DENVER WATER CASE STUDY

Climate change is one of the biggest challenges facing the Denver Water system. Due to recent and anticipated effects of climate variability and change on water availability, Denver Water faces the challenge of weighing alternative response strategies and is looking at developing options to help meet more challenging future conditions.

Denver Water is using scenario planning in its long-range planning process (looking out to 2050) to consider a range of plausible future scenarios (Figure 26.6). This approach contrasts with its traditional approach of planning for a single future based on demand projections and should better prepare the utility and enhance its ability to adapt to changing and uncertain future conditions.

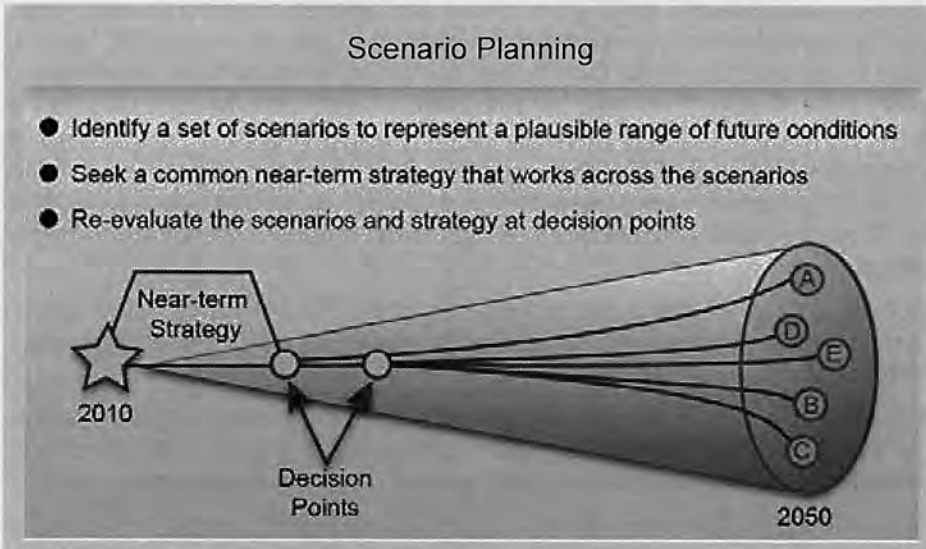

Figure 26.6: Scenario planning is an important component of decision-making. This "cone of uncertainty" is used to depict potential futures in Denver Water's scenario planning exercises. (Figure source: adapted from Waage 2010[122]).

Denver Water is assessing multiple scenarios based on several potential water system challenges, including climate change, demographic and water-use changes, and economic and regulatory changes. The scenario planning strategy includes "robust decision-making," which focuses on keeping as many future options open as possible while trying to ensure reliability of current supplies.

Scenario planning was chosen as a way to plan for multiple possible futures, given the degree of uncertainty associated with many variables, particularly demographic change and potential changes in precipitation. This method is easy to understand and has gained acceptance across the utility. It is a good complement to more technical, detailed analytical approaches.

The next step for Denver Water is to explore a more technical approach to test their existing plan and identified options against multiple climate change scenarios. Following a modified robust decision-making approach,[121] Denver Water will test and hedge its plan and options until those options demonstrate that they can sufficiently handle a range of projected climate conditions.

Scientific Assessments

Ongoing assessments of the state of knowledge allow for iterative improvements in understanding over time and can provide opportunities to work directly with decision-makers to understand their needs for information.[123] A sustained assessment process (Ch. 30: Sustained Assessment)[40] can be designed to support the adaptation and mitigation information needs of decision-makers, with ongoing improvements in data quality and utility over time. This report represents one such type of

assessment. The Intergovernmental Panel on Climate Change (IPCC) has prepared assessments of the state of the science related to climate change, impacts and adaptation, and mitigation since the late 1980s. Numerous additional assessments have been prepared for a variety of national and international bodies focused on issues such as biodiversity, ecosystem services, global change impacts in the Arctic, and many others.

WASHINGTON STATE'S CLIMATE ACTION TEAM: USES AND LIMITS TO DECISION SUPPORT

Between 2000 and 2007, pioneering work by the University of Washington's Climate Impacts Group (a NOAA RISA) tailored national climate models to the Pacific Northwest and produced, for the first time, specific information about likely adverse impacts to virtually every part of Washington's economy and environment if carbon dioxide concentrations in the atmosphere were not quickly stabilized.[124] The localized impacts predicted from these models were significant.

In February of 2007, Governor Christine Gregoire issued Executive Order 07-02, establishing the Climate Action Team (CAT).[125] Its charge was to develop a plan to achieve dramatic, climate-stabilizing reductions in emissions of greenhouse gases according to goals established in the Executive Order. The CAT was a 29-member team that included representatives of industry, utilities, environmental advocacy groups, Native American tribes, state and municipal governments, and elected officials.

The CAT met four to five times a year for two years. Between meetings, technical consultants, including boundary organizations such as the Climate Impacts Group, provided detailed analyses of the issues that were on the next CAT agenda. Technical experts were recruited to provide direct testimony to the CAT. Professional facilitators helped run the meetings, decipher the technical testimony, and keep the CAT on track to meet its obligations. All CAT meetings were open to the public, and public testimony was accepted. To assist in this effort, five subcommittees were created to develop proposals for achieving emissions reductions in the following parts of the economy: the built environment, agriculture, forestry, transportation, and energy generation. Similarly, adaptation groups were formed to develop recommendations for dealing with impacts that could not be avoided. These Preparation/Adaptation Working Groups focused on forest health, farmlands, human health, and coastal infrastructure and resources.

The CAT and the working groups were well supported with science and technical expertise. The CAT issued its first report, on reducing greenhouse gases, at the close of 2007.[126] It was well received by the legislature, and a significant number of its recommendations were implemented in the 2008 session.[127]

In 2008, the CAT continued its work. The focus shifted to whether Washington should join the Western Climate Initiative (WCI), a state and provincial organization that was developing a regional, economy-wide cap and trade system for carbon emissions. The same high-quality professional facilitation was provided at all meetings. Several highly qualified technical experts provided technical support.

With this support, the CAT produced another set of recommendations.[128] The centerpiece recommendation was that Washington join the WCI's regional cap and trade program. This time, the combination of a weakening economy and political dynamics trumped the CAT's findings, and resulted in a decision not to implement its recommendations.

Incorporating Recent Scientific Advances and Translating Science for Decision-Making

While decision support is not necessarily constrained by a lack of tools, a number of barriers restrict application of existing and emerging science and technology in adaptation and mitigation decisions.[3,8,129] In cases where tools exist, decision-makers may be 1) unaware of tools; 2) overwhelmed by the number of tools; 3) hesitant to use tools that are not appraised or updated and maintained with new information; or 4) require training in how to use tools.[8,130] Recent scientific developments could help address some of these barriers, but are not yet incorporated into decision support tools.[65] For example, individual climate models can provide very different projections of future climate conditions for a given region, and the divergence of these projections can make it seem impossible to reach a decision. But comparing different models and constructing climate model "ensembles" can highlight areas of agreement across large numbers of models and model runs, and can also be used to develop ranges and other forms of quantification of uncertainty (for further discussion, see Ch. 2: Our Changing Climate and Appendix 3: Climate Science Supplement). While results from these activities can prove difficult to present in formats that could help decision-makers,[131] new approaches to visualization and decision support can make such ensembles useful for decision-making.[132]

There is also a need for "science translators" who can help decision-makers efficiently access and properly use data and tools that would be helpful in making more informed decisions in the context of climate change.[3,4,8,83,133] The culture of research in the United States often perpetuates a belief that basic and applied research need to be kept separate, though

it has been demonstrated that research motivated by "considerations of use" can also make fundamental advances in scientific understanding and theory.[134] The U.S. climate research effort has been strongly encouraged to improve integration of social and ecological sciences and to develop the capacity for decision support to help address the need to effectively incorporate advances in climate science into decision-making.[135]

Research to Improve Decision Support

There are a number of areas where scientific knowledge needs to be expanded or tools further developed to take advantage of existing insight. The National Research Council (NRC) identifies a research agenda both *for* decision support (such as identifying specific information needs) and *on* decision support (such as improving tools for risk assessment and management).[3] A number of studies assess approaches and identify needed research and development (for example, Arvai et al. 2006[136]). A subset of the opportunities and needs identified by the NRC seem particularly relevant in the context of the National Climate Assessment, including:

- A comprehensive analysis of the state of decision support for adaptation and mitigation, including assessment of processes, tools, and applications, and development of a knowledge-sharing platform will facilitate wide public access to these resources.
- Comparisons of different adaptation and mitigation options will be improved by investments in understanding how the effects of climate change and response options can be valued and compared, especially for non-market ecosystem goods and services[101,137] and those impacts and decisions that have an effect over long time scales.
- Improvements in risk management require closing the gap between expert and public understanding of risk and building the institutions and processes needed for managing persistent risks over the long term.
- Probabilistic forecasts or other information regarding consequential climate extremes/events have the potential to be very useful for decision-makers, if used with improving information on the consequences of climate change and appropriate decision support tools.
- Better methods for assessing and communicating scientific confidence and uncertainty in the context of specific decisions would be very useful in supporting risk management strategies.
- Improvements in processes that effectively link scientists with decision-makers and the public in resource management settings and developing criteria to evaluate their effectiveness would enhance knowledge building and understanding.

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages

During March-June 2012, the author team engaged in multiple technical discussions via teleconference (6 telecons) and email and in a day-long in-person meeting (April 27, 2012, in Washington, D.C.). Authors reviewed over 50 technical inputs provided by the public and a wide variety of technical and scholarly literature related to decision support, including reports from the National Research Council that provided recent syntheses of the field (America's Climate Choices series, especially the reports *Informing an Effective Response to Climate Change*[8] and *Informing Decisions in a Changing Climate*[3]). During the in-person meeting, authors reflected on the body of work informing the chapter and drafted a number of candidate critical messages that could be derived from the literature. Following the meeting, authors ranked these messages and engaged in expert deliberation via teleconference and email discussions in order to agree on a small number of key messages for the chapter.

Key message #1 Traceable Account

Decisions about how to address climate change can be complex, and responses will require a combination of adaptation and mitigation actions. Decision-makers – whether individuals, public officials, or others – may need help integrating scientific information into adaptation and mitigation decisions.

Description of evidence base

The sensitivity of the climate system to human activities, the extent to which mitigation policies are implemented, and the effects of other demographic, social, ecological, and economic changes on vulnerability also contribute to uncertainty in decision-making.

Uncertainties can make decision-making in the context of climate change especially challenging for several reasons, including the rapid pace of changes in physical and human systems, the lags between climate change and observed effects, the high economic and political stakes, the number and diversity of potentially affected stakeholders, the need to incorporate scientific information of varying confidence levels, and the values of stakeholders and decision-makers.[2,3]

An iterative decision process that incorporates constantly improving scientific information and learning through periodic reviews of decisions over time is helpful in the context of rapid changes in environmental conditions.[3,4] The National Research Council has concluded that an "iterative adaptive risk management" framework, in which decisions are adjusted over time to reflect new scientific information and decision-makers learn from experience, is appropriate for decisions about adaptation and ways to reduce future climate change, especially given uncertainties and advances in scientific understanding.[8,26]

Well-designed decision support processes, especially those in which there is a good match between the availability of scientific information and the capacity to use it, can result in more effective outcomes based on relevant information that is perceived as useful and applicable.[6]

New information and remaining uncertainties

N/A

Assessment of confidence based on evidence and agreement or, if defensible, estimates of the likelihood of impact or consequence

N/A

Key message #2 Traceable Account

To be effective, decision support processes need to take account of the values and goals of the key stakeholders, evolving scientific information, and the perceptions of risk.

Description of evidence base

This message emphasizes that making a decision is more than picking the right tool and adopting its outcome. It is a process that should involve stakeholders, managers, and decision-makers to articulate and frame the decision, develop options, consider consequences (positive and negative), evaluate tradeoffs, make a decision, implement, evaluate, learn, and reassess.[1,8] Oftentimes having an inclusive, transparent decision process increases buy-in, regardless of whether a particular stakeholder's preferred option is chosen.[3] Decisions about investment in adaptation and mitigation measures occur in the context of uncertainty and high political and economic stakes, complicating the evaluation of information and its application in decision-making.[3,8] Decisions involve both scientific information and values – for example, how much risk is acceptable and what priorities and preferences are addressed.[2]

New information and remaining uncertainties

N/A

Assessment of confidence based on evidence

N/A

KEY MESSAGE #3 TRACEABLE ACCOUNT

Many decision support processes and tools are available. They can enable decision-makers to identify and assess response options, apply complex and uncertain information, clarify tradeoffs, strengthen transparency, and generate information on the costs and benefits of different choices.

Description of evidence base

Many decision support tools have been developed to support adaptive management in specific sectors or for specific issues. These tools include: risk assessments; geographic information system (GIS)-based analysis products; targeted projections for high-consequence events such as fires, floods, or droughts; vulnerability assessments; integrated assessment models; decision calendars; scenarios and scenario planning; and others.[3,8,84] Many of these tools have been validated scientifically and evaluated from the perspective of users. They are described in the sector and regional chapters of this assessment. In addition, a variety of clearing houses and data management systems provide access to decision support information and tools (for example, CAKE 2012; NatureServe 2012[39,85]).

There are many tools, some of which we discuss in the chapter, that are currently being used to make decisions that include a consideration of climate change and variability, or the impacts or vulnerabilities that would result from such changes.

Also important is the creation of a well-structured and transparent decision process that involves affected parties in problem framing, establishing decision criteria, fact finding, deliberation, and reaching conclusions.[1,8,26] These aspects of decision-making are often overlooked by those who focus more on scientific inputs and tools, but given the high stakes and remaining uncertainties, they are crucial for effective decision-making on adaptation and mitigation.

New information and remaining uncertainties

N/A

Assessment of confidence based on evidence

N/A

KEY MESSAGE #4 TRACEABLE ACCOUNT

Ongoing assessment processes should incorporate evaluation of decision support tools, their accessibility to decision-makers, and their application in decision processes in different sectors and regions.

Description of evidence base

As part of a sustained assessment, it is critical to understand the state of decision support, including what is done well and where we need to improve. At this point in time, there is a lack of literature that provides a robust evidence base to allow us to conduct this type of national, sector-scale assessment. Developing an evidence base would allow for a movement from case studies to larger-scale assessment across decision support and would allow us to better understand how to better utilize what decision support is available and understand what needs to be improved to support adaptation and mitigation decisions in different sectors and regions.

New information and remaining uncertainties

N/A

Assessment of confidence based on evidence

N/A

KEY MESSAGE #5 TRACEABLE ACCOUNT

Steps to improve collaborative decision processes include developing new decision support tools and building human capacity to bridge science and decision-making.

Description of evidence base

There are many challenges in communicating complex scientific information to decision makers and the public,[11] and while "translation" of complex information is one issue, there are many others. Defining the scope and scale of the relevant climate change problem can raise both scientific and social questions. These questions require both scientific insights and consideration of values and social constructs, and require that participants engage in mutual learning and the co-production of relevant knowledge.[10] Boundary processes that are collaborative and iterative[18] among scientists, stakeholders, and decision-makers, such as joint fact finding and collaborative adaptive management, foster ongoing dialogue and increasing participants' understanding of policy problems and information and analysis necessary to evaluate decision options.[12,13] Analysis of the conditions that contribute to their effectiveness of boundary processes is an emerging area of study.[13]

A large body of literature notes that the ability of decision-makers to use data and tools has not kept pace with the rate at which new tools are developed, pointing to a need for "science translators" who can help decision-makers efficiently access and properly use data and tools that would be helpful in making more informed decisions in the context of climate change.[3,4,8,83,133] The U.S. climate research effort has been strongly encouraged to improve integration of social and ecological sciences and to develop the capacity for decision support to help address the need to effectively incorporate advances in climate science into decision-making.[135]

New information and remaining uncertainties

N/A

Assessment of confidence based on evidence

N/A

CHAPTER 27
MITIGATION

Convening Lead Authors

Henry D. Jacoby, Massachusetts Institute of Technology

Anthony C. Janetos, Boston University

Lead Authors

Richard Birdsey, U.S. Forest Service

James Buizer, University of Arizona

Katherine Calvin, Pacific Northwest National Laboratory, University of Maryland

Francisco de la Chesnaye, Electric Power Research Institute

David Schimel, NASA Jet Propulsion Laboratory

Ian Sue Wing, Boston University

Contributing Authors

Reid Detchon, United Nations Foundation

Jae Edmonds, Pacific Northwest National Laboratory, University of Maryland

Lynn Russell, Scripps Institution of Oceanography, University of California, San Diego

Jason West, University of North Carolina

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

27 MITIGATION

Key Messages

1. **Carbon dioxide is removed from the atmosphere by natural processes at a rate that is roughly half of the current rate of emissions from human activities. Therefore, mitigation efforts that only stabilize global emissions will not reduce atmospheric concentrations of carbon dioxide, but will only limit their rate of increase. The same is true for other long-lived greenhouse gases.**

2. **To meet the lower emissions scenario (B1) used in this assessment, global mitigation actions would need to limit global carbon dioxide emissions to a peak of around 44 billion tons per year within the next 25 years and decline thereafter. In 2011, global emissions were around 34 billion tons, and have been rising by about 0.9 billion tons per year for the past decade. Therefore, the world is on a path to exceed 44 billion tons per year within a decade.**

3. **Over recent decades, the U.S. economy has emitted a decreasing amount of carbon dioxide per dollar of gross domestic product. Between 2008 and 2012, there was also a decline in the total amount of carbon dioxide emitted annually from energy use in the United States as a result of a variety of factors, including changes in the economy, the development of new energy production technologies, and various government policies.**

4. **Carbon storage in land ecosystems, especially forests, has offset around 17% of annual U.S. fossil fuel emissions of greenhouse gases over the past several decades, but this carbon "sink" may not be sustainable.**

5. **Both voluntary activities and a variety of policies and measures that lower emissions are currently in place at federal, state, and local levels in the United States, even though there is no comprehensive national climate legislation. Over the remainder of this century, aggressive and sustained greenhouse gas emission reductions by the United States and by other nations would be needed to reduce global emissions to a level consistent with the lower scenario (B1) analyzed in this assessment.**

Mitigation refers to actions that reduce the human contribution to the planetary greenhouse effect. Mitigation actions include lowering emissions of greenhouse gases like carbon dioxide and methane, and particles like black carbon (soot) that have a warming effect. Increasing the net uptake of carbon dioxide through land-use change and forestry can make a contribution as well. As a whole, human activities result in higher global concentrations of greenhouse gases and to a warming of the planet – and the effect is increased by various self-reinforcing cycles in the Earth system (such as the way melting sea ice results in more dark ocean water, which absorbs more heat, and leads to more sea ice loss). Also, the absorption of increased carbon dioxide by the oceans is leading to increased ocean acidity with adverse effects on marine ecosystems.

Four mitigation-related topics are assessed in this chapter. First, it presents an overview of greenhouse gas emissions and their climate influence to provide a context for discussion of mitigation efforts. Second, the chapter provides a survey of activities contributing to U.S. emissions of carbon dioxide and other greenhouse gases. Third, it provides a summary of current government and voluntary efforts to manage these emissions. Finally, there is an assessment of the adequacy of these efforts relative to the magnitude of the climate change threat and a discussion of preparation for potential future action.

While the chapter presents a brief overview of mitigation issues, it does not provide a comprehensive discussion of policy options, nor does it attempt to review or analyze the range of technologies available to reduce emissions.

These topics have also been the subject of other assessments, including those by the National Academy of Sciences[1] and the U.S. Department of Energy.[2] Mitigation topics are addressed throughout this report (see Ch. 4: Energy, Key Message 5; Ch. 5: Transportation, Key Message 4; Ch. 7: Forests, Key Message 4; Ch. 9: Human Health, Key Message 4; Ch. 10: Energy, Water, and Land, Key Messages 1, 2, 3; Ch. 13: Land Use & Land Cover Change, Key Messages 2, 4; Ch. 15: Biogeochemical Cycles, Key Message 3; Ch. 26: Decision Support, Key Messages 1, 2, 3; Appendix 3: Climate Science Supplemental Message 5; Appendix 4: FAQs N, S, X, Y, Z).

Emissions, Concentrations, and Climate Forcing

Setting mitigation objectives requires knowledge of the Earth system processes that determine the relationship among emissions, atmospheric concentrations and, ultimately, climate. Human-caused climate change results mainly from the increasing atmospheric concentrations of greenhouse gases.[3] These gases cause radiative "forcing" – an imbalance of heat trapped by the atmosphere compared to an equilibrium state. Atmospheric concentrations of greenhouse gases are the result of the history of emissions and of processes that remove them from the atmosphere; for example, by "sinks" like growing forests.[4] The fraction of emissions that remains in the atmosphere, which is different for each greenhouse gas, also varies over time as a result of Earth system processes.

The impact of greenhouse gases depends partly on how long each one persists in the atmosphere.[5] Reactive gases like methane and nitrous oxide are destroyed chemically in the atmosphere, so the relationships between emissions and atmospheric concentrations are determined by the rate of those reactions. The term "lifetime" is often used to describe the speed with which a given gas is removed from the atmosphere. Methane has a relatively short lifetime (largely removed within a decade or so, depending on conditions), so reductions in emissions can lead to a fairly rapid decrease in concentrations as the gas is oxidized in the atmosphere.[6] Nitrous oxide has a much longer lifetime, taking more than 100 years to be substantially removed.[7] Other gases in this category include industrial gases, like those used as solvents and in air conditioning, some of which persist in the atmosphere for hundreds or thousands of years.

Carbon dioxide (CO_2) does not react chemically with other gases in the atmosphere, so it does not, strictly speaking, have a "lifetime."[8] Instead, the relationship between emissions and concentrations from year to year is determined by patterns of release (for example, through burning of fossil fuels) and uptake (for example, by vegetation and by the ocean).[9] Once CO_2 is emitted from any source, a portion of it is removed from the atmosphere over time by plant growth and absorption by the oceans, after which it continues to circulate in the land-atmosphere-ocean system until it is finally converted into stable forms in soils, deep ocean sediments, or other geological repositories (Figure 27.1).

Of the carbon dioxide emitted from human activities in a year, about half is removed from the atmosphere by natural processes within a century, but around 20% continues to circu-

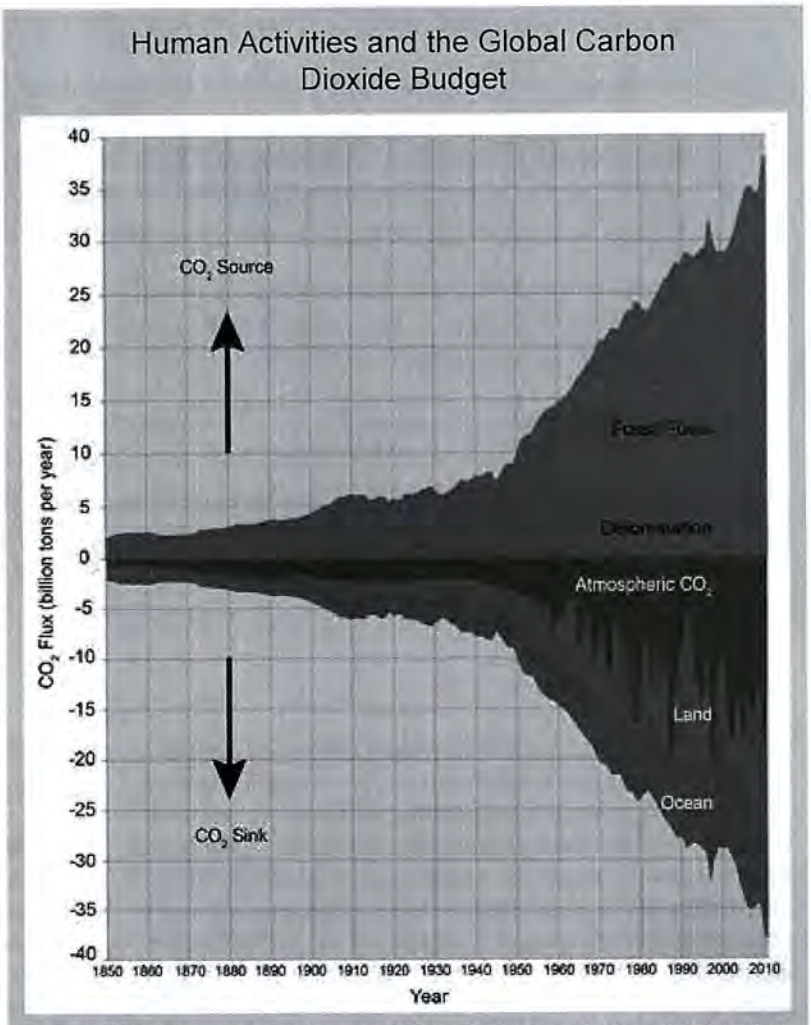


Figure 27.1. Figure shows human-induced changes in the global carbon dioxide budget roughly since the beginning of the Industrial Revolution. Emissions from fossil fuel burning are the dominant cause of the steep rise shown here from 1850 to 2012. (Global Carbon Project 2010, 2012[10]).

late and to affect atmospheric concentrations for thousands of years.[11] Stabilizing or reducing atmospheric carbon dioxide concentrations, therefore, requires very deep reductions in future emissions – ultimately approaching zero – to compensate for past emissions that are still circulating in the Earth system. Avoiding future emissions, or capturing and storing them in stable geological storage, would prevent carbon dioxide from entering the atmosphere, and would have very long-lasting effects on atmospheric concentrations.

In addition to greenhouse gases, there can be climate effects from fine particles in the atmosphere. An example is black carbon (soot), which is released from coal burning, diesel engines, cooking fires, wood stoves, wildfires, and other combustion sources. These particles have a warming influence, especially when they absorb solar energy low in the atmosphere.[12] Other particles, such as those formed from sulfur dioxide released during coal burning, have a cooling effect by reflecting some of the sun's energy back to space or by increasing the brightness of clouds (see: Ch. 2: Our Changing Climate; Appendix 3: Climate Science Supplement; and Appendix 4: FAQs).

The effect of each gas is related to both how long it lasts in the atmosphere (the longer it lasts, the greater its influence) and its potency in trapping heat. The warming influence of different gases can be compared using "global warming potentials" (GWP), which combine these two effects, usually added up over a 100-year time period. Global warming potentials are referenced to carbon dioxide – which is defined as having a GWP of 1.0 – and the combined effect of multiple gases is denoted in carbon dioxide equivalents, or CO_2-e.

The relationship between emissions and concentrations of gases can be modeled using Earth System Models.[4] Such models apply our understanding of biogeochemical processes that remove greenhouse gas from the atmosphere to predict their future concentrations. These models show that stabilizing CO_2 *emissions* would not stabilize its atmospheric concentrations but instead result in a concentration that would increase at a relatively steady rate. Stabilizing atmospheric *concentrations* of CO_2 would require reducing emissions far below present-day levels. Concentration and emissions scenarios, such as the recently developed Representative Concentration Pathways (RCPs) and scenarios developed earlier by the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Emissions Scenarios (SRES), are used in Earth System Models to study potential future climates. The RCPs span a range of atmospheric targets for use by climate modelers,[13,14] as do the SRES cases. These global analyses form a framework within which the climate contribution of U.S. mitigation efforts can be assessed. In this report, special attention is given to the SRES A2 scenario (similar to RCP 8.5), which assumes continued increases in emissions, and the SRES B1 scenario (close to RCP 4.5), which assumes a substantial reduction of emissions (Ch. 2: Our Changing Climate; Appendix 5: Scenarios and Models).

GEOENGINEERING

Geoengineering has been proposed as a third option for addressing climate change in addition to, or alongside, mitigation and adaptation. Geoengineering refers to intentional modifications of the Earth system as a means to address climate change. Three types of activities have been proposed: 1) carbon dioxide removal (CDR), which boosts CO_2 removal from the atmosphere by various means, such as fertilizing ocean processes and promoting land-use practices that help take up carbon, 2) solar radiation management (SRM), which reflects a small percentage of sunlight back into space to offset warming from greenhouse gases,[15] and 3) direct capture and storage of CO_2 from the atmosphere.[16]

Current research suggests that SRM or CDR could diminish the impacts of climate change. However, once undertaken, sudden cessation of SRM would exacerbate the climate effects on human populations and ecosystems, and some CDR might interfere with oceanic and terrestrial ecosystem processes.[17] SRM undertaken by itself would not slow increases in atmospheric CO_2 concentrations, and would therefore also fail to address ocean acidification. Furthermore, existing international institutions are not adequate to manage such global interventions. The risks associated with such purposeful perturbations to the Earth system are thus poorly understood, suggesting the need for caution and comprehensive research, including consideration of the implicit moral hazards.[18]

Section 1: U.S. Emissions and Land-Use Change

Industrial, Commercial, and Household Emissions

U.S. greenhouse gas emissions, not accounting for uptake by land use and agriculture (see Figure 27.3), rose to as high as 7,260 million tons CO_2-e in 2007, and then fell by about 9% between 2008 and 2012.[19] Several factors contributed to the decline, including the reduction in energy use in response to the 2008-2010 recession, the displacement of coal in electric generation by lower-priced natural gas, and the effect of federal and state energy and environmental policies.[20]

Carbon dioxide made up 84% of U.S. greenhouse gas emissions in 2011. Forty-one percent of these emissions were attributable to liquid fuels (petroleum), followed closely by solid fuels (principally coal in electric generation), and to a lesser extent by natural gas.[20] The two dominant production sectors responsible for these emissions are electric power generation (coal and gas) and transportation (petroleum). Flaring and cement manufacture together account for less than 1% of the total. If emissions from electric generation are allocated to their various end-uses, transportation is the largest CO_2 source, contributing a bit over one-third of the total, followed by industry at slightly over a quarter, and residential use and the commercial sector at around one-fifth each.

A useful picture of historical patterns of carbon dioxide emissions can be constructed by decomposing the cumulative change in emissions from a base year into the contributions of five driving forces: 1) decline in the CO_2 content of energy use, as with a shift from coal to natural gas in electric generation, 2) reduction in energy intensity – the energy needed to produce each unit of gross domestic product (GDP) – which results from substitution responses to energy prices, changes in the composition of the capital stock, and both autonomous and price-induced technological change, 3) changes in the structure of the economy, such as a decline in energy-intensive industries and an increase in services that use less energy, 4) growth in per capita GDP, and 5) rising population.

Over the period 1963-2008, annual U.S. carbon dioxide emissions slightly more than doubled, because growth in emissions potential attributable to increases in population and GDP per person outweighed reductions contributed by lowered energy and carbon intensity and changes in economic structure (Figure 27.2). Each series in the figure illustrates the quantity of cumulative emissions since 1963 that would have been generated by the effect of the associated driver. By 2008, fossil fuel burning had increased CO_2 emissions by 2.7 billion tons over 1963 levels. However, by itself the observed decline in energy would have reduced emissions by 1.8 billion tons, while the observed increase in per capita GDP would have increased emissions by more than 5 billion tons.

After decades of increases, CO_2 emissions from energy use (which account for 97% of total U.S. emissions) declined by around 9% between 2008 and 2012, largely due to a shift from coal to less CO_2-intensive natural gas for electricity production.[19] Trends in driving forces shown in Figure 27.2 are expected to continue in the future, though their relative contributions are subject to significant uncertainty. The reference case projection by the U.S. Energy Information Administration (EIA) shows their net effect being a slower rate of CO_2 emissions growth than in the past, with roughly constant energy sector emissions to 2040.[22] It must be recognized, however, that emissions from energy use rise and fall from year to year, as the aforementioned driving forces vary.

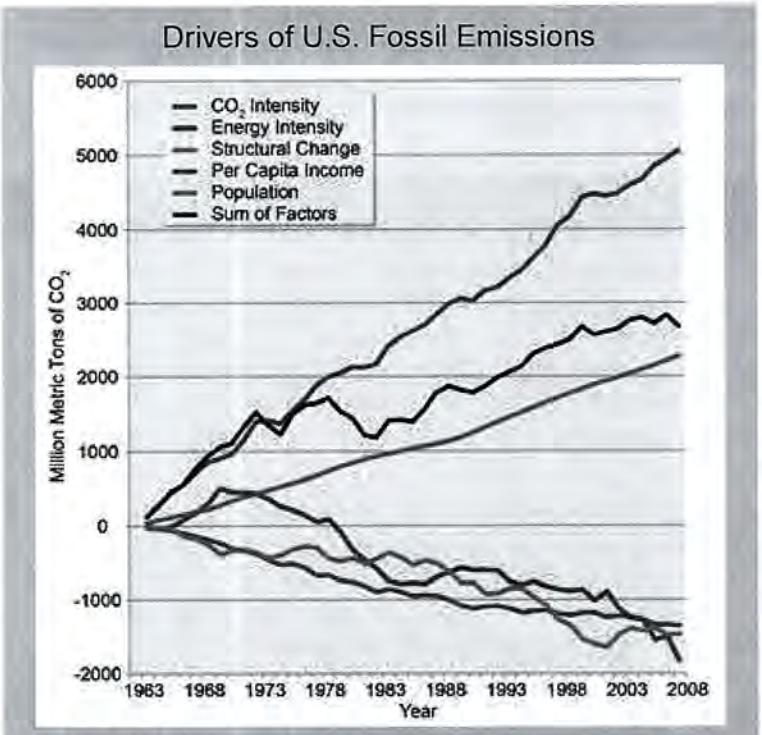


Figure 27.2. This graph depicts the changes in carbon dioxide (CO_2) emissions over time as a function of five driving forces: 1) the amount of CO_2 produced per unit of energy (CO_2 intensity); 2) the amount of energy used per unit of gross domestic product (energy intensity); 3) structural changes in the economy; 4) per capita income; and 5) population. Although CO_2 intensity and especially energy intensity have decreased significantly and the structure of the U.S. economy has changed, total CO_2 emissions have continued to rise as a result of the growth in both population and per capita income. (Baldwin and Sue Wing, 2013[21]).

The primary non-CO_2 gas emissions in 2011 were methane (9% of total CO_2-e emissions), nitrous oxide (5%), and a set of industrial gases (2%). U.S. emissions of each of these gases have been roughly constant over the past half-dozen years.[22] Emissions of methane and nitrous oxide have been roughly constant over the past couple of decades, but there has been an increase in the industrial gases as some are substituted for ozone-destroying substances controlled by the Montreal Protocol.[23]

Yet another warming influence on the climate system is black carbon (soot), which consists of fine particles that result mainly from incomplete combustion of fossil fuels and biomass. Long a public health concern, black carbon particles absorb solar radiation during their short life in the atmosphere (days to weeks). When deposited on snow and ice, these particles darken the surface and reduce the reflection of incoming solar radiation back to space. These particles also influence cloud formation in ways yet poorly quantified.[24]

Land Use, Forestry, and Agriculture

The main stocks of carbon in its various biological forms (plants and trees, dead wood, litter, soil, and harvested products) are estimated periodically and their rate of change, or flux, is calculated as the average annual difference between two time periods. Estimates of carbon stocks and fluxes for U.S. lands are based on land inventories augmented with data from ecosystem studies and production reports.[25,26]

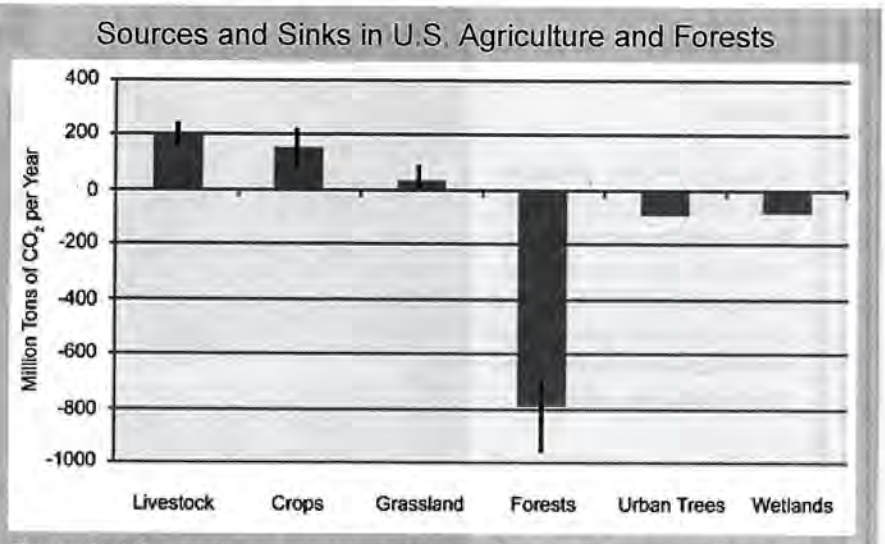


Figure 27.3 Graph shows annual average greenhouse gas emissions from land use including livestock and crop production, but does not include fossil fuels used in agricultural production. Forests are a significant "sink" that absorbs carbon dioxide from the atmosphere. All values shown are for 2008, except wetlands, which are shown for 2003. (Pacala et al. 2007;[27] USDA 2011[28]).

U.S. lands were estimated to be a net sink of between approximately 640 and 1,074 million tons CO_2-e in the late 2000s.[26,27] Estimates vary depending on choice of datasets, models, and methodologies (see Ch. 15: Biogeochemical Cycles, "Estimating the U.S. Carbon Sink," for more discussion). This net land sink effect is the result of sources (from crop production, livestock production, and grasslands) and sinks (in forests, urban trees, and wetlands). Sources of carbon have been relatively stable over the last two decades, but sinks have been more variable. Long-term trends suggest significant emissions from forest clearing in the early 1900s followed by a sustained period of net uptake from forest regrowth over the last 70 years.[28] The amount of carbon taken up by U.S. land sinks is dominated by forests, which have annually absorbed 7% to 24% (with a best estimate of about 16%) of fossil fuel CO_2 emissions in the U.S. over the past two decades.[20]

The persistence of the land sink depends on the relative effects of several interacting factors: recovery from historical land-use change, atmospheric CO_2 and nitrogen deposition, natural disturbances, and the effects of climate variability and change – particularly drought, wildfires, and changes in the length of the growing season. Deforestation continues to cause an annual loss of 877,000 acres (137,000 square miles) of forested land, offset by a larger area gain of new forest of about 1.71 million acres (268,000 square miles) annually.[29] Since most of the new forest is on relatively low-productivity lands of the Intermountain West, and much of the deforestation occurs on high-productivity lands in the East, recent land-use changes have decreased the potential for future carbon storage.[30] The positive effects of increasing carbon dioxide concentration and nitrogen deposition on carbon storage are not likely to be as large as the negative effects of land-use change and disturbances.[31] In some regions, longer growing seasons associated with climate change may increase annual productivity.[32] Droughts and other disturbances, such as fire and insect infestations, have already turned some U.S. land regions from carbon sinks into carbon sources (see Ch. 13: Land Use & Land Cover Change and Ch. 15: Biogeochemical Cycles).[31] The current land sink may not be sustainable for more than a few more decades,[33] though there is a lack of consistency in published results about the relative effects of disturbance and other factors on net land-use emissions.[31,34]

Section 2: Activities Affecting Emissions

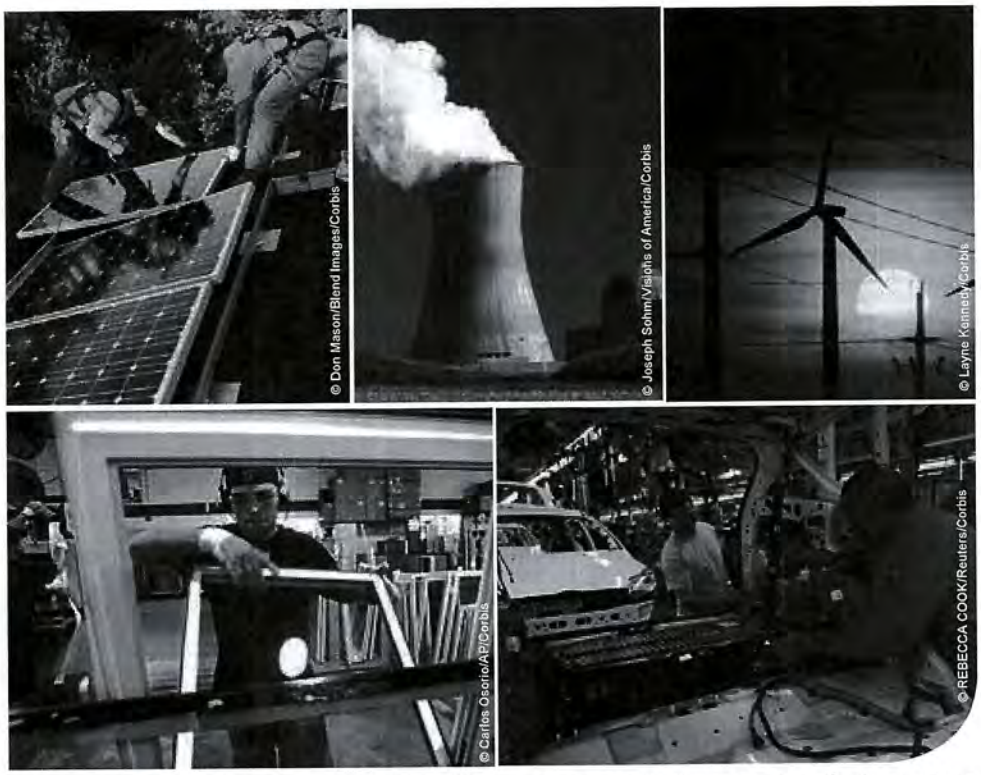
Early and large reductions in global emissions would be necessary to achieve the lower emissions scenarios (such as the lower B1 scenario; see Ch. 2: Our Changing Climate) analyzed in this assessment. The principal types of national actions that could effect such changes include putting a price on emissions, setting regulations and standards for activities that cause emissions, changing subsidy programs, and direct federal expenditures. Market-based approaches include cap and trade programs that establish markets for trading emissions permits, analogous to the Clean Air Act provisions for sulfur dioxide reductions. None of these price-based measures has been implemented at the national level in the United States, though cap and trade systems are in place in California and in the Northeast's Regional Greenhouse Gas Initiative. Moreover, a wide range of governmental actions are underway at federal, state, regional, and city levels using other measures, and voluntary efforts, that can reduce the U.S. contribution to total global emissions. Many, if not most of these programs are motivated by other policy objectives – energy, transportation, and air pollution – but some are directed specifically at greenhouse gas emissions, including:

- reduction in CO_2 emissions from energy end-use and infrastructure through the adoption of energy-efficient

components and systems – including buildings, vehicles, manufacturing processes, appliances, and electric grid systems;

- reduction of CO_2 emissions from energy supply through the promotion of renewables (such as wind, solar, and bioenergy), nuclear energy, and coal and natural gas electric generation with carbon capture and storage; and

- reduction of emissions of non-CO_2 greenhouse gases and black carbon; for example, by lowering methane emissions from energy and waste, transitioning to climate-friendly alternatives to hydrofluorocarbons (HFCs), cutting methane and nitrous oxide emissions from agriculture, and improving combustion efficiency and means of particulate capture.



Programs underway that reduce carbon dioxide emissions include the promotion of solar, nuclear, and wind power and efficient vehicles

Federal Actions

The Federal Government has implemented a number of measures that promote energy efficiency, clean technologies, and alternative fuels.[35] A sample of these actions is provided in Table 27.1 and they include greenhouse gas regulations, other rules and regulations with climate co-benefits, various standards and subsidies, research and development, and federal procurement practices.

The U.S. Environmental Protection Agency (EPA) has a 40-year history of regulating the concentration and deposition of criteria pollutants (six common air pollutants that affect human health). A 2012 Supreme Court decision upheld the EPA's finding that greenhouse gases "endanger public health and welfare."[36] This ruling added the regulation of greenhouse gas emissions to the Agency's authority under the Clean Air Act. Actions taken and proposed under the new authority have focused on road transport and electric power generation.

The U.S. Department of Energy (DOE) provides most of the funding for a broad range of programs for energy research,

development, and demonstration. DOE also has the authority to regulate the efficiency of appliances and building codes for manufactured housing. In addition, most of the other federal agencies – including the Departments of Defense, Housing and Urban Development, Transportation, and Agriculture – have programs related to greenhouse gas mitigation.

The Administration's Climate Action Plan[37] builds on these activities with a broad range of mitigation, adaptation, and preparedness measures. The mitigation elements of the plan are in part a response to the commitment made during the 2010 Cancun Conference of the Parties of the United Nations Framework Convention on Climate Change to reduce U.S. emissions of greenhouse gases by 17% below 2005 levels by 2020. Actions proposed in the Plan include: 1) limiting carbon emissions from both new and existing power plants, 2) continuing to increase the stringency of fuel economy standards for automobiles and trucks, 3) continuing to improve energy efficiency in the buildings sector, 4) reducing the emissions of non-CO_2 greenhouse gases through a variety of measures, 5) increasing federal investments in cleaner, more efficient energy sources for both power and transportation, and 6) identifying new approaches to protect and restore our forests and other critical landscapes, in the presence of a changing climate.

City, State, and Regional Actions

Jurisdiction for greenhouse gases and energy policies is shared between the federal government and the states.[1] For example, states regulate the distribution of electricity and natural gas to consumers, while the Federal Energy Regulatory Commission regulates wholesale sales and transportation of natural gas and electricity. In addition, many states have adopted climate initiatives as well as energy policies that reduce greenhouse gas emissions. For a survey of many of these state activities, see Table 27.2. Many cities are taking similar actions.

The most ambitious state activity is California's Global Warming Solutions Act (AB 32), a law that sets a state goal to reduce greenhouse gas emissions to 1990 levels by 2020. The state program caps emissions and uses a market-based system of trading in emissions credits (cap and trade), as well as a number of regulatory actions. The most well-known, multi-state effort has been the Regional Greenhouse Gas Initiative (RGGI), formed by ten northeastern and Mid-Atlantic states (though New Jersey exited in 2011). RGGI is a cap and trade system applied to the power sector with revenue from allowance auctions directed to investments in efficiency and renewable energy.

Voluntary Actions

Corporations, individuals, and non-profit organizations have initiated a host of voluntary actions. The following examples give the flavor of the range of efforts:

- The Carbon Disclosure Project has the largest global collection of self-reported climate change and water-use information. The system enables companies to measure, disclose, manage, and share climate change and water-use information. Some 650 U.S. signatories include banks, pension funds, asset managers, insurance companies, and foundations.

- Many local governments are undertaking initiatives to reduce greenhouse gas emissions within and outside of their organizational boundaries.[38] For example, over 1,055 municipalities from all 50 states have signed the U.S. Mayors Climate Protection Agreement,[39] and many of these communities are actively implementing strategies to reduce their greenhouse gas footprint.

- Under the American College and University Presidents' Climate Commitment (ACUPCC), 679 institutions have pledged to develop plans to achieve net-neutral climate emissions through a combination of on-campus changes and purchases of emissions reductions elsewhere.

- Voluntary compliance with efficiency standards developed by industry and professional associations, such as the building codes of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), is widespread.

- Federal voluntary programs include Energy STAR, a labeling program that identifies energy efficient products for use in residential homes and commercial buildings and plants, and programs and partnerships devoted to reducing methane emissions from fossil fuel production and landfill sources and high GWP emissions from industrial activities and agricultural conservation programs.

Costs of Emissions Reductions

The national cost of achieving U.S. emissions reductions over time depends on the level of reduction sought and the particular measures employed. Studies of price-based policies, such as a cap and trade system, indicate that a 50% reduction in emissions by 2050 could be achieved at a cost of a year or two of projected growth in gross domestic product over the period (for example, Paltsev et al. 2009; EIA 2009[40]). However, because of differences in analysis method, and in assumptions about economic growth and technology change, cost projections vary considerably even for a policy applying price penalties.[41] Comparisons of emissions reduction by prices versus regulations show that a regulatory approach can cost substantially more than a price-based policy.[42]

Co-benefits for air pollution and human health

Actions to reduce greenhouse gas emissions can yield co-benefits for objectives apart from climate change, such as energy security, health, ecosystem services, and biodiversity.[43,44] The co-benefits for reductions in air pollution have received particular attention. Because air pollutants and greenhouse gases share common sources, particularly from fossil fuel combustion, actions to reduce greenhouse gas emissions also reduce air pollutants. While some greenhouse gas reduction measures might increase other emissions, broad programs to reduce greenhouse gases across an economy or a sector can reduce air pollutants markedly.[14,45] (Unfortunately for climate mitigation, cutting sulfur dioxide pollution from coal burning also reduces the cooling influence of reflective particles formed from these emissions in the atmosphere.[46])

There is significant interest in quantifying the air pollution and human health co-benefits of greenhouse gas mitigation, particularly from the public health community,[44,47] as the human health benefits can be immediate and local, in contrast to the long-term and widespread effects of climate change.[48] Many studies have found that monetized health and pollution control benefits can be of similar magnitude to abatement costs (for example, Nemet et al. 2010; Burtraw et al. 2003[48,49]). Methane reductions have also been shown to generate health benefits from reduced ozone.[50] Similarly, in developing nations, reducing black carbon from household cook stoves substantially reduces air pollution-related illness and death.[51] Ancillary health benefits in developing countries typically exceed those in developed countries for a variety of reasons.[48] But only in very few cases are these ancillary benefits considered in analyses of climate mitigation policies.

Section 3: Preparation for Potential Future Mitigation Action

To meet the emissions reduction in the lower (B1) scenario used in this assessment (Ch. 2: Our Changing Climate) under reasonable assumptions about managing costs, annual global CO_2 emissions would need to peak at around 44 billion tons within the next 25 years or so and decline steadily for the rest of the century. At the current rate of emissions growth, the world is on a path to exceed the 44 billion ton level within a decade (see "Emissions Scenarios and RCPs"). Thus achievement of a global emissions path consistent with the B1 scenario will require strenuous action by all major emitters.

Policies already enacted and other factors lowered U.S. emissions in recent years. The Annual Energy Outlook prepared by the EIA, which previously forecasted sustained growth in emissions, projected in 2013 that energy-related U.S. CO_2 emissions would remain roughly constant for the next 25 years.[22]

Moreover, through the President's Climate Action Plan, the Administration has committed to additional measures not yet reflected in the EIA's projections, with the goal of reducing emissions about 17% below 2005 levels by 2020. Still, additional and stronger U.S. action, as well as strong action by other major emitters, will be needed to meet the long-term global emission reductions reflected in the B1 scenario.

Achieving the B1 emissions path would require substantial decarbonization of the global economy by the end of this century, implying a fundamental transformation of the global energy system. Details of the energy mix along the way differ among analyses, but the implied involvement by the U.S. can be seen in studies carried out under the U.S. Climate Change Science Program[54] and the Energy Modeling Forum.[55,56] In these studies, direct burning of coal without carbon capture is essentially excluded from the power system, and the same holds for natural gas toward the end of the century – to be replaced by some combination of coal or gas with carbon capture and storage, nuclear generation, and renewables. Biofuels and electricity are projected to substitute for oil in the transport sector. A substantial component of the task is accomplished with demand reduction, through efficiency improvement, conservation, and shifting to an economy less dependent on energy services.

The challenge is great enough even starting today, but delay by any of the major emitters makes meeting any such target even more difficult and may rule out some of the more ambitious goals.[54,55] A study of the climate change threat and potential responses by the U.S. National Academies therefore concludes that there is "an urgent need for U.S. action to reduce greenhouse emissions."[57] The National Research Council (NRC) goes on to suggest alternative national-level strategies that might be followed, including an economy-wide system of prices on greenhouse gas emissions and a portfolio of possible regulatory measures and subsidies. Deciding these matters will be a continuing task, and U.S. Administrations and Congress face a long series of choices about whether to take additional mitigation actions and how best to do it. Two supporting activities will help guide this process: opening future technological options and development of ever-more-useful assessments of the cost effectiveness and benefits of policy choices.

Many technologies are potentially available to accomplish emissions reduction. They include ways to increase the efficiency of fossil energy use and facilitate a shift to low-carbon energy sources, sources of improvement in the cost and performance of renewables (for example, wind, solar, and bioenergy) and nuclear energy, ways to reduce the cost of carbon capture and storage, means to expand terrestrial sinks through management of forests and soils and increased agricultural productivity,[2] and phasing down HFCs. In addition to the research and development carried out by private sector firms with their own funds, the Federal Government traditionally supports major programs to advance these technologies. This support is accomplished in part by credits and deductions in the tax code, and in part by federal expenditure. For example, the 2012 federal budget devoted approximately $6 billion to clean energy technologies.[58] Success in these ventures, lowering the cost of greenhouse gas reduction, can make a crucial contribution to future policy choices.[1]

Because they are in various stages of market maturity, the costs and effectiveness of many of these technologies remain uncertain: continuing study of their performance is important to understanding their role in future mitigation decisions.[59] In addition, evaluation of broad policies and particular mitigation measures requires frameworks that combine information from a range of disciplines. Study of mitigation in the near future can be done with energy-economic models that do not assume large changes in the mix of technologies or changes in the structure of the economy. Analysis over the time spans relevant to stabilization of greenhouse gas concentrations, however, requires Integrated Assessment Models, which consider all emissions drivers and policy measures that affect them, and that take account of how they are related to the larger economy and features of the climate system.[54,55,60] This type of analysis is also useful for exploring the relations between mitigation and measures to adapt to a changing climate.

Continued development of these analytical capabilities can help support decisions about national mitigation and the U.S. position in international negotiations. In addition, as shown

EMISSIONS SCENARIOS AND RCPS

The Representative Concentration Pathways (RCPs) specify alternative limits to human influence on the Earth's energy balance, stated in watts per square meter (W/m^2) of the Earth's surface.[13,52] The A2 emissions scenario implies atmospheric concentrations with radiative forcing slightly lower than the highest RCP, which is 8.5 W/m^2. The lower limits, at 6.0, 4.5 and 2.6 W/m^2, imply ever-greater mitigation efforts. The B1 scenario (rapid emissions reduction) is close to the 4.5 W/m^2 RCP[53] and to a similar case (Level 2) analyzed in a previous federal study.[54] Those assessments find that, to limit the economic costs, annual global CO_2 emissions from fossil fuels and industrial sources like cement manufacture, need to peak by 2035 to 2040 at around 44 billion tons of CO_2, and decline thereafter. The scale of the task can be seen in the fact that these global emissions were already at 34 billion tons CO_2 in 2011, and over the previous decade they rose at around 0.92 billion tons of CO_2 per year.[10] The lowest RCP would require an even more rapid turnaround and negative net emissions – that is, removing more CO_2 from the air than is emitted globally – in this century.[52]

above, mitigation is being undertaken by individuals and firms as well as by city, state, and regional governments. The capacity for mitigation from individual and household behavioral changes, such as increasing energy end-use efficiency with available technology, is known to be large.[63] Although there is capacity, there is not always broad acceptance of those behavioral changes, nor is there sufficient understanding of how to design programs to encourage such changes.[64] Behavioral and institutional research on how such choices are made and the results evaluated would be extremely beneficial. For many of these efforts, understanding of cost and effectiveness is limited, as is understanding of aspects of public support and institutional performance; so additional support for studies of these activities is needed to ensure that resources are efficiently employed.

Interactions between Adaptation and Mitigation

There are various ways in which mitigation efforts and adaptation measures are interdependent (see Ch. 28: Adaptation). For example, the use of plant material as a substitute for petroleum-based transportation fuels or directly as a substitute for burning coal or gas for electricity generation has received substantial attention.[61] But land used for mitigation purposes is potentially not available for food production, even as the global demand for agricultural products continues to rise.[62] Conversely, land required for adaptation strategies, like setting aside wildlife corridors or expanding the extent of conservation areas, is potentially not available for mitigation involving the use of plant material, or active management practices to enhance carbon storage in vegetation or soils. These possible interactions are poorly understood but potentially important, especially as climate change itself affects vegetation and ecosystem productivity and carbon storage. Increasing agricultural productivity to adapt to climate change can also serve to mitigate climate change.

Section 4: Research Needs

- Engineering and scientific research is needed on the development of cost-effective energy use technologies (devices, systems, and control strategies) and energy supply technologies that produce little or no CO_2 or other greenhouse gases.
- Better understanding of the relationship between emissions and atmospheric greenhouse gas concentrations is needed to more accurately predict how the atmosphere and climate system will respond to mitigation measures.
- The processes controlling the land sink of carbon in the U.S. require additional research, including better monitoring and analysis of economic decision-making about the fate of land and how it is managed, as well as the inherent ecological processes and how they respond to the climate system.
- Uncertainties in model-based projections of greenhouse gas emissions and of the effectiveness and costs of policy measures need to be better quantified. Exploration is needed of the effects of different model structures, assumptions about model parameter values, and uncertainties in input data.
- Social and behavioral science research is needed to inform the design of mitigation measures for maximum participation and to prepare a consistent framework for assessing cost effectiveness and benefits of both voluntary mitigation efforts and regulatory and subsidy programs.

Table 27.1. A number of existing federal laws and regulations target ways to reduce future climate change by decreasing greenhouse gas emissions emitted by human activities.

Sample Federal Mitigation Measures
Greenhouse Gas Regulations
Emissions Standards for Vehicles and Engines -- For light-duty vehicles, rules establishing standards for 2012-2016 model years and 2017-2025 model years. -- For heavy- and medium-duty trucks, a rule establishing standards for 2014-2018 model years.
Carbon Pollution Standard for New Power Plants -- A proposed rule setting limits on CO_2 emissions from future power plants.
Stationary Source Permitting -- A rule setting greenhouse gas emissions thresholds to define when permits under the New Source Review Prevention of Significant Deterioration and Title V Operating Permit programs are required for new and modified industrial facilities.
Greenhouse Gas Reporting Program -- A program requiring annual reporting of greenhouse gas data from large emission sources and suppliers of products that emit greenhouse gases when released or combusted.
Other Rules and Regulations with Climate Co-Benefits
Oil and Natural Gas Air Pollution Standards -- A rule revising New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants for certain components of the oil and natural gas industry.
Mobile Source Control Programs -- Particle control regulations affecting mobile sources (especially diesel engines) that reduce black carbon by controlling direct particle emissions. -- The requirement to blend increasing volumes of renewable fuels.
National Forest Planning -- Identification and evaluation of information relevant to a baseline assessment of carbon stocks. -- Reporting of net carbon stock changes on forestland.
Standards and Subsidies
Appliance and Building Efficiency Standards -- Energy efficiency standards and test procedures for residential, commercial, industrial, lighting, and plumbing products. -- Model residential and commercial building energy codes, and technical assistance to state and local governments, and non-governmental organizations.
Financial Incentives for Efficiency and Alternative Fuels and Technology -- Weatherization assistance for low-income households, tax incentives for commercial and residential buildings and efficient appliances, and support for state and local efficiency programs. -- Tax credits for biodiesel and advanced biofuel production, alternative fuel infrastructure, and purchase of electric vehicles. -- Loan guarantees for innovative energy or advanced technology vehicle production and manufacturing; investment and production tax credits for renewable energy.
Funding of Research, Development, Demonstration, and Deployment
-- Programs on clean fuels, energy end-use and infrastructure, CO_2 capture and storage, and agricultural practices.
Federal Agency Practices and Procurement
-- Executive orders and federal statutes requiring federal agencies to reduce building energy and resource consumption intensity and to procure alternative fuel vehicles. -- Agency-initiated programs in most departments oriented to lowering energy use and greenhouse gas emissions.

Table 27.2. Most states and Native communities have implemented programs to reduce greenhouse gases or adopt increased energy efficiency goals.

State Climate and Energy Initiatives
Examples of greenhouse gas policies include:
Greenhouse Gas Reporting and Registries http://www.c2es.org/us-states-regions/policy-maps/ghg-reporting[65]
Greenhouse Gas Emissions Targets http://www.c2es.org/us-states-regions/policy-maps/emissions-targets[66]
CO_2 Controls on Electric Power plants http://www.edf.org/sites/default/files/state-ghg-standards-03132012.pdf[67]
Low-Carbon Fuel Standards http://www.c2es.org/us-states-regions/policy-maps/low-carbon-fuel-standard[68]
Climate Action Plans http://www.c2es.org/us-states-regions/policy-maps/action-plan[69]
Cap and Trade Programs http://arb.ca.gov/cc/capandtrade/capandtrade.htm[70]
Regional Agreements http://www.c2es.org/us-states-regions/regional-climate-initiatives#WCI[71]
Tribal Communities http://www.epa.gov/statelocalclimate/tribal[72]
States have also taken a number of energy measures, motivated in part by greenhouse gas concerns. For example: Renewable Portfolio Standards http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf[73]
Energy Efficiency Resource Standards http://www.dsireusa.org/documents/summarymaps/EERS_map.pdf[74]
Property Tax Incentives for Renewables http://www.dsireusa.org/documents/summarymaps/[75]

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages:
Evaluation of literature by Coordinating Lead Authors

KEY MESSAGE #1 TRACEABLE ACCOUNT

Carbon dioxide is removed from the atmosphere by natural processes at a rate that is roughly half of the current rate of emissions from human activities. Therefore, mitigation efforts that only stabilize global emissions will not reduce atmospheric concentrations of carbon dioxide, but will only limit their rate of increase. The same is true for other long-lived greenhouse gases.

Description of evidence base

The message is a restatement of conclusions derived from the peer-reviewed literature over nearly the past 20 years (see Section 1 of chapter). Publications have documented the long lifetime of CO_2 in the atmosphere, resulting in long time lags between action and reduction,[9,11,76] and Earth System Models have shown that stabilizing emissions will not immediately stabilize atmospheric concentrations, which will continue to increase.[4]

New information and remaining uncertainties

There are several important uncertainties in the current carbon cycle, especially the overall size, location, and dynamics of the land-use sink[9,11] and technological development and performance.

Simulating future atmospheric concentrations of greenhouse gases requires both assumptions about economic activity, stringency of any greenhouse gas emissions control, and availability of technologies, as well as a number of assumptions about how the changing climate system affects both natural and anthropogenic sources.

Assessment of confidence based on evidence

Very High. Observations of changes in the concentrations of greenhouse gases are consistent with our understanding of the broad relationships between emissions and concentrations.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

To meet the lower emissions scenario (B1) used in this assessment, global mitigation actions would need to limit global carbon dioxide emissions to a peak of around 44 billion tons per year within the next 25 years and decline thereafter. In 2011, global emissions were around 34 billion tons, and have been rising by about 0.9 billion tons per year for the past decade. Therefore, the world is on a path to exceed 44 billion tons per year within a decade.

Description of evidence base

A large number of emissions scenarios have been modeled, with a number of publications showing what would be required to limit CO_2[13,53,54,77] to any predetermined limit. At current concentrations and rate of rise, the emissions of CO_2 would need to peak around

44 billion tons within the next 25 years in order to stabilize concentrations as in the B1 scenario. Given the rate of increase in recent years,[10] this limit is expected to be surpassed.[78]

New information and remaining uncertainties

Uncertainties about the carbon cycle could affect these calculations, but the largest uncertainties are the assumptions made about the strength and cost of greenhouse gas emissions policies.

Assessment of confidence based on evidence

The confidence in the conclusion is **high**. This is a contingent conclusion, though – we do not have high confidence that the current emission rate will be sustained. However, we do have high confidence that if we do choose to limit concentrations as in the B1 scenario, emissions will need to peak soon and then decline.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Over recent decades, the U.S. economy has emitted a decreasing amount of carbon dioxide per dollar of gross domestic product. Between 2008 and 2012, there was also a decline in the total amount of carbon dioxide emitted annually from energy use in the United States as a result of a variety of factors, including changes in the economy, the development of new energy production technologies, and various government policies.

Description of evidence base

Trends in greenhouse gas emissions intensity are analyzed and published by governmental reporting agencies.[20,23,26] Published, peer-reviewed literature cited in Section 2 of the Mitigation Chapter supports the conclusions about why these trends have occurred.[79]

New information and remaining uncertainties

Economic and technological forecasts are highly uncertain.

Assessment of confidence based on evidence

High. The statement is a summary restatement of published analyses by government agencies and interpretation from the reviewed literature.

KEY MESSAGE #4 TRACEABLE ACCOUNT

Carbon storage in land ecosystems, especially forests, has offset around 17% of annual U.S. fossil fuel emissions of greenhouse gases over the past several decades, but this carbon "sink" may not be sustainable.

Description of evidence base

Underlying data come primarily from U.S. Forest Service Forest Inventory and Analysis (FIA) plots, supplemented by additional ecological data collection efforts. Modeling conclusions come from peer-reviewed literature. All references are in Section 2 of the Mitigation Chapter. Studies have shown that there is a large land-use carbon sink in the United States.[26,27,28] Many publications attribute this sink to forest re-growth, and the sink is projected to decline as a result of forest aging[30,31,33] and factors like drought, fire, and insect infestations[31] reducing the carbon sink of these regions.

New information and remaining uncertainties

FIA plots are measured extremely carefully over long time periods, but do not cover all U.S. forested land. Other U.S. land types must have carbon content estimated from other sources. Modeling relationships between growth and carbon content, and taking CO_2 and climate change into account have large scientific uncertainties associated with them.

Assessment of confidence based on evidence

High. Evidence of past trends is based primarily on government data sources, but these also have to be augmented by other data and models in order to incorporate additional land-use types. Projecting future carbon content is consistent with published models, but these have intrinsic uncertainties associated with them.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Both voluntary activities and a variety of policies and measures that lower emissions are currently in place at federal, state, and local levels in the United States, even though there is no comprehensive national climate legislation. Over the remainder of this century, aggressive and sustained greenhouse gas emission reductions by the United States and by other nations would be needed to reduce global emissions to a level consistent with the lower scenario (B1) analyzed in this assessment.

Description of evidence base

The identification of state, local, regional, federal, and voluntary programs that will have an effect of reducing greenhouse gas emissions is a straightforward accounting of both legislative action and announcements of the implementation of such programs. Some of the programs include the Carbon Disclosure Project (CDP), the American College and University Presidents' Climate Commitment (ACUPCC), U.S. Mayors Climate Protection Agreement,[39] and many other local government initiatives.[38] Several states have also adapted climate policies including California's Global Warming Solutions Act (AB 32) and the Regional Greenhouse Gas Initiative (RGGI). The assertion that they will not lead to a reduction of US CO_2 emissions is supported by calculations from the U.S. Energy Information Administration.

New information and remaining uncertainties

The major uncertainty in the calculation about future emissions levels is whether a comprehensive national policy will be implemented.

Assessment of confidence based on evidence

Very High. There is recognition that the implementation of voluntary programs may differ from how they are originally planned, and that institutions can always choose to leave voluntary programs (as is happening with RGGI, noted in the chapter). The statement about the future of U.S. CO_2 emissions cannot be taken as a prediction of what will happen – it is a conditional statement based on an assumption of no comprehensive national legislation or regulation.

CHAPTER 28
ADAPTATION

Convening Lead Authors

Rosina Bierbaum, University of Michigan

Arthur Lee, Chevron Corporation

Joel Smith, Stratus Consulting

Lead Authors

Maria Blair, Independent

Lynne M. Carter, Louisiana State University

F. Stuart Chapin III, University of Alaska Fairbanks

Paul Fleming, Seattle Public Utilities

Susan Ruffo, The Nature Conservancy

Contributing Authors

Shannon McNeeley, Colorado State University

Missy Stults, University of Michigan

Laura Verduzco, Chevron Corporation

Emily Seyller, University Corporation for Atmospheric Research

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

28 ADAPTATION

Key Messages

1. **Substantial adaptation planning is occurring in the public and private sectors and at all levels of government; however, few measures have been implemented and those that have appear to be incremental changes.**

2. **Barriers to implementation of adaptation include limited funding, policy and legal impediments, and difficulty in anticipating climate-related changes at local scales.**

3. **There is no "one-size fits all" adaptation, but there are similarities in approaches across regions and sectors. Sharing best practices, learning by doing, and iterative and collaborative processes including stakeholder involvement, can help support progress.**

4. **Climate change adaptation actions often fulfill other societal goals, such as sustainable development, disaster risk reduction, or improvements in quality of life, and can therefore be incorporated into existing decision-making processes.**

5. **Vulnerability to climate change is exacerbated by other stresses such as pollution, habitat fragmentation, and poverty. Adaptation to multiple stresses requires assessment of the composite threats as well as tradeoffs among costs, benefits, and risks of available options.**

6. **The effectiveness of climate change adaptation has seldom been evaluated, because actions have only recently been initiated and comprehensive evaluation metrics do not yet exist.**

Over the past few years, the focus moved from the question "Is climate changing?" to the equally important question: "Can society manage unavoidable changes and avoid unmanageable changes?"[1,2] Research demonstrates that both mitigation (efforts to reduce future climate changes) and adaptation (efforts to reduce the vulnerability of society to climate change impacts) are needed in order to minimize the damages from human-caused climate change and to adapt to the pace and ultimate magnitude of changes that will occur.[3,4,5]

Adaptation and mitigation are closely linked; adaptation efforts will be more difficult, more costly, and less likely to succeed if significant mitigation actions are not taken.[2,6] The study and application of adaptation in the climate change realm is nascent compared to the many analyses of mitigation policies and practices to reduce emissions. Uncertainties about future socioeconomic conditions as well as future climate changes can make it difficult to arrive at adaptation decisions now. However, the pace and magnitude of projected change emphasize the need to be prepared for a wide range and intensity of climate impacts in the future. Planning and managing based on the climate of the last century means that tolerances of some infrastructure and species will be exceeded.[5,7,8] For example, building codes and landscaping ordinances will likely need to be updated not only for energy efficiency but also to conserve water supplies, protect against disease vectors, reduce susceptibility to heat stress, and improve protection against extreme events.[5,9] Although there is uncertainty about future conditions, research indicates that intelligent adaptive actions can still be taken now.[10,11] Climate change projections have inherent uncertainties, but it is still important to develop, refine, and deploy tools and approaches that enable iterative decision-making and increase flexibility and robustness of climate change responses (Ch. 2: Our Changing Climate).[12]

Climate change affects human health, natural ecosystems, built environments, and existing social, institutional, and legal arrangements. Adaptation considerations include local, state, regional, national, and international issues. For example, the implications of international arrangements need to be considered in the context of managing the Great Lakes, the Columbia River, and the Colorado River to deal with drought.[13,14] Both "bottom up" community planning and "top down" national strategies[11] may help regions deal with impacts such as increases in electrical brownouts, heat stress, floods, and wildfires. Such a mix of approaches will require

cross-boundary coordination at multiple levels as operational agencies integrate adaptation planning into their programs.

Adaptation actions can be implemented reactively, after changes in climate occur, or proactively, to prepare for projected changes.[11] Proactively preparing can reduce the harm from certain climate change impacts, such as increasingly intense extreme events, shifting zones for agricultural crops, and rising sea levels, while also facilitating a more rapid and efficient response to changes as they happen. This chapter highlights efforts at the federal, regional, state, tribal, and local levels, as well as initiatives in the corporate and non-governmental sectors to build adaptive capacity and resilience in response to climate change. While societal adaptation to *climate variability* is as old as civilization itself,[15] the focus of this chapter is on preparing for unprecedented human-induced *climate change* through adaptation. A map of illustrative adaptation activities and four detailed case examples that highlight ongoing adaptation activity across the U.S. are provided in Section 4 of this chapter.

ADAPTATION KEY TERMS DEFINITIONS*

Adapt, Adaptation: Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

Adaptive Capacity: The potential of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, and cope with the consequences.

Mitigation: Technological change and substitutions that reduce resource inputs and emissions per unit of output. Although several social, economic, and technological actions would reduce emissions, with respect to climate change, mitigation means implementing actions to reduce greenhouse gas emissions or increase the amount of carbon dioxide absorbed and stored by natural and man-made carbon sinks (see Ch. 27: Mitigation).

Multiple Stressors: Stress that originates from different sources that affect natural, managed, and socioeconomic systems and can cause impacts that are compounded and sometimes unexpected. An example would be when economic or market stress combines with drought to negatively impact farmers.

Resilience: A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.

Risk: A combination of the magnitude of the potential consequence(s) of climate change impact(s) and the likelihood that the consequence(s) will occur.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

*Definitions adapted from (IPCC 2007;[16] NRC 2007,[17] 2010[11]).

Adaptation Activities in the United States

Federal Government

Federal leadership, guidance, information, and support are vital to planning for and implementing adaptation actions at all scales and in all affected sectors of society (Table 28.1).[11,18,19,20] Several new federal climate adaptation initiatives and strategies have been developed in recent years, including:

- Executive Order (EO) 13514, requiring federal agencies to develop recommendations for strengthening policies and programs to adapt to the impacts of climate change;[21]
- the release of President Obama's Climate Action Plan in June 2013, which has as one of its three major pillars, preparing the United States for the impacts of climate change, including building stronger and safer communities and infrastructure, protecting the economy and natural resources, and using sound science to manage climate impacts;[22]
- the creation of an Interagency Climate Change Adaptation Task Force (ICCATF) (now the Council on Climate Preparedness and Resilience, per Executive Order 13653[23]) that led to the development of national principles for adaptation and

is leading to crosscutting and government-wide adaptation policies;

- the development of three crosscutting national adaptation strategies focused on integrating federal, and often state, local, and tribal efforts on adaptation in key sectors: 1) the National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate;[24] 2) the National Fish, Wildlife and Plants Climate Adaptation Strategy;[25] and 3) a priority objective on resilience and adaptation in the National Ocean Policy Implementation Plan;[26]

- a new decadal National Global Change Research Plan (2012–2021) that includes elements related to climate adaptation, such as improving basic science, informing decisions, improving assessments, and communicating with and educating the public;[27]

- the development of several interagency and agency-specific groups focused on adaptation, including a "community of practice" for federal agencies that are developing and implementing adaptation plans, an Adaptation Science Workgroup inside the U.S. Global Change Research Program (USGCRP), and several agency specific climate change and adaptation task forces; and

- a November 2013 Executive Order entitled "Preparing the United States for the Impacts of Climate Change" that, among other things, calls for the modernizing of federal programs to support climate resilient investments, managing lands and waters for climate preparedness and resilience, the creation of a Council on Climate Preparedness and Resilience, and the creation of a State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience.[23]

Federal agencies are all required to plan for adaptation. Actions include coordinated efforts at the White House, regional and cross-sector efforts, agency-specific adaptation plans, as well as support for local-level adaptation planning and action. Table 28.1 lists examples, but is not intended as a comprehensive list.

Table 28.1. Examples of Individual Federal Agency Actions to Promote, Implement, and Support Adaptation at Multiple Scales*

Agency	Component	Action	Description
All Federal Agencies		Developed Adaptation Plans as part of their annual Strategic Sustainability Performance Plans	The 2012 Strategic Sustainability Performance Plans for Federal agencies contain specific sections on adaptation. Agencies are required to evaluate climate risks and vulnerabilities to manage both short- and long-term effects on missions and operations.
Department of Health and Human Services (HHS)	Centers for Disease Control and Prevention (CDC)	Climate-Ready States and Cities Initiative	Through their first climate change cooperative agreements in 2010, CDC awarded $5.25 million to ten state and local health departments to assess risks and develop programs to address climate change related challenges.
Department of Agriculture (USDA)		Integrating climate change objectives into plans and networks	USDA is using existing networks such as the Cooperative Extension Service, the Natural Resource Conservation Districts, and the Forest Service's Climate Change Resource Center to provide climate services to rural and agricultural stakeholders.
USDA	Forest Service	Developed a *National Roadmap for Responding to Climate Change* and a *Guidebook for Developing Adaptation Options*, among many resources	The *National Roadmap* was developed in 2010 to identify short- and long-term actions to reduce climate change risks to the nation's forests and grasslands. The *Guidebook* builds on this previous work and provides science-based strategic and tactical approaches to adaptation.
Department of Commerce (DOC)	NOAA	Supporting research teams and local communities on adaptation-related issues and develops tools and resources	Through the Regional Integrated Sciences and Assessments (RISAs) program, develop collaboration between researchers and managers to better manage climate risks. Through the Regional Climate Centers (RCCs) and the Digital Coast partnership, deliver science to support decision-making.
Department of Defense (DoD)		Developed a DoD Climate Change Adaptation Roadmap	DoD released its initial Department-level Climate Change Adaptation Roadmap in 2012. The Roadmap identifies four goals that serve as the foundation for guiding the Department's response to climate change that include using a robust decision making approach based on the best available science.

Table 28.1. Examples of Individual Federal Agency Actions to Promote, Implement, and Support Adaptation at Multiple Scales* (Continued)

DoD	U.S. Army Corps of Engineers (USACE), Civil Works Program	Developed climate change adaptation plan; making progress in priority areas including vulnerability assessments and development of policy and guidance	The USACE Civil Works Program initial climate change adaptation plan in 2011 has a goal to reduce vulnerabilities and improve resilience of water resources infrastructure impacted by climate change. Vulnerability assessments and pilot projects are in progress. Other guidance is underway.
DoD	Department of the Navy	Developed road maps for adaptation in the Arctic and across the globe	The Navy Arctic Roadmap (November 2009) promotes maritime security and naval readiness in a changing Arctic. The Climate Change Roadmap (May 2010) examines broader issues of climate change impacts on Navy missions and capabilities globally.
Department of Energy (DOE)		Develop higher spatial and temporal scales of climate projections and integrate adaptation and climate considerations into integrated assessments	Develops community-based, high-resolution (temporal and spatial) models for climate projections and integrated assessment models that increasingly reflect multi-sectoral processes and interactions, multiple stressors, coupled impacts, and adaptation potential.
DOE		Developed climate change adaptation plan, and completed comprehensive study of vulnerabilities to the energy sector of climate change and extreme weather	The 2013 DOE Report "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather" examines current and potential future impacts of climate trends and identifies activities underway and potential opportunities to enhance energy system climate preparedness and resilience.
Department of Homeland Security (DHS)	Federal Emergency Management Agency (FEMA)	Works with communities across the Nation to help them prioritize their activities to reduce risks	FEMA released a Climate Change Adaptation Policy Statement establishing the Agency's approach to supporting the Department in ensuring resilience to disasters in the face of climate change. FEMA's action areas focus on developing actionable "future risk" tools, enabling state and local adaptation, and building resilience capabilities.
Department of the Interior (DOI)	Fish and Wildlife Service (FWS)	Developed a FWS climate change strategic plan (2010) and established a network of Landscape Conservation Cooperatives (LCCs)	Established a framework to help ensure the sustainability of fish, wildlife, plants, and habitats in the face of climate change. Created a network of 22 LCCs to promote shared conservation goals, approaches, and resource management planning and implementation across the United States.
DOI	U.S. Geological Survey (USGS)	Established a network of Climate Science Centers (CSCs)	DOI operates a National Climate Change and Wildlife Center and eight regional CSCs, which provide scientific information and tools that land, water, wildlife, and cultural resource managers and other stakeholders can apply to anticipate, monitor, and adapt to climate change.
DOI	National Park Service (NPS)	Climate Change Response Strategy (2010), Climate Change Action Plan (2012), and Green Parks Plan (2012)	NPS actions span climate change science, adaptation, mitigation, and communication across national parks, including exhibits for park visitors, providing climate trend information for all national parks, risk screening and adaptation for coastal park units, and implementing scenario planning tools.
DOI	Bureau of Land Management (BLM)	Rapid Ecoregional Assessments (REAs)	REAs synthesize information about resource conditions and trends within an ecoregion; assess impacts of climate change and other stressors; map areas best-suited for future development; and establish baseline environmental conditions, against which to gauge management effectiveness.

Table 28.1. Examples of Individual Federal Agency Actions to Promote, Implement, and Support Adaptation at Multiple Scales* (Continued)

Department of Transportation (DOT)	Federal Highway Administration (FHWA)	Developed Risk Assessment Model for transportation decisions	DOT worked with five local and state transportation authorities to develop a conceptual Risk Assessment Model to identify which assets are: a) most exposed to climate change threats and/or b) associated with the most serious potential consequences of climate change threats. Completed November 2011.
DOT		Comprehensive study of climate risks to Gulf Coast transportation infrastructure followed by in-depth study of Mobile, AL	Phase 1 of the 2008 study assessed transportation infrastructure vulnerability to climate change impacts across the Gulf. Phase 2, to be completed in 2013, focuses on Mobile, AL. This effort will develop transferable tools for transportation planners.
Environmental Protection Agency (EPA)		Established the Climate Ready Estuaries program, the Climate Ready Water Utilities initiative, and a tribal climate change adaptation planning training program	These selected EPA initiatives provide resources and tools to build the capacity of coastal managers, water utilities, and tribal environmental professionals to plan for and implement adaptation strategies.
National Aeronautics and Space Administration (NASA)		Initiated NASA's Climate Adaptation Science Investigator (CASI) Workgroup to partner NASA scientists, engineers, and institutional stewards	The CASI team builds capacity to address climate change at NASA facilities by downscaling facility-specific climate hazard information and projections; conducting customized climate research for each location; and leading resilience and adaptation workshops that spur community-based responses.

*Material provided in table is derived directly from Agency representatives and Agency websites. These are select examples and should not be considered all-inclusive.

Federal agencies can be particularly helpful in facilitating climate adaptation by:

- fostering the stewardship of public resources and maintenance of federal facilities, services, and operations such as defense, emergency management, transportation, and ecosystem conservation in the face of a changing climate;[11,28,29,30]
- providing usable information and financial support for adaptation;[11,20,30]
- facilitating the dissemination of best practices and supporting a clearinghouse to share data, resources, and lessons learned;[11,20,31]
- dealing with and anticipating impacts that cross geopolitical boundaries, assisting in disaster response, and supporting flexible regulatory frameworks;[11,30]
- ensuring the establishment of federal policies that allow for "flexible" adaptation efforts and take steps to avoid unintended consequences;[30,32] and
- building public awareness.[33]

States

States have become important actors in national climate change related efforts. State governments can create policies and programs that encourage or discourage adaptation at other governance scales (such as counties or regions)[34] through regulation and by serving as laboratories for innovation.[35,36] Although many of these actions are not specifically designed to address climate change, they often include climate adaptation components.

Many state-level climate change-specific adaptation actions focus on planning. As of 2013, fifteen states had completed climate adaptation plans; four states were in the process of writing their plans; and seven states had made recommendations to create state-wide adaptation plans.[37]

In addition to formal adaptation plans, numerous states have created sector-specific plans that consider long-term climate change (Figure 28.1). For example, at least 16 states have biodiversity conservation plans that focus on preparing for long-term changes in climate.[38] In addition to planning, some states have created legislation and/or programs that are either directly or indirectly targeted at reducing climate vulnerabilities (Table 28.2).

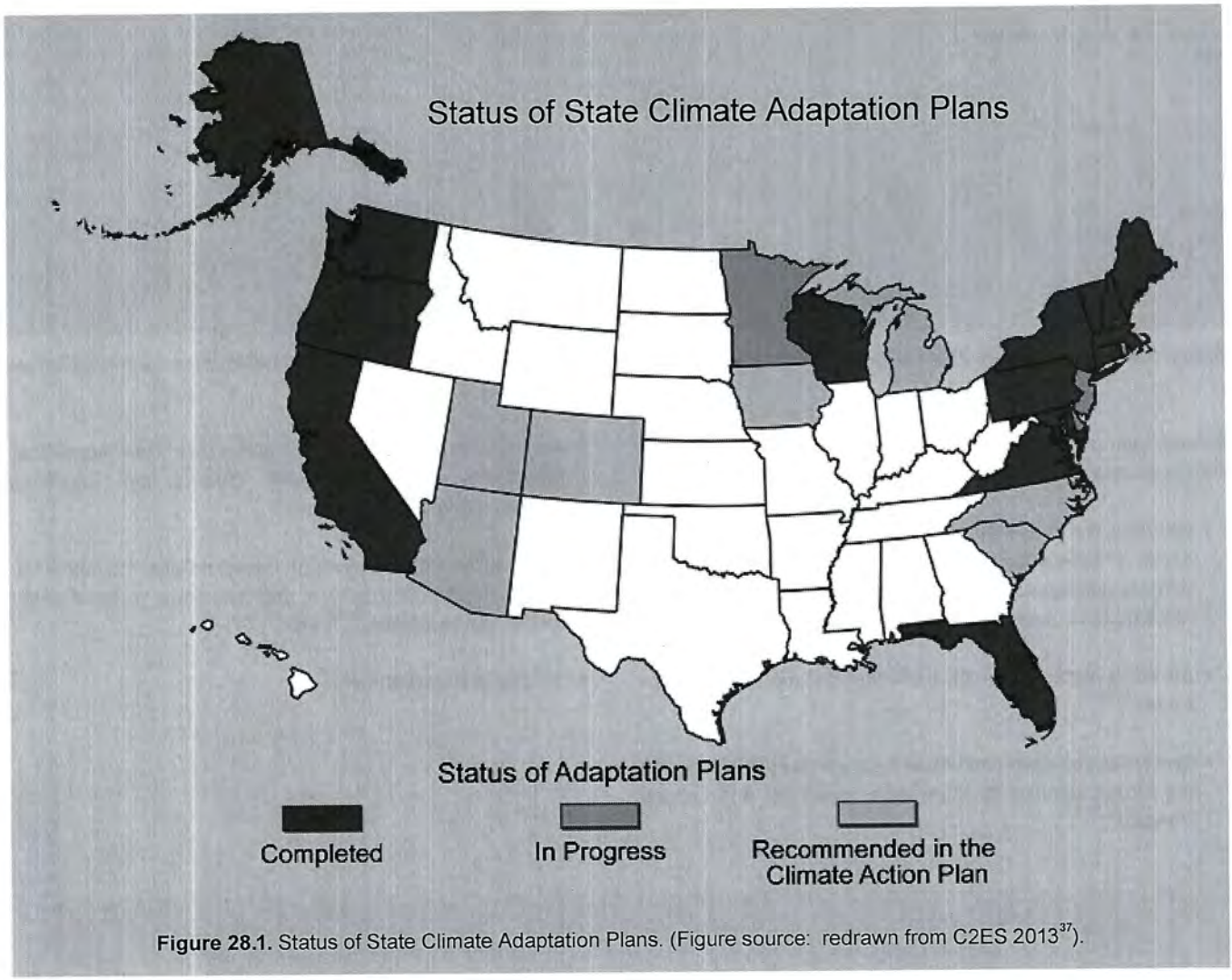


Figure 28.1. Status of State Climate Adaptation Plans. (Figure source: redrawn from C2ES 2013[37]).

Table 28.2. Examples of State-Level Adaptation Activities*

State	Adaptation Action
Alaska	Alaska Climate Change Impact Mitigation Program provides funds for hazard impact assessments to evaluate climate change related impacts, such as coastal erosion and thawing permafrost.[39]
California	Building standards mandating energy and water efficiency savings, advancing both adaptation and mitigation; State Adaptation Plan calls for 20% reduction in per capita water use.[40]
Florida	Law supporting low water use landscaping techniques.[41]
Hawaii	Water code that calls for integrated management, preservation, and enhancement of natural systems.[42]
Kentucky	*Action Plan to Respond to Climate Change in Kentucky: A Strategy of Resilience,* which identifies six goals to protect ecosystems and species in a changing climate.[43]
Louisiana	*Comprehensive Master Plan for a Sustainable Coast 2012* includes both protection and restoration activities addressing land loss from sea level rise, subsidence, and other factors over the next 50 years.[44]
Maine	The *Maine Sand Dune Rules* require that structures greater than 2,500 square feet be set back at a distance that is calculated based on the future shoreline position and considering two feet of sea level rise over the next 100 years.[45]
Maryland	Passed *Living Shorelines Act* to reduce hardened shorelines throughout the state;[46] passed "Building Resilience to Climate Change" policy which establishes practices and procedures related to facility siting and design, new land investments, habitat restoration, government operations, research and monitoring, resource planning, and advocacy.
Montana	Maintains a statewide climate change website to help stakeholders access relevant and timely climate information, tools, and resources.
New Mexico	The Active Water Resource Management program allows for temporary water rights changes in real time in case of drought.[47]
Pennsylvania	Enacted polices to encourage the use of green infrastructure and ecosystem-based approaches for managing storm water and flooding.[9]
Rhode Island	Requires public agencies considering land-use applications to accommodate a 3- to 5-foot rise in sea level.
Texas	Coordinated response to drought through National Integrated Drought Information System (NIDIS); RISAs (Southern Climate Impacts Planning Program [SCIPP], Climate Assessment for the Southwest [CLIMAS]); and state and private sector partners through anticipatory planning and preparedness (for example, implemented in 2011 drought).[48]

*This list contains selected examples of state-level adaptation activities and should not be considered all-inclusive.

Tribal Governments

Tribal governments have been particularly active in assessing and preparing for the impacts of climate change (see Ch. 12: Indigenous Peoples). For example:

- Adaptation planning in Point Hope, Alaska, emphasizes strategies for enhancing community health.[49]
- In Newtok, Alaska, the village council is leading a land-acquisition and planning effort to relocate the community, because climate change induced coastal erosion has destroyed essential infrastructure, making the current village site unsafe.[50]
- The Tulalip Tribes in Washington State are using traditional knowledge gleaned from elders, stories, and songs and combining this knowledge with downscaled climate data to inform decision-making.[51] Also in Washington State, the Swinomish Indian Tribal Community integrated climate change into decision-making in major sectors of the Swinomish Community, such as education, fisheries, social services, and human health.[52]
- The Haudenosaunee Confederacy in the northeastern U.S. is addressing climate impacts by preserving a native food base through seed-banking (Ch. 12: Indigenous Peoples).[53]

Local and Regional Governments

Most adaptation efforts to date have occurred at local and regional levels.[53,54,55,56,57] Primary mechanisms that local governments are using to prepare for climate change include land-use planning; provisions to protect infrastructure and ecosystems; regulations related to the design and construction of buildings, roads, and bridges; and emergency preparation, response, and recovery (Table 28.3).[9,45,56,58]

According to a recent survey of 298 U.S. local governments, 59% indicated they are engaged in some form of adaptation planning.[59] Local adaptation planning and actions are unfolding in municipalities of varying sizes and in diverse geographical areas. Communities such as Keene, New Hampshire; New York City, New York; King County, Washington; and Chicago, Illinois are vanguards in the creation of climate adaptation strategies.[9,11,60] In addition to local government action, regional agencies and regional aggregations of governments are becoming significant climate change adaptation actors.[8,57]

Table 28.3. Examples of Local and Regional Adaptation Activities*

Local or Regional Government	Adaptation Action
Satellite Beach, FL	Collaboration with the Indian River Lagoon National Estuary Program led to efforts to try to incorporate sea level rise projections and policies into the city's comprehensive growth management plan.[54]
Portland, OR	Updated the city code to require on-site stormwater management for new development and re-development. Provides a downspout disconnection program to help promote on-site stormwater management .[61]
Lewes, DE	In partnership with Delaware Sea Grant, ICLEI-Local Governments for Sustainability, the University of Delaware, and state and regional partners, the City of Lewes undertook a stakeholder-driven process to understand how climate adaptation could be integrated into the hazard mitigation planning process. Recommendations for integration and operational changes were adopted by the City Council and are currently being implemented.[62]
Groton, CT	Partnered with federal, state, regional, local, non-governmental, and academic partners through the EPA's Climate Ready Estuaries program to assess vulnerability to and devise solutions for sea level rise.[63]
San Diego Bay, CA	Five municipalities partnered with the port, the airport, and more than 30 organizations with direct interests in the Bay's future to develop the San Diego Bay Sea Level Rise Adaptation Strategy. The strategy identified key vulnerabilities for the Bay and adaptation actions that can be taken by individual agencies, as well as through regional collaboration.[9]
Chicago, IL	Through a number of development projects, the city has added 55 acres of permeable surfaces since 2008 and has more than four million square feet of green roofs planned or completed.[64]
King County, WA	Created King County Flood Control District in 2007 to address increased impacts from flooding through activities such as maintaining and repairing levees and revetments, acquiring repetitive loss properties, and improving countywide flood warnings.[65]
New York City, NY	Through a partnership with the Federal Emergency Management Agency (FEMA), the city is updating FEMA Flood Insurance Rate Maps based on more precise elevation data. The new maps will help stakeholders better understand their current flood risks and allow the city to more effectively plan for climate change.[66]
Southeast Florida Climate Change Compact	Joint commitment among Broward, Miami-Dade, Palm Beach, and Monroe Counties to partner in reducing heat-trapping gas emissions and adapting to climate impacts, including adaptation in transportation, water resources, natural resources, agriculture, and disaster risk reduction. Notable policies emerging from the Compact include regional collaboration to revise building codes and land development regulations to discourage new development or post-disaster redevelopment in vulnerable areas.[67]
Phoenix, AZ; Boston, MA; Philadelphia, PA; and New York, NY	Climate change impacts are being integrated into public health planning and implementation activities that include creating more community cooling centers, neighborhood watch programs, and reductions in the urban heat island effect.[9,68,69]
Boulder, CO; New York, NY; and Seattle, WA	Water utilities in these communities are using climate information to assess vulnerability and inform decision-making.[61]
City of Philadelphia	In 2006, the Philadelphia Water Department began a program to develop a green stormwater infrastructure, intended to convert more than one-third of the city's impervious land cover to "Greened Acres": green facilities, green streets, green open spaces, green homes, etc., along with stream corridor restoration and preservation.[5]

*This table includes select examples of local and regional adaptation activities and should not be considered all-inclusive.

There is no one-size-fits-all adaptation solution to the challenges of adapting to climate change impacts, as solutions will differ depending on context, local circumstance, and scale as well as on local culture and internal capacity.[9,31]

Non-governmental and Private Sector

Many non-governmental entities have been significant actors in the national effort to prepare for climate change by providing assistance that includes planning guidance, implementation tools, contextualized climate information, best practice exchange, and help with bridging the science-policy divide to a wide array of stakeholders (Table 28.4).[70,71] The Nature Conservancy, for example, established the Canyonlands Research Center in Monticello, Utah, to facilitate research and develop conservation applications for resource issues under the multi-stresses of climate change and land-use demands in the Colorado Plateau region.[72]

With regard to the private sector, evidence from organizations such as the Carbon Disclosure Project (CDP) and the Securities and Exchange Commission's (SEC) Climate Change 10-K Disclosure indicate that a growing number of companies are beginning to actively address risks from climate change (Table 28.5).[73] The World Business Council for Sustainable Development (WBCSD) and the Center for Climate and Energy Solutions (C2ES) have identified three types of risks driving private sector adaptation efforts, including risks to core operations, the value chain, and broader changes in the economy and infrastructure (see Figure 28.2).[74,75,76]

This analysis is supported by responses to the 2011 CDP, and suggests that companies are concerned about how changes in the climate will impact issues such as feedstock, water supply and quality, infrastructure, core operations, supply chains, and customers' ability to use (and their need for) services.[73]

Some companies are taking action to not only avoid risk, but to explore potential opportunities that may emerge in a changing climate, such as developing new products and services, developing or expanding existing consulting services, expanding into new operational territories, extending growing seasons and hours of operation, and responding to increased demand for existing products and services.[73,75,77,78]

This one-acre stormwater wetland was constructed in Philadelphia to treat stormwater runoff in an effort to improve drinking water quality while minimizing the impacts of storm-related flows on natural ecosystems.

Table 28.4. Examples of Non-governmental Adaptation Efforts and Services*

Types of Adaptation Efforts and Services	Examples of Organizations Providing Services
Adaptation planning assistance, including creation of guides, tools, and templates	Center for Climate Strategies, ICLEI-Local Governments for Sustainability, International Institute for Sustainable Development, Natural Resources Defense Council, The Nature Conservancy, World Resources Institute, World Wildlife Fund
Networking and best practice exchange	C40 Cities Climate Leadership Group, Adaptation Network, Center for Clean Air Policy, Climate Adaptation Knowledge Exchange, ICLEI-Local Governments for Sustainability, Institute for Sustainable Communities, Urban Sustainability Directors Network, World Business Council for Sustainable Development
Climate information providers	Union of Concerned Scientists, Urban Climate Change Research Network, Stockholm Environment Institute–U.S. Center
Policy, legal, and institutional support	Center for Climate and Energy Solutions (formerly Pew Center on Global Climate Change), Georgetown Climate Center
Aggregation of adaptation-pertinent information	Carbon Disclosure Project, Climate Adaptation Knowledge Exchange, Georgetown Climate Center

*This list contains examples of non-governmental organizations providing the identified services and should not be considered all-inclusive or a validation of actions claimed by the organizations.

Table 28.5. Examples of Private Sector Actions to Adapt to Climate Risks as Reported to the Carbon Disclosure Project*

Company	Sector	Climate Risk	Examples of Actions Undertaken
Coca-Cola Company	Consumer Staples	Changes in physical climate parameters; Changes in other climate-related developments	Coca-Cola is working around the world to replenish the water used in finished beverages by participating in locally relevant water projects that support communities and nature. Since 2005, the Coca-Cola system has engaged in more than 320 projects in 86 countries. The range of community projects includes watershed protection; expanding community drinking water and sanitation access; water for productive use, such as agricultural water efficiency; and education and awareness programs. (http://www.thecoca-colacompany.com/citizenship/conservation_partnership.html)
ConAgra Foods, Inc.	Consumer Staples	Company experienced weather-related sourcing challenges, such as delayed tomato harvesting due to unseasonably cool weather, and difficulty sourcing other vegetables due to above normal precipitation.	As part of its business continuity planning, ConAgra Foods has analyzed its supply risk to develop strategic partnerships with suppliers, minimize sole-sourced ingredients, and identify alternate suppliers and contract manufacturers to minimize production disruptions in the instance of an unexpected disruption in supply. (http://company.conagrafoods.com/phoenix.zhtml?c=202310&p=Policies_Environment)
Constellation Brands	Consumer Staples	Changes in physical climate parameters; Changes in other climate-related developments	Constellation has already taken adaptation actions, particularly in California where water availability is an issue, to manage or adapt to these risks. Constellation is working with numerous organizations to help fund industry-based research to determine potential climate change impacts on vineyard production.
Munich Re	Reinsurance	Changes in regulation; Changes in physical climate parameters; Changes in other climate-related developments	Since 2007, a Group-wide climate change strategy covering all aspects of climate change – for example, weather-related impacts, regulatory impacts, litigation and health risks, etc. – has supported their core corporate strategy. The strategy is based on five pillars: mitigation, adaptation, research, in-house carbon dioxide reduction, and advocacy. (http://www.munichre.com/en/group/focus/climate_change/default.aspx)
Pacific Gas and Electric Company (PG&E)	Utilities	Changes in regulation; changes in physical climate parameters; Changes in other climate-related developments	PG&E's adaptation strategies for potential increased electricity demand include expanded customer energy efficiency and demand response programs and improvements to its electric grid. PG&E is proactively tracking and evaluating the potential impacts of reductions to Sierra Nevada snowpack on its hydroelectric system and has developed adaptation strategies to minimize them. Strategies include maintaining higher winter carryover reservoir storage levels, reducing conveyance flows in canals and flumes in response to an increased portion of precipitation falling as rain, and reducing discretionary reservoir water releases during the late spring and summer. PG&E is also working with both the U.S. Geological Survey (USGS) and the California Department of Water Resources to begin using the USGS Precipitation-Runoff Modeling System (PRMS) watershed model, to help manage reservoirs on watersheds experiencing mountain snowpack loss. (http://www.pge.com/about/environment/commitment/)
SC Johnson & Son, Inc.	Household Products	Changes in physical climate parameters	SC Johnson is adjusting to the various physical risks that climate change imposes through a diversified supplier and global manufacturing base. In March 2009, SC Johnson announced a broad ingredient communication program. SC Johnson assesses risks along each ingredient's supply chain to ensure that the company is sourcing from a geographically diverse supplier base. In addition to evaluating product ingredients, SC Johnson has also diversified its operations around the world, allowing it to maintain business continuity in the face of a regional climate change related disruption. (http://www.scjohnson.com/en/commitment/overview.aspx)
Spectra Energy, Inc.	Energy	Changes in regulation; Changes in physical climate parameters; Changes in other climate-related developments	Spectra Energy uses a corporate-wide risk analysis framework to ensure the oversight and management of its four major risk categories: financial, strategic, operational, and legal risks. Physical risks posed by climate change fall within these categories and the company uses risk management committees to ensure that all material risks are identified, evaluated, and managed prior to financial approvals of major projects. (http://www.spectraenergy.com/Sustainability/)

* This list contains examples of private sector actions to adapt to climate risks as reported to the Carbon Disclosure Project and should not be considered all-inclusive or a validation of actions claimed by the organizations.

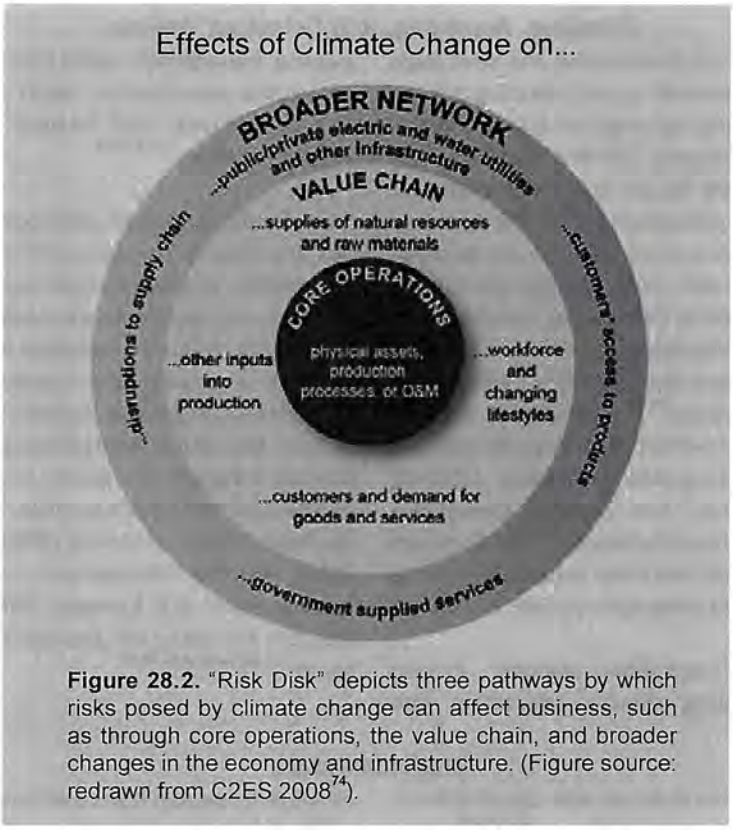


Figure 28.2. "Risk Disk" depicts three pathways by which risks posed by climate change can affect business, such as through core operations, the value chain, and broader changes in the economy and infrastructure. (Figure source: redrawn from C2ES 2008[74]).

Section 1: Adaptation Process

General patterns in adaptation processes are beginning to emerge, with similarities discernible across sectors, systems, and scales.[53,78,79]

Figure 28.3. Generalized Adaptation Process
(Figure source: adapted from NRC 2010[11]).

This is not a stepwise or linear process; various stages can be occurring simultaneously, in a different order, or be omitted completely. However, as shown clockwise in Figure 28.3, the process generally involves characterizing vulnerability, developing options, implementing actions, monitoring outcomes, and reevaluating strategies. Each of these is described in more detail below.

Identifying and Understanding Risk, Vulnerabilities, and Opportunities

Most adaptation actions are currently in the initial phase, with many actors focusing on identifying the relevant climate risks and conducting current and future risk and vulnerability assessments of their assets and resources.[8,11,59,80,81,82] In 2011, only 13% of 298 U.S. municipalities surveyed had completed vulnerability or risk assessments, but 42% expected to complete an assessment in the future.[59] At least 21 state fish and wildlife agencies have undertaken climate vulnerability assessments or recently completed an assessment of a particular species, habitat, or both.[38] Multiple qualitative and quantitative methods are used to understand climate vulnerability and risk, including case studies and analogue analyses, scenario analyses, sensitivity analyses, monitoring of key species, and peer information sharing.[8,28,83,84]

Planning, Assessing, and Selecting Options

Once risks and vulnerabilities are understood, the next stage typically involves identifying, evaluating, and selecting options for responding to and managing existing and future changes in the climate.[28] Decision support planning methods and associated tools help to identify flexible and context-relevant adaptation activities for implementation.[11,79] Participatory approaches support the integration of stakeholder perspectives and context-specific information into decision-making.[85,86] This approach can include having community members and governing institutions work collectively to define the problem and design adaptation strategies that are robust while being sensitive to stakeholder values.[86,87] Moreover, regional collaboration has emerged as an effective strategy for defining common approaches to reducing potential threats, selecting metrics for tracking purposes, and creating governance structures to help navigate political challenges.[67,88] As discussed above, a number of government and other organizations have developed plans with identified adaptation options.

Common approaches to adaptation planning include "mainstreaming" or integrating climate adaptation into existing management plans (for example, hazard mitigation, ecosystem conservation, water management, public health, risk contingency, and energy) or developing stand-alone adaptation plans.[68,82,89,90]

Many frameworks, tools, and approaches have emerged to help decision-makers make decisions in light of both uncertainty and the need to achieve multiple societal goals.[7,79] Some of these, however, are specific to particular localities or resources, are not easy to use by the intended audiences, do not adequately evaluate tradeoffs, and require sophisticated knowledge of climate change.[91] In general, these approaches promote options that allow reversibility, preserve future options, can tolerate a variety of impacts, and are flexible, such that mid-course adjustments are possible.[32,92] Among these approaches are Robust Decision Making (RDM), Iterative Risk Management (IRM), Adaptive Management or Co-Management, Portfolio Management, and Scenario Planning (see Ch. 26: Decision Support for more on decision frameworks, processes, and tools).[7,11,28,54,93,94,95,96,97]

Implementation

There is little peer-reviewed literature on adaptation actions, or evaluations of their successes and failures.[11,36,81,98] Many of the documents submitted as part of this Third National Climate Assessment (NCA) process indicate that adaptation actions are being implemented for a variety of reasons. Often, these are undertaken with an aim toward reducing current vulnerabilities to hazards or extreme weather events, such as forest thinning and fuel treatments that reduce fire hazards in national forests or through the diversification of supply chain sourcing in the private sector.[72,73] Additionally, an increasing movement toward mainstreaming climate adaptation concerns into existing processes means that discerning unique climate adaptation activities will be a challenge.[82,99]

Monitoring and Evaluation

There is little literature evaluating the effectiveness of adaptation actions.[9,72,79,86] Evaluation and monitoring efforts, to date, have focused on the creation of process-based rather than outcome-based indicators.[86,90] A number of efforts are underway to create indicators related to climate adaptation,[27] including work by the National Climate Assessment and Development Advisory Committee Indicators Working Group[100] and the U.S. Environmental Protection Agency.[101] Part of monitoring should include accounting for costs of adaptation. To be sure, this may be difficult to account for because of challenges in attribution of climate events to climate change versus climate variability. A few studies summarize projected future costs of adaptation.[102,103]

Revise Strategies/Processes and Information Sharing

Uncertainty about future climate as well as population growth, economic development, response strategies, and other social and demographic issues can stymie climate adaptation activity.[95,104,105] Through iterative processes, however, stakeholders can regularly evaluate the appropriateness of planned and implemented activities and revise them as new information becomes available.[11,28,84] Additionally, the sharing of best practices and lessons learned can be pivotal means to advancing understanding and uptake of climate adaptation activity.[82,86] The use of established information-sharing networks, such as regional climate initiatives, are illustrations of the types of networks that have supported stakeholder adaptation activity to-date.[9,76,79,86]

Section 2: Barriers to Adaptation and Examples of Overcoming Barriers

Despite emerging recognition of the necessity of climate change adaptation, many barriers still impede efforts to build local, regional, and national-level resilience. Barriers are obstacles that can delay, divert, or temporarily block the adaptation process,[106] and include difficulties in using climate change projections for decision-making; lack of resources to begin and sustain adaptation efforts; lack of coordination and collaboration within and across political and natural system boundaries as well as within organizations; institutional constraints; lack of leadership; and divergent risk perceptions/cultures and values (Table 28.6).[11,20,107] Barriers are distinguished from physical or ecological limits to adaptation, such as physiological tolerance of species to changing climatic conditions that cannot be overcome (except with technology or some other physical intervention).[8,54,108]

Despite barriers, individuals within and across sectors and regions are organizing to collectively overcome barriers and adapt to climate change. In many cases, lessons learned from initial programs help inform future adaptation strategies. Figure 28.4 highlights ongoing climate adaptation activities that have overcome some of these barriers in different regions led

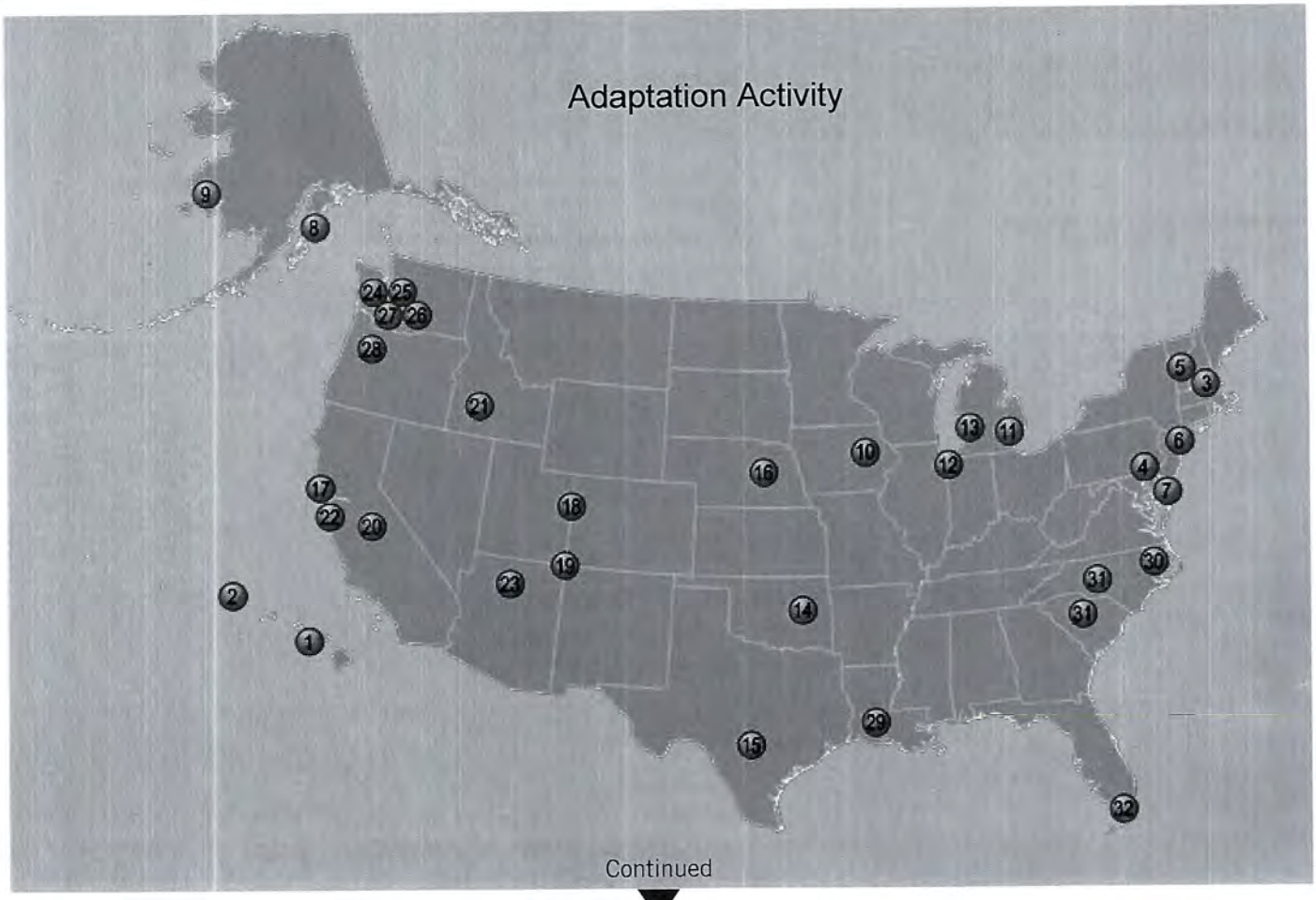
Table 28.6. Summary of Adaptation Barriers

Barrier	Specific Examples
Climate Change Information and Decision-Making References: 7,8,10,11,14,17,31,32,42,59,68,69,72,82,90,93,104,109,110,111,112	• Uncertainty about future climate impacts and difficulty in interpreting the cause of individual weather events • Disconnect between information providers and information users • Fragmented, complex, and often confusing information • Lack of climate education for professionals and the public • Lack of usability and accessibility of existing information • Mismatch of decision-making timescales and future climate projections
Lack of Resources to Begin and Sustain Adaptation Efforts References: 8,13,42,51,54,59,81,82,111,112,113,114	• Lack of financial resources / no dedicated funding • Limited staffing capacity • Underinvestment in human dimensions research
Fragmentation of Decision-Making References: 8,14,31,32,51,68,115,116	• Lack of coordination within and across agencies, private companies, and non-governmental organizations • Uncoordinated and fragmented research efforts • Disjointed climate related information • Fragmented ecosystem and jurisdictional boundaries
Institutional Constraints References: 8,13,42,51,54,97,113,117,118,119	• Lack of institutional flexibility • Rigid laws and regulations • No legal mandate to act • Use of historical data to inform future decisions • Restrictive management procedures • Lack of operational control or influence
Lack of Leadership References: 30,96,112,113,119,120,121	• Lack of political leadership • Rigid and entrenched political structures • Polarization
Divergent Risk Perceptions, Cultures, and Values References: 51,71,82,116,117,120,122	• Conflicting values/risk perceptions • Little integration of local knowledge, context, and needs with traditional scientific information • Cultural taboos and conflict with cultural beliefs • Resistance to change due to issues such as risk perception

by state, local, and private actors in the United States. It is not a comprehensive compilation of national adaptation activity, but is intended to identify some of the variety of adaptation efforts taking place across the country.

In addition, Section 4 of this chapter provides four in-depth case studies of climate adaptation strategies at different scales, with multiple stakeholders, and tackling different challenges. Each of these case studies highlights the different ways stakeholders are approaching adaptation.

- Through the creation of the National Integrated Drought Information System (NIDIS), the Federal Government, in partnership with the National Drought Mitigation Center (NDMC), states, tribes, universities, and others, has improved capacity to proactively manage and respond to drought-related risks and impacts through: 1) the provision of drought early warning information systems with local/regional input on extent, onset, and severity; 2) a web-based drought portal featuring the U.S. Drought Monitor and other visualization tools; 3) coordination of research in support and use of these systems; and 4) leveraging of existing partnerships, forecasting, and assessment programs.
- In the Colorado River Basin, water resource managers, government leaders, federal agencies, tribes, universities, nongovernmental organizations (NGOs), and the private sector are collaborating on strategies for managing water under a changing climate through partnerships like the Western Governors' Association (WGA) and WestFAST (Western Federal Agency Support Team).
- In Wisconsin, the Northern Institute of Applied Climate Science and the U.S. Forest Service, working with multiple partners, initiated a "Climate Change Response Framework" integrating climate-impacts science with forest management.
- In Cape Cod, Massachusetts, the U.S. Department of Transportation's Volpe Center worked with federal, regional, state, and local stakeholders to integrate climate change mitigation and adaptation considerations into existing and future transportation, land-use, coastal, and hazard-mitigation processes.



Continued

Figure 28.4. Adaptation Activity

1. The State of Hawai'i, Office of Planning, in cooperation with university, private, state, and federal scientists and others, has drafted a framework for climate change adaptation that identifies sectors affected by climate change, and outlines a process for coordinated statewide adaptation planning.[123]

2. One of the priorities of the Hawai'i State Plan is preserving water sources through forest conservation, as indicated in their "Rain Follows The Forest" report.[124]

3. New England Federal Partners is a multi-agency group formed to support the needs of the states, tribes, and communities of the New England Region and to facilitate and enable informed decision-making on issues pertaining to coastal and marine spatial planning, climate mitigation, and climate adaptation throughout the region.[125]

4. Philadelphia is greening its combined sewer infrastructure to protect rivers, reduce greenhouse gas emissions, improve air quality, and enhance adaptation to a changing climate.[126]

5. Keene, NH, developed a Comprehensive Master Plan that emphasizes fostering walkable, mixed-use neighborhoods by putting services, jobs, homes, arts and culture, and other community amenities within walking distance of each other. The plan also calls for sustainable site and building designs that use resources efficiently. These strategies were identified in the city's 2007 Adaptation Plan as ways to build resilience while reducing greenhouse gas emissions.[127]

6. New York City has created a Green Infrastructure Plan and is committed to goals that include the construction of enough green infrastructure throughout the city to manage 10% of the runoff from impervious surfaces by 2030.[128]

7. Lewes, DE, undertook an intensive stakeholder process to integrate climate change into the city's updated hazard mitigation plan.[62]

8. Local governments and tribes throughout Alaska, such as those in Homer, are planting native vegetation and changing the coastal surface, moving inland or away from rivers, and building riprap walls, seawalls or groins, which are shore-protection structures built perpendicular to the shoreline (see also: Ch. 22:Alaska; Ch. 12: Indigenous Peoples).[129]

9. Alaskan villages are physically being relocated because of climate impacts such as sea level rise and erosion; these include Newtok, Shishmaref, Kivalina, and dozens of other villages.[130]

10. Cedar Falls, Iowa, passed legislation in 2009 that includes a new floodplain ordinance that expands zoning restrictions from the 100-year floodplain to the 500-year floodplain, because this expanded floodplain zone better reflects the flood risks experienced by the city during the 2008 floods.[131]

11. In January 2011, the Michigan Department of Community Health (MDCH) released the *Michigan Climate and Health Adaptation Plan*, which has a goal of "preparing the public health system in Michigan to address the public health consequences of climate change in a coordinated manner." In September 2010, MDCH received three years' funding to implement this plan as part of the Climate-Ready States and Cities Initiative of CDC.[132]

12. Chicago was one of the first cities to officially integrate climate adaptation into a citywide climate adaptation plan. Since its release, a number of strategies have been implemented to help the city manage heat, protect forests, and enhance green design, such as their work on green roofs.[64]

13. Grand Rapids, MI, recently released a sustainability plan that integrates future climate projections to ensure that the economic, environmental, and social strategies embraced are appropriate for today as well as the future.[133]

14. Tulsa, OK, has a three-pronged approach to reducing flooding and managing stormwater: a) prevent new problems by looking ahead and avoiding future downstream problems from new development (for example, requiring on-site stormwater detention); b) correct existing problems and learn from disasters to reduce future disasters (for example, through watershed management and the acquisition and relocation of buildings in flood-prone areas); and c) act to enhance the safety, environment, and quality of life of the community through public awareness, an increase in stormwater quality, and emergency management.[134]

15. Firewise Communities USA is a nationwide program of the National Fire Protection Association and is co-sponsored by USDA Forest Service, DOI, and the National Association of State Foresters. According to the Texas Forest Service, there are more than 20 recognized Texas Firewise Communities. The Texas Forest Service works closely with communities to help them to reach Firewise Community status and offers a variety of awareness, educational, informational, and capacity-building efforts, such as *Texas Wildscapes*, a program that assists in choosing less fire-friendly plants.[135]

Continued

16. After the heavy rainfall events of 2004 that resulted in significant erosion on his farms, Dan Gillespie, a farmer with the Natural Resources Conservation Service in Norfolk, NE, began experimenting with adding cover crops to the no-till process. It worked so well in reducing erosion and increasing crop yields that he is now sharing his experience with other farmers. (http://www.lenrd.org/projects-programs/; http://www.notill.org/)[136]

17. Point Reyes National Seashore is preparing for climate change by removing two dams that are barriers to water flow and fish migration. This change restores ecological continuity for anadromous fish (those that migrate from the sea to fresh water to spawn), creating a more resilient ecosystem.[137]

18. Western Adaptation Alliance is a group of eleven cities in five states in the Intermountain West that share lessons learned in adaptation planning, develop strategic thinking that can be applied to specific community plans, and join together to generate funds to support capacity building, adaptation planning, and vulnerability assessment.[138]

19. Navajo Nation used information on likely changes in future climate to help inform their drought contingency plan.[139]

20. California Department of Health and the Natural Resources Defense Council collaborated to create the *Public Health Impacts of Climate Change in California: Community Vulnerability Assessment and Adaptation Strategies* report, which is being used to inform public health preparedness activities in the state.[140]

21. State of Idaho successfully integrated climate adaptation into the state's Wildlife Management Plan. (http://fishandgame.idaho.gov/public/wildlife/cwcs/)[8]

22. The Rising Tides Competition was held in 2009 by the San Francisco Bay Conservation and Development Commission to elicit ideas for how the Bay could respond to sea level rise.[141]

23. Flagstaff, Arizona, created a resilience strategy and passed a resilience policy, as opposed to a formal adaptation plan, as a means to institutionalize adaptation efforts in city government operations.[142]

24. The Olympic National Forest and Olympic National Park were sites of case studies looking at how to adapt management of federal lands to climate change. Sensitivity assessments, review of management activities and constraints, and adaptation workshops in the areas of hydrology and roads, fish, vegetation, and wildlife were all components of the case study process.[143]

25. King County Flood Control District was reformed to merge multiple flood management zones into a single county entity for funding and policy oversight for projects and programs – partly in anticipation of increased stormwater flows due to climate change.[144]

26. The Water Utilities Climate Alliance has been working with member water utilities to ensure that future weather and climate considerations are integrated into short- and long-term water management planning. (http://www.wucaonline.org/html/)[90]

27. Seattle's RainWatch program uses an early warning precipitation forecasting tool to help inform decisions about issues such as drainage operations. (http://www.atmos.washington.edu/SPU/)[19]

28. City of Portland and Multnomah County created a Climate Action Plan that includes indicators to help them gauge progress in planning and implementing adaptation actions.[145]

29. In 2010, the state of Louisiana launched a $10 million program to assist communities that had been affected by Hurricanes Gustav and Ike in becoming more resilient to future environmental problems. Twenty-nine communities from around the state were awarded resiliency development funds. The Coastal Sustainability Studio at Louisiana State University started working in 2012 with all 29 funded communities, as well as many that did not receive funds, to develop peer-learning networks, develop best practices, build capacity to implement plans, and develop planning tools and a user-inspired and useful website to increase community resiliency in the state.[146]

30. U.S. Fish and Wildlife Service and The Nature Conservancy are cooperating in a pilot adaptation project to address erosion and saltwater intrusion, among other issues, in the Alligator River Refuge. This project incorporates multiple agencies, native knowledge, community involvement, local economics, and technical precision.[147]

31. North and South Carolina are actively working to revise their state wildlife strategies to include climate adaptation.[82]

32. The Southeast Florida Climate Change Compact is a collaboration of the four southernmost counties in Florida (Monroe, Broward, Palm Springs, and Miami-Dade) focusing on enhancing regional resilience to climate change and reducing regional greenhouse gas emissions.[67]

Section 3: Next Steps

Adaptation to climate change is in a nascent stage. The Federal Government is beginning to develop institutions and practices necessary to cope with climate change, including efforts such as regional climate centers within the U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration (a division of the U.S. Department of Commerce), and the U.S. Department of the Interior. While the Federal Government provides financial assistance in federally-declared disasters, it is also enabling and facilitating early adaptation within states, regions, local communities, and the public and private sectors.[11] The approaches include working to limit current institutional constraints to effective adaptation, funding pilot projects, providing useful and usable adaptation information – including disseminating best practices and helping develop tools and techniques to evaluate successful adaptation.

Despite emerging efforts, the pace and extent of adaptation activities are not proportional to the risks to people, property, infrastructure, and ecosystems from climate change; important opportunities available during the normal course of planning and management of resources are also being overlooked. A number of state and local governments are engaging in adaptation planning, but most have not taken action to implement the plans.[107] Some companies in the private sector and numerous non-governmental organizations have also taken early action, particularly in capitalizing on the opportunities associated with facilitating adaptive actions. Actions and collaborations have occurred across all scales. At the same time, barriers to effective implementation continue to exist (see Section 2).

One of the overarching key areas of focus for global change research is enabling research and development to advance adaptation across scales, sectors, and disciplines. This includes social science research for overcoming the barriers identified in Section 2, such as strategies that foster coordination, better communication, and knowledge sharing amongst fragmented governing structures and stakeholders. Research on the kinds of information that users desire and how to deliver that information in contextually appropriate ways and research on decision-making in light of uncertainty about climate change and other considerations will be equally important. In addition to these areas, emerging areas of emphasis include:

- Costs and Benefits of Adaptation: Methodologies to evaluate the relevant costs of adaptation options, as well as the costs of inaction, need to be developed.[6,102]

- A Compendium of Adaptation Practices: A central and streamlined database of adaptation options implemented at different scales in space and time is needed. Information on the adaptation actions, how effective they were, what they cost, and how monitoring and evaluation were conducted should be part of the aggregated information.[11,20,31]

- Adaptation and Mitigation Interactions: Research and analysis on the growing and competing demands for land, water, and energy and how mitigation actions could affect adaptation options, and vice versa.[4,27,81,148]

- Critical Adaptation Thresholds: Research to identify critical thresholds beyond which social and/or ecological systems are unable to adapt to climate change. This should include analyzing historical and geological records to develop models of "breakpoints".[2,31,149]

- Adaptation to Extreme Events: Research on preparedness and response to extreme events such as droughts, floods, intense storms, and heat waves in order to protect people, ecosystems, and infrastructure. Increased attention must be paid to how extreme events and variability may change as climate change proceeds, and how that affects adaptation actions.[11,150]

Effective adaptation will require ongoing, flexible, transparent, inclusive, and iterative decision-making processes, collaboration across scales of government and sectors, and the continual exchange of best practices and lessons learned. All stakeholders have a critical role to play in ensuring the preparedness of our society to extreme events and long-term changes in climate.

Section 4: Case Studies

Illustrative Case One: National Integrated Drought Information System

NIDIS (National Integrated Drought Information System), originally proposed by the Western Governors' Association (WGA) and established by Congress in 2006,[151] is a federally-created entity that improves the nation's capacity to proactively manage drought-related risks across sectors, regions, and jurisdictions. It was created by Congress to "enable the Nation to move from a reactive to a more proactive approach to managing drought risks and impacts." NIDIS has successfully brought together government partners and research organizations to advance a warning system for drought-sensitive areas.

The creation of NIDIS involved many years of development and coordination among federal, state, local, regional, and tribal partners with the help of Governors' associations and Senate and Congressional leaders. NIDIS provides: 1) drought early warning information systems with regional detail concerning onset and severity; 2) a web-based portal (www.drought.gov);

3) coordination of federal research in support of and use of these systems; and 4) leveraging of existing partnerships and of forecasting and assessment programs. NIDIS currently supports work on water supply and demand, wildfire risk assessment and management, and agriculture. Regional drought early warning system pilot projects have been established to illustrate the benefits of improved knowledge management, improved use of existing and new information products, and coordination and capacity development for early warning systems. These prototype systems are in the Upper Colorado Basin, the Apalachicola-Chattahoochee-Flint River Basin in the Southeast, the Four Corners region in the Southwest, and California. The NIDIS Outlook in the Upper Colorado Basin provides early warning information every week, for example, that is utilized by a variety of users from federal agencies, water resource management, and the recreation industry.

The Western Governors' Association, the U.S. Congress, and others have formally acknowledged that NIDIS provides a successful example of achieving effective federal-state partnerships by engaging both leadership and the public, and establishing an authoritative basis for integrating monitoring and research to support risk management. Some of NIDIS's keys to success include:

- Usable Technology and Information for Decision Support: The production of the U.S. Drought Monitor map, which integrates multiple indicators and indices from many data sources, was developed before NIDIS was established and has become a useful visual decision support tool for monitoring and characterizing drought onset, severity, and persistence. NIDIS has engaged regional and local experts in refining the regional details of this national product and in "ground truthing" maps via email discussions and webinars (Figure 28.5).

- Financial Assistance: Federal funding was allocated to NOAA specifically for NIDIS, but leveraged in kind by other agencies and partners.

- Institutional/Partnerships: Effective collaborations, partnerships, and coordination with NOAA, WGA, USDA, DOI, and USGS as well as local, regional, state, and tribal partners and with the National Drought Mitigation Center at the University of Nebraska, Lincoln, have led to multi-institutional "buy-in."

- Institutional/Policy: The NIDIS Act was oriented toward the improvement of coordination across federal agencies and with regional organizations, universities, and states. It focused on the application of technology, including the Internet, and on impact assessments for decision support. A key aspect of NIDIS is the development of an ongoing regional outlook forum based on the above information to build awareness of the drought hazard and to embed information in planning and practice (in partnership with the National Drought Mitigation Center, the Regional Integrated Sciences and Assessments (RISA), and other research-based boundary organizations) to reduce risks and impacts associated with drought.

- Leadership and Champions: NIDIS supporters worked at all levels over more than two decades (1990s and 2000s) to establish the NIDIS Act, including political groups (WGA, Southern Governors' Association, National Governors Association, and U.S. Senators and Representatives), scientific leaders, and federal agencies (NOAA, USDA, DOI).

- Risk Perceptions: Whereas drought had been considered primarily a western issue in previous decades, drought is now regularly affecting the southern, southeastern, and northeastern parts of the country and response strategies are needed. During the 2012 drought, more than 63% of the contiguous U.S. by the end of July was classified as experiencing moderate to exceptional drought, and more than 3,200 heat records were broken in June 2012 alone.[152]

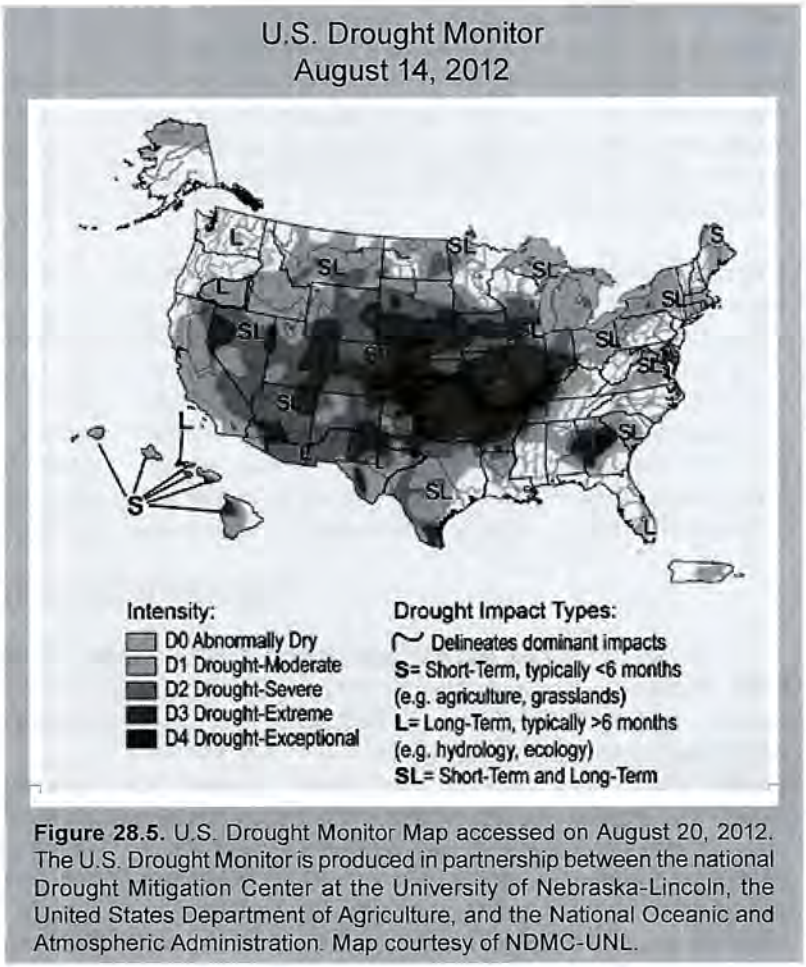


Figure 28.5. U.S. Drought Monitor Map accessed on August 20, 2012. The U.S. Drought Monitor is produced in partnership between the national Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Map courtesy of NDMC-UNL.

Illustrative Case Two: Adaptive Governance in the Colorado River Basin

The Colorado River supplies water and valuable ecosystem services to 33 million people and is vulnerable to climate change because of decreases in mountain snowpack and water availability, increased competition among water users, fires, drought, invasive species, and extended extreme heat events, among other threats.[13,153] The 1922 Colorado River Compact, which allocates water among seven U.S. states and Mexico, was agreed upon in a particularly wet time period;[154] thus the river water is already over-allocated for current conditions. Given the likelihood of having less water because of climate change, resource managers and government leaders are increasingly recognizing that water must be managed with flexibility to respond to the projected impacts and the range of possible future climates (see Ch. 2: Our Changing Climate; Ch. 3: Water).[13,155] Multiple actors across multiple disciplines, scales of governance (including tribal, local, state, and federal), non-governmental organizations, and the private sector are organizing and working together to address these concerns and the relationship between climate and other stresses in the basin.

The Western Governors' Association (WGA) spearheaded adaptation efforts to enable federal, state, tribal, local, and private sector partners to address a range of issues, including climate change.[13,155,156] For example, the Western Federal Agency Support Team (WestFAST), which was established in 2008, created a partnership between the Western States Water Council (WSWC) and 11 federal agencies with water management responsibilities in the western United States. The agencies created a work plan in 2011 to address three key areas: 1) climate change; 2) water availability, water use, and water reuse; and 3) water quality. To date they have produced the WestFAST Water-Climate Change Program Inventory, the Federal Agency Summary, and a Water Availability Studies Inventory (http://www.westgov.org/wswc/WestFAST.htm).

The WSWC and the USACE produced the Western States Watershed Study (WSWS), which demonstrated how federal agencies could work collaboratively with western states on planning activities.[157] In 2009, the WGA also adopted a policy resolution titled "Supporting the Integration of Climate Change Adaptation Science in the West" that created a Climate Adaptation Work Group composed of western state experts in air quality, forest management, water resources, and wildlife management. Other important adaptation actions were the SECURE Water Act in 2009, the Reclamation Colorado River Basin water supply and demand study, and the creation of NIDIS to support stakeholders in coping with drought.[151,158]

Illustrative Case Three: Climate Change Adaptation in Forests

Northern Wisconsin's climate has warmed over the past 50 years, and windstorms, wildfires, insect outbreaks, and floods are projected to become more frequent in this century.[160] The resulting impacts on forests, combined with fragmented and complex forest ownership, create management challenges that extend across ownership boundaries, creating the need for a multi-stakeholder planning process.[161]

To address these concerns, the Northern Institute of Applied Climate Science, the USDA's Forest Service, and many other partners initiated the Climate Change Response Framework to incorporate scientific research on climate change impacts into on-the-ground management. Originally developed as a pilot project for all-lands conservation in northern Wisconsin, it has expanded to cover three ecological regions (Northwoods [Figure 28.6], Central Hardwoods, and Central Appalachians) across eight states in the Midwest and Northeast. The Framework uses a collaborative and iterative approach to provide information and resources to forest owners and managers across a variety of private and public organizations. Several products were developed through the Framework in northern Wisconsin:

Figure 28.6. Northwoods Climate Change Response Framework Region (Figure Source: USDA Forest Service 2012[159]).

1. Vulnerability and mitigation assessments summarized the observed and projected changes in the northern Wisconsin climate, projected changes in forest composition and carbon stocks across a range of potential climates, and assessed related vulnerabilities of forest ecosystems in northern Wisconsin.[160]

2. Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers[162] was developed to help managers identify management tactics that facilitate adaptation. A "menu" of adaptation strategies and approaches for planning, implementing, and monitoring adaptation activities was synthesized into an adaptation workbook from a broad set of literature and refined based on feedback from regional scientists and managers.[163]

3. A series of adaptation demonstrations was initiated to showcase ground-level implementation. The Framework and adaptation workbook provide a common process shared by diverse landowners and a formal network that supports

cross-boundary discussion about different management objectives, ecosystems, and associated adaptation tactics.

From the beginning, the Framework has taken an adaptive management approach in its adaptation planning and projects. Lessons learned include:

- Define the purpose and scope of the Framework and its components early, but allow for refinement to take advantage of new opportunities.
- Begin projects with a synthesis of existing information to avoid duplicating efforts.
- Plan for the extra time necessary to implement true collaboration.
- Carefully match the skills, commitment, and capacity of people and organizations to project tasks.
- Maintain an atmosphere of trust, positivity, and sense of adventure, rather than dwelling on failures.
- Acknowledge and work with uncertainty, rather than submit to "uncertainty paralysis."
- Recognize the necessity of effective communication among people with different goals, disciplinary backgrounds, vocabulary, and perspectives on uncertainty.
- Integrate the ecological and socioeconomic dimensions early by emphasizing the many ways that communities value and depend on forests.
- Use technology to increase efficiency of internal communication and collaboration, as well as outreach.

The Framework brings scientists and land managers together to assess the vulnerability of ecosystems based on scientific information and experience in order to plan adaptation actions that meet management goals. On-the-ground implementation has just begun, and an increased focus on demonstrations, monitoring, and evaluation will inform future adaptation efforts.

Illustrative Case Four: Transportation, Land Use, and Climate Change – Integrating Climate Adaptation and Mitigation in Cape Cod, Massachusetts

Cape Cod, Massachusetts, a region of scenic beauty and environmental significance, is currently affected by sea level rise, coastal erosion, and localized flooding – impacts that are likely to be exacerbated by climate change.[164,165] To address these concerns and help meet the state's greenhouse gas (GHG) reduction target (25% reduction based on 1990 levels by 2020), the U.S. Department of Transportation's Volpe Center worked with federal, regional, state, and local stakeholders to integrate climate change into existing and future transportation, land-use, coastal zone, and hazard mitigation planning through an initiative called the Transportation, Land Use, and Climate Change Pilot Project.[164,166]

The process was initiated through an expert elicitation held in mid-2010 to identify areas on Cape Cod that are or could potentially be vulnerable to sea level rise, flooding, and erosion. The Volpe Center then used a geographic information system (GIS) software tool to develop and evaluate a series of transportation and land-use scenarios for the Cape under future development projections.[165,167] All scenarios were evaluated against a series of criteria that included: 1) reduction in vehicle miles traveled; 2) reduced heat-trapping gas emissions; 3) reduction in transportation energy use; 4) preservation of natural/existing ecosystems; 5) reduction in percentage of new population in areas identified as vulnerable to climate change impacts; and 6) increased regional accessibility to transportation.[164]

Once the preliminary scenarios were developed, a workshop was convened in which community and transportation planners, environmental managers, and Cape Cod National Seashore stakeholders selected areas for development and transit improvements to accommodate new growth while meeting the goals of reduced heat-trapping gas emissions, increased resilience to climate change, and the conservation of natural systems.[165] Through interactive visualization tools, participants were able to see in real-time the impacts of their siting decisions, allowing them to evaluate synergies and potential tradeoffs of their choices and to highlight areas where conflict could or already does exist, such as increasing density of development in areas already or likely to be vulnerable to climate change.[168] As a result, the stakeholders developed a refined transportation and land-use scenario that will support the region's long-range transportation planning as well as other local, regional, and state plans. This updated scenario identifies strategies that have climate adaptation and mitigation value, helping to ensure that the region simultaneously reduces its heat-trapping gas footprint while building resilience to existing and future changes in climate.[164,165] The overall success of the pilot project stemmed from the intensive stakeholder interaction at each phase of the project (design, implementation, and evaluation).

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages

A central component of the process were bi-weekly technical discussions held from October 2011 to June 2012 via teleconference that focused on collaborative review and summary of all technical inputs relevant to adaptation (130+) as well as additional published literature, the iterative development of key messages, and the final drafting of the chapter. An in-person meeting was held in Washington, D.C., in June 2012. Meeting discussions were followed by expert deliberation of draft key messages by the authors and targeted consultation with additional experts by the lead author of each key message. Consensus was reached on all key messages and supporting text.

Key message #1 Traceable Account

Substantial adaptation planning is occurring in the public and private sectors and at all levels of government; however, few measures have been implemented and those that have appear to be incremental changes.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the peer-reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications indicate that a growing number of sectors, governments at all scales, and private and non-governmental actors are starting to undertake adaptation activity.[9,13] Much of this activity is focused on planning with little literature documenting implementation of activities.[8,11,82] Supporting this statement is also plentiful literature that profiles barriers or constraints that are impeding the advancement of adaptation activity across sectors, scales, and regions.[42,68]

Additional citations are used in the text of the chapter to substantiate this key message.

New information and remaining uncertainties

n/a

Assessment of confidence based on evidence

n/a

Key message #2 Traceable Account

Barriers to implementation of adaptation include limited funding, policy and legal impediments, and difficulty in anticipating climate-related changes at local scales.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the peer reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input. A significant quantity of reviewed literature profiles barriers or constraints that are impeding the advancement of adaptation activity across sectors, scales, and regions.[11,20,42,68]

Numerous peer-reviewed documents describe adaptation barriers (see Table 28.6). Moreover, additional citations are used in the text of the chapter to substantiate this key message.

New information and remaining uncertainties

n/a

Assessment of confidence based on evidence

n/a

Key message #3 Traceable Account

There is no "one-size fits all" adaptation, but there are similarities in approaches across regions and sectors. Sharing best practices, learning by doing, and iterative and collaborative processes including stakeholder involvement, can help support progress.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the peer-reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input.

Literature submitted for this assessment, as well as additional literature reviewed by the author team, fully supports the concept that adaptations will ultimately need to be selected for their local applicability based on impacts, timing, political structure, finances, and other criteria.[11,90] Similarities do exist in the types of adaptation being implemented, although nuanced differences do make most adaptation uniquely appropriate for the specific implementer. The selection of locally and context-appropriate adaptations is enhanced by iterative and collaborative processes in which stakeholders directly engage with decision-makers and information providers.[11,20,28] While there are no "one-size fits all" adaptation strategies, evidence to date supports the message that the sharing of best practices and lessons learned are greatly aiding in adaptation progress across sectors, systems, and governance systems.[82,86]

Additional citations are used in the text of the chapter to substantiate this key message.

NEW INFORMATION AND REMAINING UNCERTAINTIES

n/a

ASSESSMENT OF CONFIDENCE BASED ON EVIDENCE

n/a

KEY MESSAGE #4 TRACEABLE ACCOUNT

Climate change adaptation actions often fulfill other societal goals, such as sustainable development, disaster risk reduction, or improvements in quality of life, and can therefore be incorporated into existing decision-making processes.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the peer-reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input.

Literature submitted for this assessment, as well as additional literature reviewed by the author team, supports the message that a significant amount of activity that has climate adaptation value is initiated for reasons other than climate preparedness and/or has other co-benefits in addition to increasing preparedness to climate and weather impacts.[11,20,82,86,116] In recognition of this and other factors, a movement has emerged encouraging the integration of climate change considerations into existing decision-making and planning processes (i.e., mainstreaming).[5,11,40] The case studies discussed in the chapter amplify this point.

Additional citations are used in the text of the chapter to substantiate this key message.

New information and remaining uncertainties

n/a

Assessment of confidence based on evidence

n/a

KEY MESSAGE #5 TRACEABLE ACCOUNT

Vulnerability to climate change is exacerbated by other stresses such as pollution, habitat fragmentation, and poverty. Adaptation to multiple stresses requires assessment of the composite threats as well as tradeoffs amongst costs, benefits, and risks of available options.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the peer-reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input.

Climate change is only one of a multitude of stresses affecting social, environmental, and economic systems. Activity to date and literature profiling those activities support the need for climate adaptation activity to integrate the concerns of multiple stresses in decision-making and planning.[16,17,32] As evidenced by activities to date, integrating multiple stresses into climate adaptation decision-making and vice versa will require the assessment of tradeoffs amongst costs, benefits, the risks of available options, and the potential value of outcomes.[5,90,111]

Additional citations are used in the text of the chapter to substantiate this key message.

New information and remaining uncertainties

n/a

Assessment of confidence based on evidence

n/a

KEY MESSAGE #6 TRACEABLE ACCOUNT

The effectiveness of climate change adaptation has seldom been evaluated, because actions have only recently been initiated and comprehensive evaluation metrics do not yet exist.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the peer-reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications indicate that no comprehensive adaptation evaluation metrics exist, meaning that no substantial body of literature or guidance materials

exist on how to thoroughly evaluate the success of adaptation activities.[11,81,110] This is an emerging area of research. A challenge of creating adaptation evaluation metrics is the growing interest in mainstreaming; this means that separating out adaptation activities from other activities could prove difficult.

Additional citations are used in the text of the chapter to substantiate this key message.

New information and remaining uncertainties
n/a

Assessment of confidence based on evidence
n/a

Climate Change Impacts in the United States

CHAPTER 29
RESEARCH NEEDS FOR CLIMATE AND GLOBAL CHANGE ASSESSMENTS

Convening Lead Authors

Robert W. Corell, Florida International University and the GETF Center for Energy and Climate Solutions

Diana Liverman, University of Arizona

Lead Authors

Kirstin Dow, University of South Carolina

Kristie L. Ebi, ClimAdapt, LLC

Kenneth Kunkel, CICS-NC, North Carolina State Univ., NOAA National Climatic Data Center

Linda O. Mearns, National Center for Atmospheric Research

Jerry Melillo, Marine Biological Laboratory

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29 RESEARCH NEEDS FOR CLIMATE AND GLOBAL CHANGE ASSESSMENTS

Overview

This chapter identifies key areas of research to provide foundational understanding and advance climate assessments. Many of these research topics overlap with those needed for advancing scientific understanding of climate and its impacts and for informing a broader range of relevant decisions.

The research areas and activities discussed in this chapter were identified during the development of the regional and sectoral technical input reports, from the contributions of over 250 National Climate Assessment (NCA) chapter authors and experts, and from input from reviewers. The five high-level research goals, five foundational cross-cutting research capabilities, and more specific research elements described in this chapter also draw from a variety of previous reports and assessments. These lists are provided as recommendations to the Federal Government. Priority activities for global change research across 13 federal agencies are coordinated by the U.S. Global Change Research Program, which weighs all activities within the more than $2 billion annual climate science portfolio relative to one another, considering agency missions, priorities, and budgets.

The last National Climate Assessment report, released by the U.S. Global Change Research Program (USGCRP) in 2009, recommended research on: 1) climate change impacts on ecosystems, the economy, health, and the built environment; 2) projections of climate change and extreme events at local scales; 3) decision-relevant information on climate change and its impacts; 4) thresholds that could lead to abrupt changes in climate or ecosystems; 5) understanding the ways to reduce the rate and magnitude of climate change through mitigation; and 6) understanding how society can adapt to climate change.[1]

Some of these topics have received continued or increased attention in the last five years – such as ecosystem impacts, downscaled climate projections, and mitigation options – but the current assessment finds that significant knowledge gaps remain for all of the research priorities identified in 2009. This conclusion is reinforced by the findings of many subsequent reviews by the National Research Council (NRC) and others who have continued to identify these as priorities. For example, the NRC's *America's Climate Choices Panel on Advancing the Science of Climate Change and the Panel on Informing Effective Decisions and Actions*[2,3] highlighted several priorities that are relevant to climate assessments (see "Cross-Cutting Themes for the New Era of Climate Change Research Identified by America's Climate Choices"). These included the need for a more comprehensive, interdisciplinary, use-inspired, and integrated research enterprise that combines fundamental understanding of climate change and response choices, that improves understanding of human-environment systems; that supports effective adaptation and mitigation responses, and that provides better observing systems and projections. In recognition of fiscal limitations, it is clear that research agencies and partners will need to work together to leverage resources and ensure coordinated and collaborative approaches.

Research Goals and Cross-Cutting Capabilities

Five Research Goals

- Improve understanding of the climate system and its drivers
- Improve understanding of climate impacts and vulnerability
- Increase understanding of adaptation pathways
- Identify the mitigation options that reduce the risk of longer-term climate change
- Improve decision support and integrated assessment

Five Foundational Cross-Cutting Research Capabilities

- Integrate natural and social science, engineering, and other disciplinary approaches
- Ensure availability of observations, monitoring, and infrastructure for critical data collection and analysis
- Build capacity for climate assessment through training, education, and workforce development
- Enhance the development and use of scenarios
- Promote international research and collaboration

CROSS-CUTTING THEMES FOR THE NEW ERA OF CLIMATE CHANGE RESEARCH IDENTIFIED BY *AMERICA'S CLIMATE CHOICES*

Research to Improve Understanding of Human-Environment Systems

1. Climate forcings, feedbacks, responses, and thresholds in the Earth system
2. Climate-related human behaviors and institutions

Research to Support Effective Responses to Climate Change

3. Vulnerability and adaptation analyses of coupled human-environment systems
4. Research to support strategies for limiting climate change
5. Effective information and decision support systems

Research Tools and Approaches to Improve Both Understanding and Responses

6. Integrated climate observing systems
7. Improved projections, analyses, and assessments

Source: *America's Climate Choices, Advancing the Science of Climate Change, National Academy of Sciences 2010*, p. 92.[4]

The U.S. Global Change Research Program's 2012-2021 Strategic Plan[5] lists a number of strategic goals and objectives for advancing science, informing decisions, conducting sustained assessments, and communicating and educating about global change. The plan includes research priorities to understand Earth system components, their interactions, vulnerability and resilience; advance observations, modeling, and information management; and evaluate assessment processes and products.

This chapter focuses specifically on the research identified through the National Climate Assessment process as needed to improve climate assessments. It is not intended to cover the full range of goals and related research priorities of the USGCRP and other groups, but instead to focus on research that will improve ongoing assessments. Therefore, many USGCRP priorities for climate change and global change science more broadly are not reflected here. The chapter does, however, directly support the USGCRP Strategic Plan's sustained assessment activities (see "Goal 3 of the USGCRP Strategic Plan").

This chapter is not intended to prescribe a specific research agenda but summarizes the research needs and gaps that emerged during development of this Third National Climate Assessment report that are relevant to the development of future USGCRP research plans.

During the development of this report, the authors were concerned that several important topics could not be comprehensively covered. In addition, several commenters noted the absence of these topics and felt that they were critical to consider in future reports. These include analyses of the economic costs of climate change impacts (and the associated benefits of mitigation and adaptation strategies); the implications of climate change for U.S. national security as a topic integrated with other regional and sectoral discussions; and the interactions of adaptation and mitigation options, including consideration of the co-benefits and potential unintended consequences of particular decisions.

GOAL 3 OF THE USGCRP STRATEGIC PLAN

Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

The USGCRP will conduct and participate in national and international assessments to evaluate past, current, and likely future scenarios of global change and their impacts, as well as how effectively science is being used to support and inform the United States' response to change. The USGCRP will integrate emerging scientific understanding of the Earth system into assessments and identify critical gaps and limitations in scientific understanding. It will also build a standing capacity to conduct national assessments and support those at regional levels. The USGCRP will evaluate progress in responding to change and identify science and stakeholder needs for further progress. The program will use this regular assessment to inform its priorities.

Research Goals

Research Goal 1: Improve understanding of the climate system and its drivers

Research investments across a broad range of disciplines are critically important to building understanding of, and in some cases reducing uncertainties related to, the physical and human-induced processes that govern the evolution of the climate system. This assessment demonstrates the continued need for high quality data and observations, analysis of Earth system processes and changes, and modeling that increases understanding and projections of climate change across scales. Social science research is also essential to improved understanding and modeling of the drivers of climate change, such as energy use and land-use change, as well as understanding impacts (see Research Goal 2). Assessing a changing climate requires understanding the role of feedbacks, thresholds, extreme events, and abrupt changes and exploring a range of scenarios (see Cross-Cutting Research Capabilities section) that drive changes in the climate system.

This assessment reveals several research needs including:

- **Continue efforts to improve the understanding, modeling, and projections of climate changes,** especially at the regional scale, including driving forces of emissions and land-use change, changes in temperature, precipitation, soil moisture, runoff, groundwater, evapotranspiration, permafrost, ice and snow cover, sea level change, and ocean processes and chemistry;

- **Improve characterization of important sources of uncertainty, including feedbacks and possible thresholds in the climate system** associated with changes in clouds, land and sea ice, aerosols (tiny particles in the atmosphere), greenhouse gases, land use and land cover, emissions scenarios, and ocean dynamics;

- **Develop indicators that allow for timely reporting and enhanced public understanding** of climate changes and that allow anticipation and attribution of changes, including abrupt changes and extreme events in the context of a changing climate; and

- **Advance understanding of the interactions of climate change and natural variability** at multiple time scales, including seasonal to decadal changes (and consideration of climate oscillations including the El Niño Southern Oscillation, Pacific Decadal Oscillation, and the North Atlantic Oscillation), and extreme events (such as hurricanes, droughts, and floods).

Research Goal 2: Improve understanding of climate impacts and vulnerability

Assessing the implications of climate change for the U.S. relies not just on studies of the threats associated with changing weather patterns due to climate change and emerging chronic stresses such as sea level rise, but also on studies of who or what is exposed and sensitive to those threats, their underlying vulnerability, the associated costs, and adaptive capacity. The detailed sectoral and regional chapters of this assessment show that considerable progress has been made in understanding the extent to which natural and human systems in the U.S. are vulnerable to climate change and how these vulnerabilities combine with climatic trends and exposures to create impacts, but there is still a need to build capacity for assessing vulnerability.

This assessment suggests related research goals and activities including:

- **Maintain and enhance research and development of data collection and analyses to monitor and attribute ongoing and emerging climate impacts across the United States,** including changes in ecosystems, pests and pathogens, disaster losses, water resources, oceans, and social, urban, and economic systems. Priorities include ensuring enhanced geographic coverage of impacts research; the assessment of economic costs and benefits, as well as comparative studies of alternative response options; social science research focused on impacts; and the use of geospatial data systems;

- **Assess the impacts of climatic extremes, high-end temperature scenarios, and abrupt climate change** on ecosystems, health, food, water, energy, infrastructure, and other critical sectors, and improve modeling capabilities to better project and understand the vulnerability and resilience of human systems and ecosystems to climate change and other stresses such as land-use change and pollution;

- **Increase the understanding of how climate uncertainties combine with socioeconomic and ecological uncertainties** and identify improved ways to communicate the combined outcomes;

- **Develop measurement tools and valuation methods** for documenting the economic consequences of climate changes;

- **Expand climate impact analyses to focus on understudied but significant economic sectors** such as natural resources and energy development (for example, mining,

oil, gas, and timber); manufacturing; infrastructure, land development, and urban areas; finance and other services; retail; and human health and well-being; and

- **Investigate how climate impacts are affected by, or increase inequity in, patterns of vulnerability of particular population groups** within the U.S. and abroad (for example, children, the elderly, the poor, and natural resource dependent communities).

Research Goal 3: Increase understanding of adaptation pathways

This assessment and others, including the *America's Climate Choices Adapting to the Impacts of Climate Change* report[2] and Chapter 4 (on adaptation and mitigation options and responses) of the Intergovernmental Panel on Climate Change's (IPCC) AR4 Synthesis Report,[6] identifies a broad set of research needs for understanding and implementing adaptation. These include research on adaptation processes, adaptive capacity, adaptation option identification, implementation and evaluation, and adaptive management of risks and opportunities.

Important needs include research on the limits to, timing of, and tradeoffs in adaptation, and understanding of how adaptation interacts with mitigation activities, other stresses, and broader sustainability issues.

This assessment suggests research activities to:

- **Identify the best practices for adaptation planning, implementation, and evaluation** across federal, state, and local agencies, tribal entities, private firms, non-governmental organizations, and local communities. This requires the rigorous and comparative analysis of the effectiveness of iterative risk management, adaptation strategies and decision support tools (for example, in terms of stakeholder views, institutional structures including regional centers and multi-agency programs, cost/benefit, assessment against stated goals or social and ecological indicators, model validation, and use of relevant information, including traditional knowledge); and

- **Understand the institutional and behavioral barriers to adaptation and how to overcome them,** including revisions to legal codes, building and infrastructure standards, urban planning, and policy practices.

Research Goal 4: Identify the mitigation options that reduce the risk of longer-term climate change

The severity of climate change impacts in the U.S. and the need for adapting to them over the longer term will depend on the success of efforts to reduce or sequester heat-trapping greenhouse gas (GHG) emissions, particularly those associated with the burning of fossil fuels but also those associated with changes in land use. Managing the consequences of climate change over this century depends on reducing concentrations of greenhouse gases, including short-lived climate pollutants such as black carbon (soot).

While such efforts are necessarily worldwide, the U.S. produces a significant share of global greenhouse gases and can assist and influence other countries to reduce their emissions. Assessments can play a significant role in providing a better information base from which to analyze mitigation options.

Therefore, the mitigation section of this assessment (Ch. 27: Mitigation) noted the importance of research to understand and develop emission reductions through: 1) identifying climate and global change scenarios and their impacts; 2) providing a range of options for reducing the risks to climate and global change; and 3) developing options that allow joint mitigation-adaptation strategies, such as buildings that are more energy efficient and resilient to climate change impacts.

More generally, the *America's Climate Choices* report on *Limiting the Magnitude of Climate Change*[3] recommended that the U.S. promptly develop and implement appropriate strategies to reduce GHG emissions and identified important research needs, including the need to study the feasibility, costs, and consequences of different mitigation options. In addition, the report recommended research to support new technologies and the effective deployment of existing options, research into how best to monitor emissions and adherence to international policies, and research into how human behavior and institutions enable mitigation.[3]

This Third National Climate Assessment also suggests research activities to:

- **Develop information that supports analysis of new technologies** for energy production and use, carbon capture and storage, agricultural and land-use practices, and other technologies that could reduce or offset greenhouse gas emissions; research into the policy mechanisms that could be used to foster their development and implementation; analyses of the costs, benefits, tradeoffs, and synergies associated with different actions and combinations of actions; and improved understanding of the potential and risks of geoengineering;

- **Investigate the co-benefits, interactions, feedbacks, and tradeoffs between adaptation and mitigation** at the local and regional level, for example, in sectors such as agriculture, forestry, energy, health, and

the built environment. This involves, as a priority, the assessment of the economics of impacts, mitigation, and adaptation;

- **Improve understanding of the effectiveness and timescales of mitigation measures** through deepened understanding of the relationship between the fate of human-induced and natural carbon emissions, uptake by the terrestrial biosphere and oceans, and atmospheric concentrations; and

- **Identify the critical social, cultural, institutional, economic, and behavioral processes that present barriers and opportunities for mitigation** at the federal and international levels and by individuals, state and local governments, and corporations.

Research Goal 5: Improve decision support and integrated assessment

For assessments to be useful to policy makers, they need to provide integrated results that can be used in decision-making. Research can develop tools that facilitate decision-making and the integration of knowledge.

Critical gaps in knowledge for decision support include the issues that affect the capacity of agencies, individuals, and communities to access and use the best available scientific information in support of decision-making, including the need to assess the ability of existing institutions, legal, and regulatory structures to respond to highly interdependent climate impacts. There are instances where policy barriers, institutional capacity or structure, or conflicting laws and regulations can create barriers to effective decisions. For instance, Chapter 12 (Indigenous Peoples) notes that there is no institutional framework for addressing village relocation in response to climate change in Alaska,[7] and Chapter 3 (Water) points out that existing water management institutions may be inadequate in the context of rapidly changing conditions. These instances point to research to evaluate whether the existing legal and regulatory structures, largely developed to address specific issues in isolation, can adequately respond to the highly interconnected issues associated with climate change. Decision support and integrated assessment also require research into the behavioral and other factors that influence individual decisions.

Assessments can benefit from research activities that:

- **Identify decision-maker needs** within regions and sectors, and support the development of research methods, tools, and information systems and models for managing carbon, establishing early warning systems, providing climate and drought information services, and analyzing the legal, regulatory, and policy approaches that support adaptation and mitigation efforts in the context of a changing climate;

- **Develop tools to support risk-based decision processes**, including tools to identify risk management information needs, develop transferable vulnerability assessment techniques, and evaluate alternative adaptation options. In addition, tools are needed to improve understanding of consumption patterns and environmental consequences; effective resource management institutions; iterative risk management strategies; and social learning, cognition, and adaptive processes;

- **Improve, fill gaps, and enhance research efforts to evaluate the effectiveness, costs, and benefits of mitigation and adaptation actions,** including economic and non-economic metrics that evaluate the costs of action, inaction, and residual impacts. Focus is also needed on the development of methods and baseline information supporting evaluation of completed and ongoing adaptation, mitigation, and assessment efforts that will foster adaptive learning; and

- **Develop, test, and expand integrated assessment models** that link decisions about emissions with impacts under different development pathways and ways to categorize uncertainties in the supporting data.

Foundational Cross-Cutting Research Capabilities to Support Future Climate Assessments

This assessment identifies a set of five foundational cross-cutting research capabilities that are essential for advancing our ability to continue to conduct climate and global change assessments and for addressing the five research goals.

1. Integrate natural and social sciences, engineering, and other disciplinary approaches

Continued advances in comprehensive and useful climate assessments will rely on additional interdisciplinary research. Understanding of the coupled human-environment system is enriched by combining research from natural and social sciences with research and experience from the engineering, law, and business professions.

Because human activities and decisions are influencing many Earth system processes, models and observations of natural and social changes at planetary, regional, and local scales are needed to understand how climate is changing, its impacts on people and environments, and how human responses feedback on the Earth system.

Building experienced interdisciplinary research teams that are able to understand each other's theories, methods, and language as well as the needs of stakeholders will allow for more rapid and effective assessments.

Interdisciplinary research is needed, for example, to:

- Understand how hydrological drivers of water supply interact with changing patterns of water demand and evolving water management practices to increase risks of drought, or influence the effectiveness of adaptation and mitigation options;
- Understand climate change in the context of multiple stresses on Earth, ecological, and human systems;
- Bring together economic and quantitative assessment of climate impacts and policies with other more qualitative assessments that include non-market and cultural values; and
- Integrate the understanding of human behavior, engineering, and genomics to expand the range of choice in responding to climate change by providing and thoroughly evaluating new options for adaption and mitigation that improve economic development, energy, health, and food security.

2. Ensure availability of observations, monitoring, and infrastructure for critical data collection and analysis

Our understanding and ability to assess changes in climate and other global processes is based on a comprehensive and sustained system of observations that document the history of climate, socioeconomic, and related changes at spatial and time scales relevant to global, regional, and sectoral needs. The most recent USGCRP Strategic Plan[5] states that to advance scientific knowledge of an integrated natural and human Earth system, an interoperable and integrated observational, monitoring, and data access capability is also essential. This observational capability is needed to gain the fundamental scientific understanding of essential status, trends, variability, and changes in the Earth system. It should include the physical, chemical, biological, and human components of the Earth system over multiple space and time scales.

To attain their full value, observational systems must provide data that are responsive to the needs of decision-makers in government, industry, and society. These needs include observations and data that can inform the nation's strategies to respond to climate and global change, including, for example, efforts to limit emissions, monitor public health, capture and store carbon, monitor changes in ocean processes, and implement adaptation strategies. This will require establishing explicit baseline conditions, specifying spatial detail and temporal frequency of observations, including social data, and setting standards for metadata (information about collected data), interoperability, and regulatory and voluntary reporting, such as those outlined in the *Informing an Effective Response to Climate Change Panel Report* of the National Research Council's *Americas Climate Choices* series.[8] These data need to be openly and widely available in order to support the best and most comprehensive science and for use in decision-making by a range of stakeholders.

This assessment shows that enhanced research and development will be necessary to ensure that the scope and integration of relevant scientific data improves overall utility for decision-makers, including better ways to communicate metadata, data quality, and uncertainties. The observations must include critical geophysical variables such as temperature, precipitation, sea level changes, ocean circulation, atmospheric composition, and hydrology; the essential parameters that describe the biosphere; and social science information on drivers, impacts, and responses to climate and other global changes. More comprehensive and integrated data capabilities are needed to document the processes and patterns that drive natural and social feedbacks and better describe the mechanisms of abrupt change. Progress is needed in particular for data-poor regions,

focusing on inadequately documented socioeconomic, ecological, and health-related factors, and under-observed regional and sectoral data. There are opportunities to take advantage of citizen science observations where appropriate; monitor system resilience and robustness; and attend to physical and social systems that are not currently observed with sufficient temporal or spatial resolution to enable vulnerability analysis and decision support at regional and sectoral scales. More explicitly, strategic integration of our nation's observations, monitoring, and data capabilities should be considered in order to:

- **Sustain and integrate the nation's capacity to observe** long-term changes in the Earth system and improve fundamental understanding of the complex causes and consequences of global change, including integration of essential socioeconomic, health, and ecological observations;

- **Maintain and enhance advanced modeling capability**, including high-performance computing infrastructure, improvements in analysis of large and complex data sets, comprehensive Earth system and integrated assessment models, reanalysis, verification, and model comparisons;

- **Better integrate observations and modeling** to advance scientific understanding about past, present, and future climate within government, industry, and civil society; and

- **Develop more fully the components and structure of a national climate and global change indicator system** to support assessment that includes indicators of climate change, impacts, vulnerabilities, opportunities, and preparedness as well as trends and changes in land use, air and water pollution, water supply and demand, extreme events, diseases, public health, and agronomic data, coastal and ocean conditions (such as marine ecosystem health, ocean acidity, sea level, and salinity), cryosphere data (such as snow, sea ice conditions, ice sheets and glacier melt rates), and changes in public attitudes and understanding of climate change. All of these are important to assessing climate change, and should eventually be better coordinated at local, as well as national and regional levels in collaboration with local agencies.

3. Build capacity for climate assessment through training, education, and workforce development

Building human capacity for improved assessments requires expansion of skills within the existing public and private sectors and developing a much larger workforce that excels at critical and interdisciplinary thinking. Useful capacities include the ability to facilitate and communicate research and practice, manage collaborative processes to allow for imaginative analysis and solutions, develop sustainable technologies to reduce climate risks, and build tools for decision-making in an internationally interdependent world.

A deeper understanding of the processes and impacts of climate change, disaster risk reduction, energy policy impacts, ecosystem services and biodiversity, poverty reduction, food security, and sustainable consumption requires new approaches to training and curriculum, as well as research to evaluate the effectiveness of different approaches to research and teaching.

Assessments will benefit from activities that:

- **Strengthen approaches to education about climate, impacts, and responses** including developing and evaluating the best ways to educate in the fields of science (natural and social), technology, engineering, and mathematics and related fields of study (such as business, law, medicine, and other relevant professional disciplines). Ideally, such training would include a deeper understanding of the climate system, natural resources, adaptation and energy policy options, and economic sustainability, and would build capacity at colleges and institutions, including minority institutions such as tribal colleges; and

- **Identify increasingly effective approaches to developing a more climate-informed society** that understands and can participate in assessments, including alternative media and methods for communication; this could also include a program to certify climate interpreters to actively assist decision-makers and policymakers to understand and use climate scenarios.[8]

4. Enhance the development and use of scenarios

Scenarios are "coherent, internally consistent and plausible descriptions of possible future states of the world"[9] that provide reasoned projections of energy and land use, future population levels, economic activity, the structure of governance, social values, and patterns of technological change. They survey, integrate, and synthesize science, within and among scientific disciplines and across sectors and regions. Such scenarios are essential tools that enable projections of emissions, climate, vulnerabilities, and global change. They are indispensable for linking science and decision-making and for assessing choices about America's climate future.

Stakeholders and scientists within this assessment identified a need for more fully developed scenario-building capabilities that better enable assessments at regional and sectoral scales in timeframes of relevance to policy and decision-making and that more effectively reflect climate and global change at these scales.

Achieving capacity in scenario development will:

- **Enhance understanding of how and why climate may change and its implications,** especially at the regional scale. For example, a set of scenarios can be used to better understand the way energy, land use, and policy choices create alternative emissions pathways; how changes at global scales can be downscaled to estimate local climate possibilities; how various socioeconomic development pathways increase or decrease climate vulnerability; and to assess alternative strategies for reducing emissions and implementing adaptation; and

- **Develop new methods, tools, and skills for applying scenarios to policy development** at local levels in order to broaden society's understanding of a changing climate and to analyze the full range of policy choices. In addition, improve capabilities in integrated assessment modeling to inform policy analysis and allow stakeholders to co-produce information and explore options for local and national decisions.

5. Promote international research and collaboration

Research efforts in support of climate assessment are very dependent on the international research community. International teams conduct Earth system monitoring and analysis using observing systems that cannot be funded and maintained by any one country alone. Many of the impacts of climate change in the U.S. are closely linked to how climate affects other parts of the world. There is general understanding that impacts of climate change on U.S. socioeconomic systems are mediated or amplified through globally connected commodity chains and prices; more detailed research on climate change and its impacts elsewhere is needed to provide accurate assessments of what could happen to U.S. regional and local economies. The U.S. has the capacity to leverage investments in collaborative international climate and global change scientific research efforts, examples of which include IGBP (International Geosphere-Biosphere Programme), WCRP (World Climate Research Programme), DIVERSITAS (an international program of biodiversity science), IHDP (International Human Dimensions Programme) (as they evolve into or in affiliation with the new Future Earth program), and IGFA (International Group of Funding Agencies for Global Change Research).

Supporting international collaborative research will:

- **Contribute to international systems of data collection, monitoring, indicators, and modeling** that closely track and project changes in Earth system dynamics, climate, human drivers, and climate impacts that are needed for national and international assessments;

- **Assess the implications of climate change for globally shared common resources** such as the oceans, polar regions, and migratory species; and

- **Fill important gaps in understanding of how climate change in other countries** affects U.S. food, energy, health, manufacturing, and national security.

Conclusions

This chapter summarizes research recommendations across a broad range of topics – research that the assessment authors deem essential to support future assessments. The authors recognize that federal agencies and others are making progress on many of these research areas and that sustained assessment is included in the goals of the USGCRP.

While the research goals discussed in this chapter are not ranked, the objectives listed below can be used as criteria for prioritizing these activities. The nation's federal research investments in support of the sustained assessment strategy should be designed to enhance the nation's ability to limit climate-related risk and increase the utility of scientific understanding in supporting decisions.

- **Promote understanding of the fundamental behavior of the Earth's climate and environmental systems:** The consequences of climate variability and change will require enhanced investment in use-inspired research using both fundamental and applied analysis, providing a foundation for the nation's sustained assessment process;

- **Promote understanding of the socioeconomic impacts of a changing climate:** Provide comprehensive understanding, including the development of indicators of the impacts and consequences of climate variability and change for regions and sectors within the United States;

- **Build capacity to assess risks and consequences:** Support improved, timely, and accessible estimations and projections of climate and other global change risks, their consequences and relevance for stakeholders, associated costs and benefits, and interactions with other stresses;

- **Support research that enables infrastructure for analysis:** Sustain and enhance critical infrastructure, including observations and data essential to monitoring trends, projecting climate risks, and evaluating the effectiveness of responses in decision-making and policy implementation;

- **Build decision-support capacity:** Build the knowledge base essential for decision support including developing and evaluating climate mitigation and adaptation solutions, technology innovation, institutions, and behavioral change; and

- **Support engagement of the private sector and investment communities:** Develop strategies to leverage federal research investments by engaging the private sector more fully in research and technology development, including partnerships with the nation's universities and scientific research institutions, to address critical gaps in knowledge and to build the nation's future scientific, technical, and sustained assessment capacities.

- **Leverage private sector, university, and international resources and partnerships:** Take advantage of topics and expertise where the U.S. can leverage and complement private sector and university capabilities, obtain return on research investments, and lead internationally on research investment efforts; build capacity through education and training; support humanitarian response; and fill critical gaps in global knowledge of relevance to the United States.

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29: RESEARCH NEEDS FOR CLIMATE AND GLOBAL CHANGE ASSESSMENTS

SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Chapter Process:

The author team asked each of the other chapter author teams to identify important gaps in knowledge and key research needs in the course of writing their chapters, particularly in the context of the needs for research to support future assessments. In addition to the lists provided by each chapter author team, the team also drew on analyses from over 100 technical and public review suggestions and a wide variety of technical and scholarly literature, especially the U.S. Global Change Research Program's Strategic Plan[5] and the National Research Council's *America's Climate Choices* reports,[2,3,4,8,10] to compile a list of potential research needs. Using expert deliberation, including a number of teleconference meetings and email conversations among author team members, the author team agreed on high-priority research needs, organized under five research goals.

CHAPTER 30
SUSTAINED ASSESSMENT: A NEW VISION FOR FUTURE U.S. ASSESSMENTS

Convening Lead Authors

John A. Hall, U.S. Department of Defense

Maria Blair, Independent

Lead Authors

James L. Buizer, University of Arizona

David I Gustafson, Monsanto Company

Brian Holland, ICLEI – Local Governments for Sustainability

Susanne C. Moser, Susanne Moser Research & Consulting and Stanford University

Anne M. Waple, Second Nature and University Corporation for Atmospheric Research

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On the Web: http://nca2014.globalchange.gov/report/response-strategies/sustained-assessment

30 SUSTAINED ASSESSMENT: A NEW VISION FOR FUTURE U.S. ASSESSMENTS

A primary goal of the U.S. National Climate Assessment (NCA) is to help the nation anticipate, mitigate, and adapt to impacts from global climate change, including changes in climate variability, in the context of other national and global change factors. Since 1990, when Congress authorized the U.S. Global Change Research Program (USGCRP) through the Global Change Research Act[1] and required periodic updates on climate science and its implications, researchers from many fields have observed significant climate change impacts in every region of the United States. The accelerating pace of these changes (for example, the recent rapid reductions observed in the extent and thickness of Arctic sea ice), as well as scenario-based projections for future climate changes and effects, is articulated in this third NCA.

Based on recommendations stemming from the National Research Council (NRC), USGCRP in its most recent strategic plan[2] identified the rationale and benefits of implementing a sustained assessment process. In response, a vision for a new approach to assessments took shape as the third NCA report was being prepared. The vision includes an ongoing process of working to understand and evaluate the nation's vulnerabilities to climate variability and change and its capacity to respond. A sustained assessment, in addition to producing quadrennial assessment reports as required by law, recognizes that the ability to understand, predict, assess, and respond to rapid changes in the global environment requires ongoing efforts to integrate new knowledge and experience. It accomplishes this by: 1) advancing the science needed to improve the assessment process and its outcomes, building associated foundational knowledge, and collecting relevant data; 2) developing targeted scientific reports and other products that respond directly to the needs of federal agencies, state and local governments, tribes, other decision-makers, and end users; 3) creating a framework for continued interactions between the assessment partners and stakeholders and the scientific community; and 4) supporting the capacity of those engaged in assessment activities to maintain such interactions.

To provide decision-makers with more timely, concise, and useful information, a sustained assessment process would include both ongoing, extensive engagement with public and private partners and targeted, scientifically rigorous reports that address concerns in a timely fashion. A growing body of assessment literature has guided and informed the development of this approach to a sustained assessment.[3,4,5]

The envisioned sustained assessment process includes continuing and expanding engagement with scientists and other professionals from government, academia, business, and non-governmental organizations. These partnerships broaden the knowledge base from which conclusions can be drawn. In addition, sustained engagement with decision-makers and end users helps scientists understand what information society wants and needs, and it provides mechanisms for researchers to receive ongoing feedback on the utility of the tools and data they provide.

An ongoing process that supports these forms of outreach and engagement allows for more comprehensive and insightful evaluation of climate changes across the nation, including how decision-makers and end users are responding to these changes. The most thoughtful and robust responses to climate change can be made only when these complex issues, including the underlying science and its many implications for the nation, are documented and communicated in a way that both scientists and non-scientists can understand.

This sustained assessment process will lead to better outcomes for the people of the United States by providing more relevant, comprehensible, and usable knowledge to guide decisions related to climate change at local, regional, and national scales. Additional details about the components of the sustained assessment process are provided in "Preparing the Nation for Change: Building a Sustained National Climate Assessment Process," the first special report of the National Climate Assessment and Development Advisory Committee.[6]

Contributions of a Sustained Assessment Process

A sustained assessment process will not only include producing the quadrennial assessment reports required by the 1990 GCRA, but it also will enable many other important outcomes. A well-designed and executed sustained assessment process will:

1. Increase the nation's capacity to measure and evaluate the impacts of and responses to further climate change in the United States, locally, regionally, and nationally.
2. Improve the collection of assessment-related critical data, access to those data, and the capacity of users to work with datasets – including their use in decision support tools – relevant to their specific issues and interests. This includes periodically assessing how users are applying such data.

3. Support the creation of the first integrated suite of national indicators of climate-related trends across a variety of important climate drivers and responses.

4. Catalyze the production of targeted, in-depth special assessment reports on sectoral topics (for example, agriculture), cross-sectoral topics (for example, the connection between water and energy production), regional topics, and other topics that will help inform Americans' climate choices about mitigation and adaptation. These reports will generate new insights about climate change, its impacts, and the effectiveness of societal responses. In addition, a second report category, referred to as foundational reports, will focus on improvements to specific aspects of the process (for example, scenarios and indicators) to reinforce the foundation for the overarching, but necessarily more constrained, quadrennial assessment reports.

5. Facilitate the creation of, support, and leverage a network of scientific, decision-maker, and user communities for extended dialog and engagement regarding climate change.

6. Provide a systematic way to identify gaps in knowledge and uncertainties faced by the scientific community and by U.S. domestic and international partners and to assist in setting priorities for their resolution.

7. Enhance integration with other assessment efforts such as the Intergovernmental Panel on Climate Change and modeling efforts such as the Coupled Model Intercomparison Project.

8. Develop and apply tools to evaluate progress and guide improvements in processes and products over time. This will support an iterative approach to managing risks and opportunities associated with changing global and national conditions.

Assessments facilitate the collection of different kinds of information that can be integrated to yield new and useful scientific insights. The vision for the sustained assessment process is to continue to build knowledge about human and natural systems and their interactions to better understand the risks and opportunities of global change at multiple spatial and temporal scales. The sustained assessment process also can help define the range of information needs of decision-makers and end users relative to adaptation and mitigation, as well as the associated costs of impacts and benefits of response actions. Moreover, it is by its very nature a continuous process, uniquely positioned to support an iterative, risk-based approach to adaptation.

Finally, although a sustained assessment process allows for ongoing improvements in products and processes, it also requires underlying support systems. These can include access to observational data sources, support networks, and information management systems such as the Global Change Information System (GCIS; see section on "Data Collection, Access, and Analysis"). Other fundamental support for assessments includes various types of integrated and vulnerability assessment models, climate model intercomparison projects, data streams (for example, emissions data and socioeconomic data), processes for building scenarios and deploying them at critical junctures in the assessment process, and evaluation approaches.

Assessment Capacity

Scientific assessments require substantial scientific expertise and judgment, involving skills atypical of those required for routine research.[4,5] Assessment capacity includes engaging knowledgeable and experienced people, developing networks to promote interactions, identifying and mentoring new scientific talent, and building in-depth understanding of a variety of economic, technical, and scientific topics. Building and maintaining capacity through all of these approaches is therefore critical to the smooth and efficient functioning of the assessment process.

Sustained interactions among scientists and stakeholders have consistently been shown to improve the utility and effectiveness of assessment processes and outcomes[5] and to facilitate the development of decision support tools.[7] A sustained assessment provides the necessary coordination and infrastructure needed to maintain an ongoing dialog among producers and users of information so that decision-makers can manage risks and take advantage of opportunities more efficiently. This provides the capacity and flexibility to react to, and take advantage of, rapidly advancing developments in decision and climate science and changing conditions to inform robust decision-making and improve the utility and timeliness of future quadrennial assessment reports.

Data Collection, Access, and Analysis

Credible scientific information is needed on an ongoing basis to support fundamental understanding of the climate system and its interactions with ecological, economic, and social systems – and for the development of adaptation and mitigation strategies. Improved systems for data access can more effectively meet the requests of stakeholders for accessible, relevant, and timely information. An ongoing process can build a more complete information base relevant to climate change related impacts and vulnerabilities, and it can result in more sophisticated scientific analyses that support the mandated

quadrennial assessment reports in a more efficient and effective manner. Selecting which data to collect and analyze is a critical component of assessments of change. In addition, for certain assessment-related purposes, use of traditional knowledge may be appropriate and require different analytical approaches.

The sustained assessment process will facilitate the development and maintenance of a web-based assessment information discovery, access, and retrieval system that facilitates easy access to a range of information for those who need it, in a timely and authoritative manner (the GCIS of the USGCRP). A major short-term goal is to provide transparent and highly-linked access to the data used to support conclusions in the third NCA report, but this is only the first step in a much larger effort. Initially targeted audiences include assessment practitioners across various sectors and governmental levels.

Indicators

Indicators are measurements or calculations that represent important features of the status, trends, or performance of a system (such as the economy, agriculture, natural ecosystems, or Arctic sea ice cover). Indicators are used to identify and communicate changing conditions to inform both research and management decisions.[8] The NCA indicator system is intended to focus on key aspects of change – as well as vulnerabilities, impacts, and states of preparedness – to inform decision-makers and the public. In the context of ongoing assessment activities, these indicators can be tracked to provide timely, authoritative, and climate-relevant measurements regarding the status, rates of change, and trends of key physical, ecological, and societal variables.

Special and Foundational Reports

As currently envisioned, the sustained assessment process also paves the way for additional types of assessment-related reports that can help inform local, regional, and sectoral mitigation and adaptation activities and provide a foundation for more useful and more comprehensive quadrennial assessment reports. Completing in-depth assessments of national or regional importance and providing a constantly improving foundation for the quadrennial assessment reports provides for significant flexibility and enhanced policy relevance. Special topical assessment reports can investigate emerging issues of concern or help decision-makers understand the tradeoffs among different courses of action. Moreover, these types of assessments can encompass a more holistic, multi-disciplinary, and integrated approach that considers various types of data analyses that may not have been previously attempted. These more focused reports that emerge from ongoing assessment activities can blend the objectives of incorporating the latest science with responding relatively quickly to the most pressing stakeholder and government needs. Finally, foundational reports also can be produced on scenarios of climate change, sea level rise, demography, land-use change, and other issues critical to the assessment process.

A Network to Foster Partnerships, Encourage Engagement, and Develop Solutions

The USGCRP has long recognized the importance of partnerships, effective two-way communication, and ongoing and meaningful engagement.[2] The five NRC *America's Climate Choices* reports published in 2010 and 2011 also underscore the essential nature of this engagement (for example, NRC 2010[9]). Partnerships and engagement strategies among federal and non-federal participants are needed to: 1) communicate effectively about the assessment, including its products and processes and their relevance as actionable information;[10] 2) encourage participation and knowledge sharing; 3) create opportunities for meaningful engagement of end users and public and private decision-makers to inform the substance of the assessment; and 4) offer opportunities for input, direction, review, and feedback.

An important component of the new sustained assessment vision is NCAnet: a "network of networks" that helps to foster engagement in the NCA process and communicate products to a broader audience (for additional details about NCAnet, please see Appendix 1: Process). This network of partner organizations, including private sector, government, non-governmental organizations, and professional societies, leverages resources and facilitates communication and partnerships. By its first meeting in January 2012, NCAnet consisted of over three dozen partner organizations. Much of the network's subsequent growth to over 100 partner organizations (as of fall 2013) has been driven by the partners' own outreach and interest in building a community around the practice of assessment. NCAnet can assist in developing and supporting diverse science capabilities and assessment competencies within and outside of the Federal Government.

Evaluation of the Process

Ongoing evaluation of assessment processes and products, as well as incorporating the lessons learned over time, is a specific objective of the USGCRP Strategic Plan.[2] Evaluation efforts are considered integral to enabling learning and adaptive management of the assessment process, measuring the ability to meet both legally required objectives and strategic goals, maintaining institutional memory, and improving the assessment process and its contributions to scientific understanding as well as to society. Ongoing improvements in the assessment process also will support an iterative approach to decision-making in the context of rapid change.

Recommendations on Research Priorities

The GCRA requires regular evaluations of gaps in knowledge and assessments of uncertainties that require additional scientific input. A sustained assessment process provides for regular updates on science needs to the USGCRP's annual research prioritization process, as well as to the triennial and decadal revisions to its research plan.

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30: SUSTAINED ASSESSMENT: A NEW VISION FOR FUTURE U.S. ASSESSMENTS

SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages:

Planning for the sustained assessment process, and for including a description of the process in a chapter of the third NCA report, began as soon as the report process was launched. Mechanisms for creating and implementing a sustained process were included as key discussion points in early NCA process workshops.[11] Prior to the formation of the chapter author teams, the need for a sustained assessment was described in the NCA Strategy Summary.[12] The amended charter for the National Climate Assessment and Development Advisory Committee (NCADAC) specifies that the NCADAC is "to provide advice and recommendations toward the development of an ongoing, sustainable national assessment of global change impacts and adaptation and mitigation strategies for the Nation."[13] To that end, the NCADAC formed a working group on sustained assessment, and the USGCRP Interagency National Climate Assessment Working Group (INCA) made this topic a priority in their regular meetings. The USGCRP also established "conduct sustained assessments" as one of four programmatic pillars in its recent Strategic Plan.[2]

The sustained assessment author team drew on a wide variety of source materials in framing the need for a sustained assessment process, including calls for sustained assessment in both previous National Climate Assessment reports[14] and in several publications from the National Research Council[5,9,15] that focused specifically on the National Climate Assessment. The author team also considered a rich literature on assessments in general (for example, Farrell and Jäger 2005 and Mitchell et al. 2006[4]). In developing the chapter describing the sustained assessment process, the author team first worked with the NCADAC, especially the initial NCADAC working group on sustained assessment, and the INCA to develop a vision for sustained assessment and a list of activities required to implement this vision. They then collected feedback from each of the chapters' convening lead authors, agencies, chairs of other NCADAC working groups, and targeted stakeholders. Drawing on these comments and the knowledge bases cited above, the author team came to consensus on the objectives and categories of activities provided in the chapter through teleconference and email discussions. The NCADAC formed a new author team to produce a longer special report on the sustained assessment process. The report was completed in the late summer of 2013.[6]