wastewater load, and those that treat wastewater using methods that result in CH_4 emissions. The top six industries that are likely to produce significant CH_4 emissions from wastewater treatment are pulp and paper manufacturing; meat and poultry processing; vegetables, fruits, and juices processing; starch-based ethanol production; petroleum refining; and breweries.

Methodology

Projections of methane emissions from industrial wastewater treatment were calculated using activity drivers for three industry groups: pulp and paper manufacturing; food and beverage processing (includes meat and poultry, vegetables and fruits, and breweries); and others (ethanol and petroleum refining). For the paper and the food industries, the activity drivers that EPA used are value of shipments from the *AEO* (EIA 2020). For other industries, EPA applied a linear interpolation to the historical production of ethanol and petroleum refining from the base year out to the final projection year.

Equation 47

$$E_{CH4,y} = E_{C,y} \times 92.8\% \times \left(\frac{44}{12}\right) \times ER_{CH4,y}$$

Where:

$E_{ind,y}$ =CH_4 emissions from all industrial waste water for year ***y***

$E_{ind\ ,}$ =CH_4 emissions from paper and pulp manufacturing waste water for year ***y***

$E_{ind,y}$ =CH_4 emissions from food and beverage processing waste water for year ***y***

$E_{ind,y}$ =CH_4 emissions from other industrial wastewater for year ***y***

Equation 48

$$E_{N2O,y} = E_{C,y} \times 92.8\% \times \left(\frac{44}{12}\right) \times ER_{N2O,y}$$

Where:

$E_{i,y}$ =CH_4 emissions from wastewater from industry ***i*** in year ***y***

$E_{i,b}$ =CH_4 emissions from wastewater from industry ***i*** in base year ***b***

$CO_2Emissions_{i,y}$ =Projected CO_2 emissions from wastewater from industry ***i*** in year ***y***

$CO_2Emissions_{i,}$ =Projected CO_2 emissions from wastewater from industry ***i*** in base year ***b***

i =Industries paper and pulp or food and