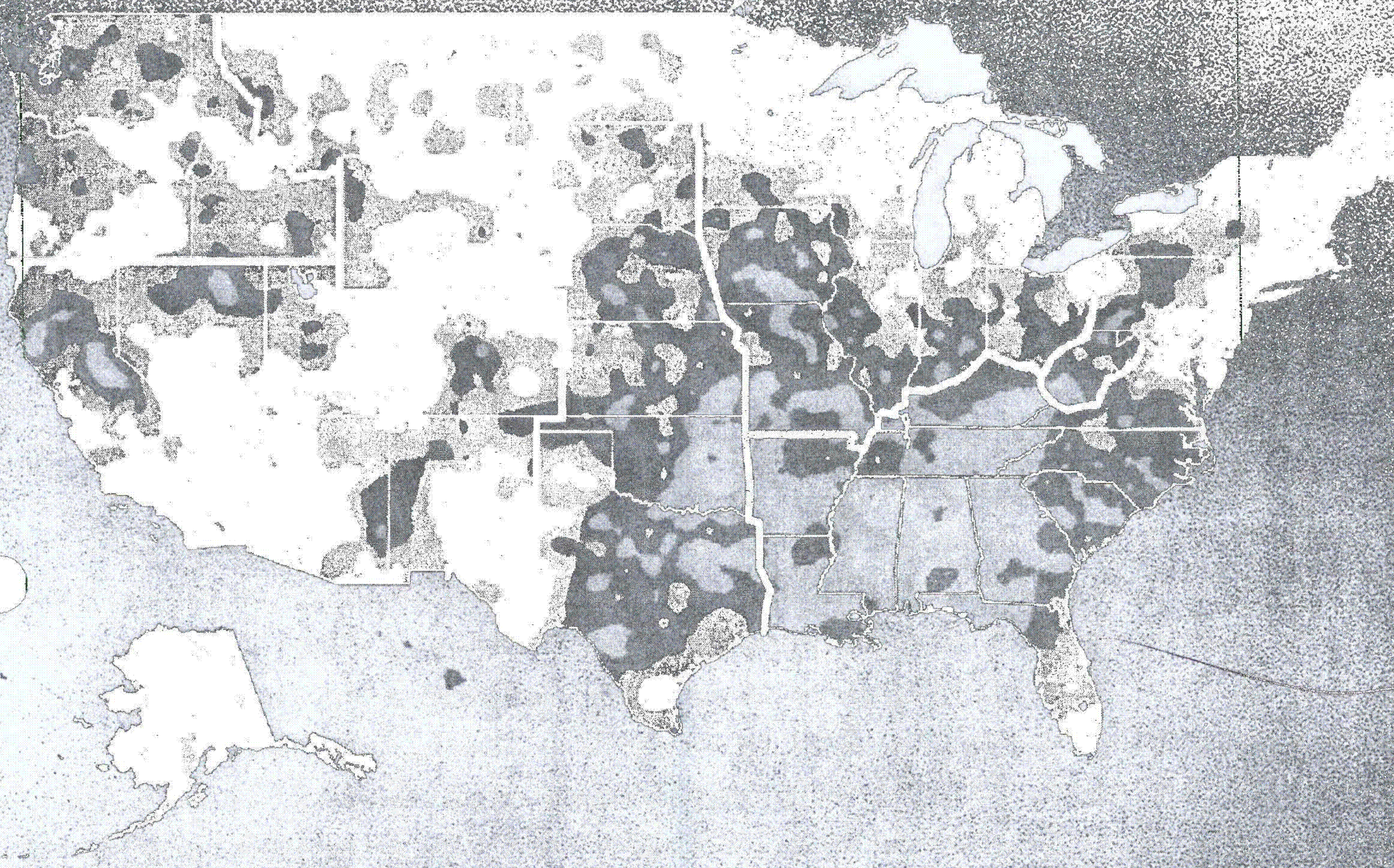
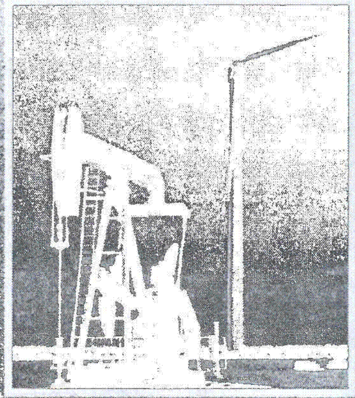
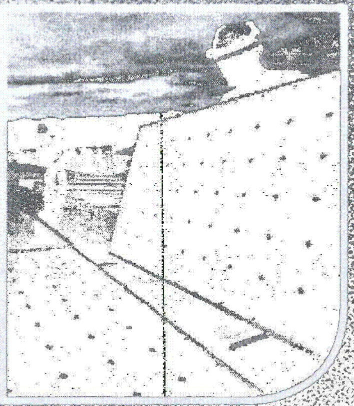
Climate Change Impacts in the United States





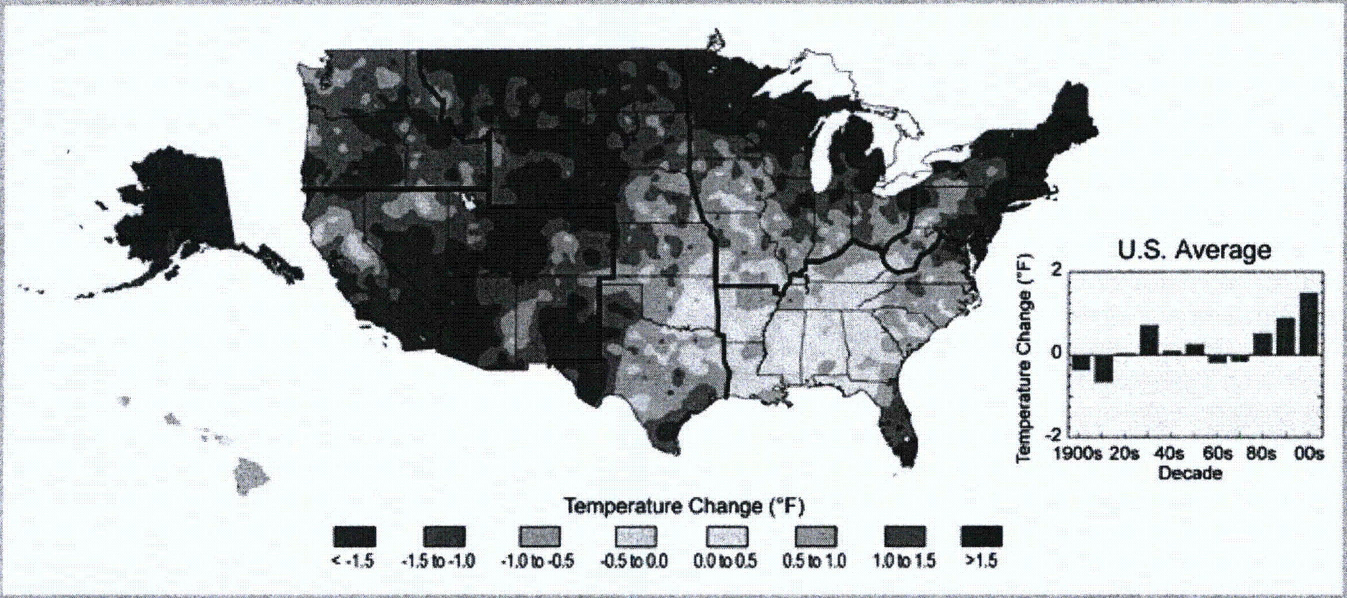


U.S. National Climate Assessment

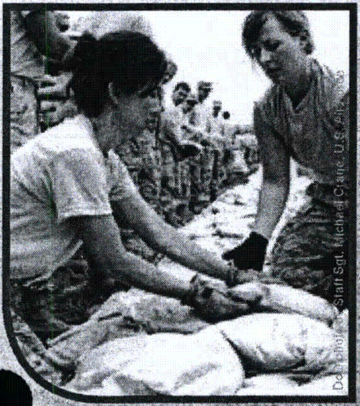
U.S. Global Change Research Program

Climate Change Impacts in the United States

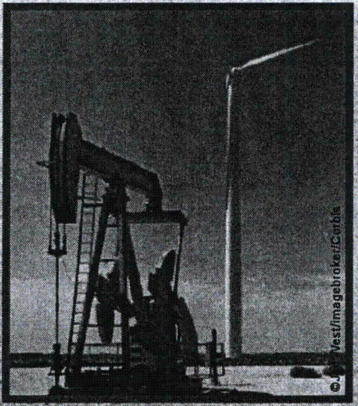
Observed U.S. Temperature Change



The colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average for the contiguous U.S., and to the 1951-1980 average for Alaska and Hawaii. The bars on the graph show the average temperature changes for the U.S. by decade for 1901-2012 (relative to the 1901-1960 average). The far right bar (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region. (Figure source: NOAA NCDC / CICS-NC).

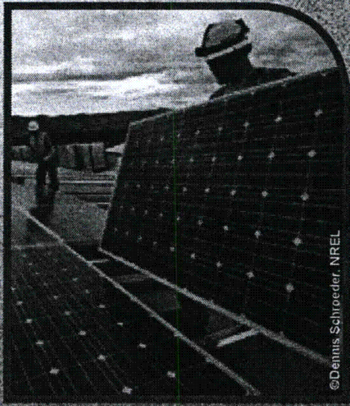


Members of the National Guard lay sandbags to protect against Missouri River flooding.



Energy choices will affect the amount of future climate change.

Climate change is contributing to an increase in wildfires across the U.S. West.



Solar power use is increasing and is part of the solution to climate change.

Online at:
nca2014.globalchange.gov

First published 2014

Printed in the United States of America

ISBN 9780160924026

Recommended Citation

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

Published by the U.S. Government Printing Office
Internet: bookstore.gpo.gov; Phone: toll free (866) 512-1800; DC area (202) 512-1800
Fax: (202) 512-2104 Mail: Stop IDCC, Washington, DC 20402-0001

May 2014

Members of Congress:
On behalf of the National Science and Technology Council and the U.S. Global Change Research Program, we are pleased to transmit the report of the Third National Climate Assessment: *Climate Change Impacts in the United States.* As required by the Global Change Research Act of 1990, this report has collected, evaluated, and integrated observations and research on climate change in the United States. It focuses both on changes that are happening now and further changes that we can expect to see throughout this century.

This report is the result of a three-year analytical effort by a team of over 300 experts, overseen by a broadly constituted Federal Advisory Committee of 60 members. It was developed from information and analyses gathered in over 70 workshops and listening sessions held across the country. It was subjected to extensive review by the public and by scientific experts in and out of government, including a special panel of the National Research Council of the National Academy of Sciences. This process of unprecedented rigor and transparency was undertaken so that the findings of the National Climate Assessment would rest on the firmest possible base of expert judgment.

We gratefully acknowledge the authors, reviewers, and staff who have helped prepare this Third National Climate Assessment. Their work in assessing the rapid advances in our knowledge of climate science over the past several years has been outstanding. Their findings and key messages not only describe the current state of that science but also the current and future impacts of climate change on major U.S. regions and key sectors of the U.S. economy. This information establishes a strong base that government at all levels of U.S. society can use in responding to the twin challenges of changing our policies to mitigate further climate change and preparing for the consequences of the climate changes that can no longer be avoided. It is also an important scientific resource to empower communities, businesses, citizens, and decision makers with information they need to prepare for and build resilience to the impacts of climate change.

When President Obama launched his Climate Action Plan last year, he made clear that the essential information contained in this report would be used by the Executive Branch to underpin future policies and decisions to better understand and manage the risks of climate change. We strongly and respectfully urge others to do the same.

Sincerely,

John P. Holdren

Dr. John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy
Executive Office of the President

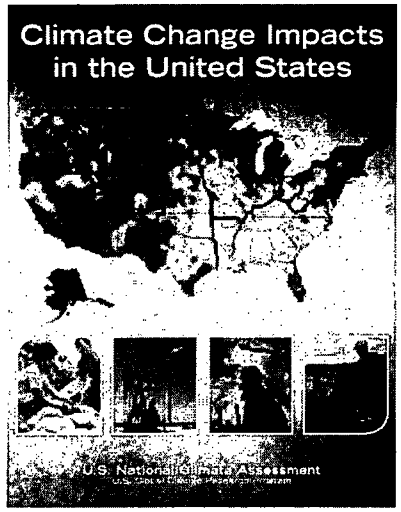
Dr. Kathryn D. Sullivan
Under Secretary for Oceans and Atmosphere
NOAA Administrator
U.S. Department of Commerce

About the NATIONAL CLIMATE ASSESSMENT

The National Climate Assessment assesses the science of climate change and its impacts across the United States, now and throughout this century. It documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

A team of more than 300 experts (see page 98), guided by a 60-member National Climate Assessment and Development Advisory Committee (listed on page vi) produced the full report – the largest and most diverse team to produce a U.S. climate assessment. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public. More than 70 workshops and listening sessions were held, and thousands of public and expert comments on the draft report provided additional input to the process.

The assessment draws from a large body of scientific peer-reviewed research, technical input reports, and other publicly available sources; all sources meet the standards of the Information Quality Act. The report was extensively reviewed by the public and experts, including a panel of the National Academy of Sciences, the 13 Federal agencies of the U.S. Global Change Research Program, and the Federal Committee on Environment, Natural Resources, and Sustainability.



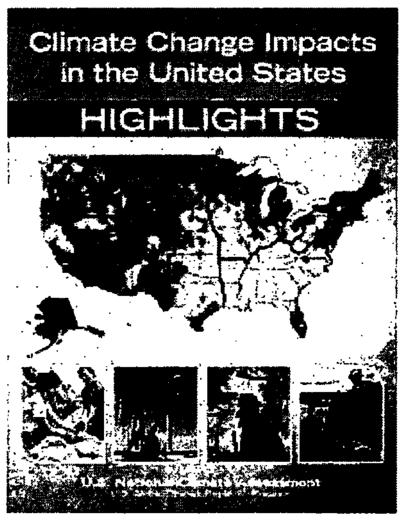
Online at:
nca2014.globalchange.gov

About the HIGHLIGHTS

The *Highlights* presents the major findings and selected highlights from *Climate Change Impacts in the United States*, the third National Climate Assessment.

The *Highlights* report is organized around the National Climate Assessment's 12 Report Findings, which take an overarching view of the entire report and its 30 chapters. All material in the *Highlights* report is drawn from the full report. The Key Messages from each of the 30 report chapters appear in boxes throughout this document.

A 20-page *Overview* booklet is available online.



Online at:
nca2014.globalchange.gov/highlights

Federal National Climate Assessment and Development Advisory Committee (NCADAC)

Chair
Jerry Melillo, Marine Biological Laboratory

Vice-Chairs
Terese (T.C.) Richmond, Van Ness Feldman, LLP
Gary Yohe, Wesleyan University

Committee Members
Daniel Abbasi, GameChange Capital, LLC
E. Virginia Armbrust, University of Washington
Timothy (Bull) Bennett, Kiksapa Consulting, LLC
Rosina Bierbaum, University of Michigan and PCAST
Maria Blair, Independent
James Buizer, University of Arizona
Lynne M. Carter, Louisiana State University
F. Stuart Chapin III, University of Alaska
Camille Coley, Florida Atlantic University
Jan Dell, ConocoPhillips
Placido dos Santos, WestLand Resources, Inc.
Paul Fleming, Seattle Public Utilities
Guido Franco, California Energy Commission
Mary Gade, Gade Environmental Group
Aris Georgakakos, Georgia Institute of Technology
David Gustafson, Monsanto Company
David Hales, Second Nature
Sharon Hays, Computer Sciences Corporation
Mark Howden, CSIRO
Anthony Janetos, Boston University
Peter Kareiva, The Nature Conservancy
Rattan Lal, Ohio State University
Arthur Lee, Chevron Corporation
Jo-Ann Leong, Hawai'i Institute of Marine Biology
Diana Liverman, University of Arizona and Oxford University
Rezaul Mahmood, Western Kentucky University
Edward Maibach, George Mason University
Michael McGeehin, RTI International
Susanne C. Moser, Susanne Moser Research & Consulting and Stanford University
Richard Moss, University of Maryland and PNNL
Philip Mote, Oregon State University
Jayantha Obeysekera, South Florida Water Management District
Marie O'Neill, University of Michigan
Lindene Patton, Zurich Financial Services
John Posey, East-West Gateway Council of Governments
Sara Pryor, Indiana University
Andrew Rosenberg, University of New Hampshire and Union of Concerned Scientists
Richard Schmalensee, Massachusetts Institute of Technology
Henry Schwartz, HGS Consultants, LLC
Joel Smith, Stratus Consulting
Donald Wuebbles, University of Illinois

Ex Officio Committee Members
Ko Barrett, U.S. Department of Commerce
Katharine Batten, U.S. Agency for International Development
Virginia Burkett, U.S. Department of the Interior
Patricia Cogswell, U.S. Department of Homeland Security
Gerald Geernaert, U.S. Department of Energy
John Hall, U.S. Department of Defense
Leonard Hirsch, Smithsonian Institution
William Hohenstein, U.S. Department of Agriculture
Patricia Jacobberger-Jellison, National Aeronautics and Space Administration
Thomas R. Karl, Subcommittee on Global Change Research, U.S. Department of Commerce
George Luber, U.S. Department of Health and Human Services
C. Andrew Miller, U.S. Environmental Protection Agency
Robert O'Connor, National Science Foundation
Susan Ruffo, White House Council on Environmental Quality
Arthur Rypinski, U.S. Department of Transportation
Trigg Talley, U.S. Department of State

Federal Executive Team
John Holdren, Assistant to the President for Science and Technology and Director, White House Office of Science and Technology Policy
Katharine Jacobs, Director, National Climate Assessment, White House Office of Science and Technology Policy (through December 2013)
Thomas Armstrong, Director, U.S. Global Change Research Program National Coordination Office, White House Office of Science and Technology Policy
Thomas R. Karl, Chair, Subcommittee on Global Change Research, U.S. Department of Commerce
Tamara Dickinson, Principal Assistant Director for Environment and Energy, White House Office of Science and Technology Policy
Fabien Laurier, Director, Third National Climate Assessment, White House Office of Science and Technology Policy
Glynis C. Lough, NCA Chief of Staff, U.S. Global Change Research Program
David Easterling, NCA Technical Support Unit Director, NOAA NCDC

USGCRP National Climate Assessment Coordination Office

Katharine Jacobs, Director, National Climate Assessment, White House Office of Science and Technology Policy (OSTP) (through December 2013) / University of Arizona
Fabien Laurier, Director, Third National Climate Assessment, White House OSTP (previously Deputy Director, USGCRP) (from December 2013)
Glynis Lough, NCA Chief of Staff, USGCRP / UCAR (from June 2012)
Sheila O'Brien, NCA Chief of Staff, USGCRP / UCAR (through May 2012)
Susan Aragon-Long, NCA Senior Scientist and Sector Coordinator, U.S. Geological Survey
Ralph Cantral, NCA Senior Scientist and Sector Coordinator, NOAA (through November 2012)
Tess Carter, Student Assistant, Brown University
Emily Therese Cloyd, NCA Public Participation and Engagement Coordinator, USGCRP / UCAR
Chelsea Combest-Friedman, NCA International Coordinator, Knauss Marine Policy Fellow, NOAA (February 2011-February 2012)
Alison Delgado, NCA Scientist and Sector Coordinator, Pacific Northwest National Laboratory, Joint Global Change Research Institute, University of Maryland (from October 2012)
William Emanuel, NCA Senior Scientist and Sector Coordinator, Pacific Northwest National Laboratory, Joint Global Change Research Institute, University of Maryland (June 2011-September 2012)
Matt Erickson, Student Assistant, Washington State University (July-October 2012)
Ilya Fischhoff, NCA Program Coordinator, USGCRP / UCAR
Elizabeth Fly, NCA Coastal Coordinator, Knauss Marine Policy Fellow, NOAA (February 2013-January 2014)
Chelcy Ford, NCA Sector Coordinator, USFS (August-November 2011)
Wyatt Freeman, Student Assistant, George Mason University / UCAR (May-September 2012)
Bryce Golden-Chen, NCA Program Coordinator, USGCRP / UCAR
Nancy Grimm, NCA Senior Scientist and Sector Coordinator, NSF / Arizona State University (July 2011-September 2012)
Tess Hart, NCA Communications Assistant, USGCRP / UCAR (June-July 2011)
Melissa Kenney, NCA Indicators Coordinator, NOAA / University of Maryland
Fredric Lipschultz, NCA Senior Scientist and Regional Coordinator, NASA / Bermuda Institute of Ocean Sciences
Stuart Luther, Student Assistant, Arizona State University / UCAR (June-August 2011)
Julie Maldonado, NCA Engagement Assistant and Tribal Coordinator, USGCRP / UCAR
Krista Mantsch, Student Assistant, Indiana University / UCAR (May-September 2013)
Rebecca Martin, Student Assistant, Washington State University (June-August 2012)
Paul Schramm, NCA Sector Coordinator, Centers for Disease Control and Prevention (June-November 2010)

Technical Support Unit, National Climatic Data Center, NOAA/NESDIS

David Easterling, NCA Technical Support Unit Director, NOAA National Climatic Data Center (from March 2013)
Anne Waple, NCA Technical Support Unit Director, NOAA NCDC / UCAR (through February 2013)
Susan Joy Hassol, Senior Science Writer, Climate Communication, LLC / Cooperative Institute for Climate and Satellites, North Carolina State University (CICS-NC)
Paula Ann Hennon, NCA Technical Support Unit Deputy Director, CICS-NC
Kenneth Kunkel, Chief Scientist, CICS-NC
Sara W. Veasey, Creative Director, NOAA NCDC
Andrew Buddenberg, Software Engineer/Scientific Programmer, CICS-NC
Fred Burnett, Administrative Assistant, Jamison Professional Services, Inc.
Sarah Champion, Scientific Data Curator and Process Analyst, CICS-NC
Doreen DiCarlo, Program Coordinator, CICS-NC (August 2011-April 2012)
Daniel Glick, Editor, CICS-NC
Jessicca Griffin, Lead Graphic Designer, CICS-NC
John Keck, Web Consultant, LMI, Inc. (August 2010 - September 2011)
Angel Li, Web Developer, CICS-NC
Clark Lind, Administrative Assistant, The Baldwin Group, Inc. (January-September 2012)
Liz Love-Brotak, Graphic Designer, NOAA NCDC
Tom Maycock, Technical Editor, CICS-NC
Janice Mills, Business Manager, CICS-NC
Deb Misch, Graphic Designer, Jamison Professional Services, Inc.
Julie Moore, Administrative Assistant, The Baldwin Group, Inc. (June 2010-January 2012)
Ana Pinheiro-Privette, Data Coordinator, CICS-NC (January 2012-July 2013)
Deborah B. Riddle, Graphic Designer, NOAA NCDC
April Sides, Web Developer, ERT, Inc.
Laura E. Stevens, Research Scientist, CICS-NC
Scott Stevens, Support Scientist, CICS-NC
Brooke Stewart, Science Editor/Production Coordinator, CICS-NC
Liqiang Sun, Research Scientist/Modeling Support, CICS-NC
Robert Taylor, Student Assistant, UNC Asheville, CICS-NC
Devin Thomas, Metadata Specialist, ERT, Inc.
Teresa Young, Print Specialist, Team ERT/STG, Inc.

Review Editors

Joseph Arvai, University of Calgary
Peter Backlund, University Corporation for Atmospheric Research
Lawrence Band, University of North Carolina
Jill S. Baron, U.S. Geological Survey / Colorado State University
Michelle L. Bell, Yale University
Donald Boesch, University of Maryland
Joel R. Brown, New Mexico State University
Ingrid C. (Indy) Burke, University of Wyoming
Gina Campoli, Vermont Agency of Transportation

Mary Anne Carroll, University of Michigan
Scott L. Collins, University of New Mexico
John Daigle, University of Maine
Ruth DeFries, Columbia University
Lisa Dilling, University of Colorado
Otto C. Doering III, Purdue University
Hadi Dowlatabadi, University of British Columbia
Charles T. Driscoll, Syracuse University
Hallie C. Eakin, Arizona State University
John Farrington, Woods Hole Oceanographic Institution
Chris E. Forest, Pennsylvania State University
Efi Foufoula-Georgiou, University of Minnesota
Adam Freed, The Nature Conservancy
Robert Fri, Resources for the Future
Stephen T. Gray, U.S. Geological Survey
Jay Gulledge, Oak Ridge National Laboratory
Terrie Klinger, University of Washington
Ian Kraucunas, Pacific Northwest National Laboratory
Larissa Larsen, University of Michigan
William J. Massman, U.S. Forest Service
Michael D. Mastrandrea, Stanford University
Pamela Matson, Stanford University
Ronald G. Prinn, Massachusetts Institute of Technology
J.C. Randolph, Indiana University
G. Philip Robertson, Michigan State University
David Robinson, Rutgers University
Dork Sahagian, Lehigh University
Christopher A. Scott, University of Arizona
Peter Vitousek, Stanford University
Andrew C. Wood, NOAA

United States Global Change Research Program

Thomas Armstrong (OSTP), Executive Director, USGCRP
Chris Weaver (OSTP / EPA), Deputy Executive Director, USGCRP

Subcommittee on Global Change Research

Chair

Thomas Karl, U.S. Department of Commerce

Vice Chairs

Ann Bartuska, U.S. Department of Agriculture, Vice Chair, Adaptation Science
Gerald Geernaert, U.S. Department of Energy, Vice Chair, Integrated Modeling
Mike Freilich, National Aeronautics and Space Administration, Vice Chair, Integrated Observations
Roger Wakimoto, National Science Foundation, Vice-Chair

Principals

John Balbus, U.S. Department of Health and Human Services
Katharine Batten, U.S. Agency for International Development
Joel Clement, U.S. Department of the Interior
Robert Detrick, U.S. Department of Commerce
Scott L. Harper, U.S. Department of Defense
Leonard Hirsch, Smithsonian Institution
William Hohenstein, U.S. Department of Agriculture
Jack Kaye, National Aeronautics and Space Administration
Michael Kuperberg, U.S. Department of Energy
C. Andrew Miller, U.S. Environmental Protection Agency
Arthur Rypinski, U.S. Department of Transportation
Joann Roskoski, National Science Foundation
Trigg Talley, U.S. Department of State

Interagency National Climate Assessment Working Group

Chair

Katharine Jacobs, White House Office of Science and Technology Policy (through December 2013)
Fabien Laurier, White House Office of Science and Technology Policy (from December 2013)

Vice-Chair

Virginia Burkett, U.S. Department of the Interior – U.S. Geological Survey (from March 2013)
Anne Waple, NOAA NCDC / UCAR (through February 2013)

National Aeronautics and Space Administration

Allison Leidner, Earth Science Division / Universities Space Research Association

National Science Foundation

Anjuli Bamzai, Directorate for Geosciences (through May 2011)
Eve Gruntfest, Directorate for Geosciences (January-November 2013)
Rita Teutonico, Directorate for Social, Behavioral, and Economic Sciences (through January 2011)

Smithsonian Institution

Leonard Hirsch, Office of the Undersecretary for Science

U.S. Department of Agriculture

Linda Langner, U.S. Forest Service (through January 2011)
Carolyn Olson, Office of the Chief Economist
Toral Patel-Weynand, U.S. Forest Service
Louie Tupas, National Institute of Food and Agriculture
Margaret Walsh, Office of the Chief Economist

U.S. Department of Commerce

Ko Barrett, National Oceanic and Atmospheric Administration (from February 2013)
David Easterling, National Oceanic and Atmospheric Administration – National Climatic Data Center (from March 2013)
Nancy McNabb, National Institute of Standards and Technology (from February 2013)
Adam Parris, National Oceanic and Atmospheric Administration
Anne Waple, NOAA NCDC / UCAR (through February 2013)

U.S. Department of Defense

William Goran, U.S. Army Corps of Engineers
John Hall, Office of the Secretary of Defense
Katherine Nixon, Navy Task Force Climate Change (from May 2013)
Courtney St. John, Navy Task Force Climate Change (through August 2012)

U.S. Department of Energy

Robert Vallario, Office of Science

U.S. Department of Health and Human Services

John Balbus, National Institutes of Health
Paul Schramm, Centers for Disease Control and Prevention (through July 2011)

U.S. Department of Homeland Security

Mike Kangior, Office of Policy (from November 2011)
John Laws, National Protection and Programs Directorate (from May 2013)

U.S. Department of the Interior

Susan Aragon-Long, U.S. Geological Survey
Virginia Burkett, U.S. Geological Survey
Leigh Welling, National Park Service (through May 2011)

U.S. Department of State

David Reidmiller, Bureau of Oceans and International Environmental & Scientific Affairs
Kenli Kim, Bureau of Oceans and International Environmental & Scientific Affairs (from February 2013)

U.S. Department of Transportation

Arthur Rypinski, Office of the Secretary
Mike Savonis, Federal Highway Administration (through March 2011)
AJ Singletary, Office of the Secretary (through August 2010)

U.S. Environmental Protection Agency

Rona Birnbaum, Office of Air and Radiation
Anne Grambsch, Office of Research and Development
Lesley Jantarasami, Office of Air and Radiation

White House Council on Environmental Quality

Jeff Peterson (through July 2013)
Jamie Pool (from February 2013)

White House Office of Management and Budget

Stuart Levenbach (through May 2012)

White House Office of Science and Technology Policy

Katharine Jacobs, Environment and Energy Division (through December 2013)
Fabien Laurier, Environment and Energy Division (from December 2013)

With special thanks to former NOAA Administrator, Jane Lubchenco and former Associate Director of the Office of Science and Technology Policy, Shere Abbott

CLIMATE CHANGE AND THE AMERICAN PEOPLE

Climate change, once considered an issue for a distant future, has moved firmly into the present. Corn producers in Iowa, oyster growers in Washington State, and maple syrup producers in Vermont are all observing climate-related changes that are outside of recent experience. So, too, are coastal planners in Florida, water managers in the arid Southwest, city dwellers from Phoenix to New York, and Native Peoples on tribal lands from Louisiana to Alaska. This National Climate Assessment concludes that the evidence of human-induced climate change continues to strengthen and that impacts are increasing across the country.

Americans are noticing changes all around them. Summers are longer and hotter, and extended periods of unusual heat last longer than any living American has ever experienced. Winters are generally shorter and warmer. Rain comes in heavier downpours. People are seeing changes in the length and severity of seasonal allergies, the plant varieties that thrive in their gardens, and the kinds of birds they see in any particular month in their neighborhoods.

Other changes are even more dramatic. Residents of some coastal cities see their streets flood more regularly during storms and high tides. Inland cities near large rivers also experience more flooding, especially in the Midwest and Northeast. Insurance rates are rising in some vulnerable locations, and insurance is no longer available in others. Hotter and drier weather and earlier snowmelt mean that wildfires in the West start earlier in the spring, last later into the fall, and burn more acreage. In Arctic Alaska, the summer sea ice that once protected the coasts has receded, and autumn storms now cause more erosion, threatening many communities with relocation.

Scientists who study climate change confirm that these observations are consistent with significant changes in Earth's climatic trends. Long-term, independent records from weather stations, satellites, ocean buoys, tide gauges, and many other data sources all confirm that our nation, like the rest of the world, is warming. Precipitation patterns are changing, sea level is rising, the oceans are becoming more acidic, and the frequency and intensity of some extreme weather events are increasing. Many lines of independent evidence demonstrate that the rapid warming of the past half-century is due primarily to human activities.


©Ted Wood Photography

The observed warming and other climatic changes are triggering wide-ranging impacts in every region of our country and throughout our economy. Some of these changes can be beneficial over the short run, such as a longer growing season in some regions and a longer shipping season on the Great Lakes. But many more are detrimental, largely because our society and its infrastructure were designed for the climate that we have had, not the rapidly changing climate we now have and can expect in the future. In addition, climate change does not occur in isolation. Rather, it is superimposed on other stresses, which combine to create new challenges.

This National Climate Assessment collects, integrates, and assesses observations and research from around the country, helping us to see what is actually happening and understand what it means for our lives, our livelihoods, and our future. This report includes analyses of impacts on seven sectors – human health, water, energy, transportation, agriculture, forests, and ecosystems – and the interactions among sectors at the national level. This report also assesses key impacts on all U.S. regions: Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawai'i and the Pacific Islands, as well as the country's coastal areas, oceans, and marine resources.

Over recent decades, climate science has advanced significantly. Increased scrutiny has led to increased certainty that we are now seeing impacts associated with human-induced climate change. With each passing year, the accumulating evidence further expands our understanding and extends the record of observed trends in temperature, precipitation, sea level, ice mass, and many other variables recorded by a variety of measuring systems and analyzed by independent research groups from around the world. It is notable that as these data records have grown longer and climate models have become more comprehensive, earlier predictions have largely been confirmed. The only real surprises have been that some changes, such as sea level rise and Arctic sea ice decline, have outpaced earlier projections.

What is new over the last decade is that we know with increasing certainty that climate change is happening now. While scientists continue to refine projections of the future, observations unequivocally show that climate is changing and that the warming of the past 50 years is primarily due to human-induced emissions of heat-trapping gases. These emissions come mainly from burning coal, oil, and gas, with additional contributions from forest clearing and some agricultural practices.

Global climate is projected to continue to change over this century and beyond, but there is still time to act to limit the amount of change and the extent of damaging impacts.

This report documents the changes already observed and those projected for the future. It is important that these findings and response options be shared broadly to inform citizens and communities across our nation. Climate change presents a major challenge for society. This report advances our understanding of that challenge and the need for the American people to prepare for and respond to its far-reaching implications.

ABOUT THIS REPORT

This report assesses the science of climate change and its impacts across the United States, now and throughout this century. It integrates findings of the U.S. Global Change Research Program (USGCRP)[a] with the results of research and observations from across the U.S. and around the world, including reports from the U.S. National Research Council. This report documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

REPORT REQUIREMENTS, PRODUCTION, AND APPROVAL

The Global Change Research Act[1] requires that, every four years, the USGCRP prepare and submit to the President and Congress an assessment of the effects of global change in the United States. As part of this assessment, more than 70 workshops were held involving a wide range of stakeholders who identified issues and information for inclusion (see Appendix 1: Process). A team of more than 300 experts was involved in writing this report. Authors were appointed by the National Climate Assessment and Development Advisory Committee (NCADAC),[b] the federal advisory committee assembled for the purpose of conducting this assessment. The report was extensively reviewed and revised based on comments from the public and experts, including a panel of the National Academy of Sciences. The report was reviewed and approved by the USGCRP agencies and the federal Committee on Environment, Natural Resources, and Sustainability (CENRS). This report meets all federal requirements associated with the Information Quality Act (see Appendix 2: IQA), including those pertaining to public comment and transparency.

REPORT SOURCES

The report draws from a large body of scientific, peer-reviewed research, as well as a number of other publicly available sources. Author teams carefully reviewed these sources to ensure a reliable assessment of the state of scientific understanding. Each source of information was determined to meet the four parts of the IQA Guidance provided to authors: 1) utility, 2) transparency and traceability, 3) objectivity, and 4) integrity and security (see Appendix 2: IQA). Report authors made use of technical input reports produced by federal agencies and other interested parties in response to a request for information by the NCADAC;[2] other peer-reviewed scientific assessments (including those of the Intergovernmental Panel on Climate Change); the U.S. National Climate Assessment's 2009 report titled Global Climate Change Impacts in the United States;[3] the National Academy of Science's America's Climate Choices reports;[4] a variety of regional climate impact assessments, conference proceedings, and government statistics (such as population census and energy usage); and observational data. Case studies were also provided as illustrations of climate impacts and adaptation programs.

[a] The USGCRP is made up of 13 Federal departments and agencies that carry out research and support the nation's response to global change The USGCRP is overseen by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's Committee on Environment, Natural Resources and Sustainability (CENRS), which in turn is overseen by the White House Office of Science and Technology Policy (OSTP). The agencies within USGCRP are: the Department of Agriculture, the Department of Commerce (NOAA), the Department of Defense, the Department of Energy, the Department of Health and Human Services, the Department of the Interior, the Department of State, the Department of Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, the Smithsonian Institution, and the U.S. Agency for International Development.

[b] The NCADAC is a federal advisory committee sponsored by the National Oceanic and Atmospheric Administration under the requirements of the Federal Advisory Committee Act.

A GUIDE TO THE REPORT

The report has eight major sections, outlined below:

- **Overview and Report Findings:** gives a high-level perspective on the full National Climate Assessment and sets out the report's 12 key findings. The Overview synthesizes and summarizes the ideas that the authors consider to be of greatest importance to the American people.
- **Our Changing Climate:** presents recent advances in climate change science, which includes discussions of extreme weather events, observed and projected changes in temperature and precipitation, and the uncertainties associated with these projections. Substantial additional material related to this chapter can be found in the Appendices.
- **Sectors:** focuses on climate change impacts for seven societal and environmental sectors: human health, water, energy, transportation, agriculture, forests, and ecosystems and biodiversity; six additional chapters consider the interactions among sectors (such as energy, water, and land use) in the context of a changing climate.
- **Regions:** assesses key impacts on U.S. regions – Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, and Hawai'i and the U.S. affiliated Pacific Islands – as well as coastal areas, oceans, and marine resources.
- **Responses:** assesses the current state of responses to climate change, including adaptation, mitigation, and decision support activities.
- **Research Needs:** highlights major gaps in science and research to improve future assessments. New research is called for in climate science in support of assessments, climate impacts in regions and sectors, and adaptation, mitigation, and decision support.
- **Sustained Assessment Process:** describes an initial vision for and components of an ongoing, long-term assessment process.
- **Appendices:** Appendix 1 describes key aspects of the report process, with a focus on engagement; Appendix 2 describes the guidelines used in meeting the terms of the Federal Information Quality Act; Appendix 3 supplements the chapter on Our Changing Climate with an extended treatment of selected science issues; Appendix 4 provides answers to Frequently Asked Questions about climate change; Appendix 5 describes scenarios and models used in this assessment; and Appendix 6 describes possible topics for consideration in future assessments.

OVERARCHING PERSPECTIVES

Four overarching perspectives, derived from decades of observations, analysis, and experience, have helped to shape this report: 1) climate change is happening in the context of other ongoing changes across the U.S. and the globe; 2) climate change impacts can either be amplified or reduced by societal decisions; 3) climate change related impacts, vulnerabilities, and opportunities in the U.S. are linked to impacts and changes outside the United States, and vice versa; and 4) climate change can lead to dramatic tipping points in natural and social systems. These overarching perspectives are briefly discussed below.

Global Change Context

Climate change is one of a number of global changes affecting society, the environment, and the economy; others include population growth, land-use change, air and water pollution, and rising consumption of resources by a growing and wealthier global population. This perspective has implications for assessments of climate change impacts and the design of research questions at the national, regional, and local scales. This assessment explores some of the consequences of interacting factors by focusing on sets of crosscutting issues in a series of six chapters: Energy, Water, and Land Use; Biogeochemical Cycles; Indigenous Peoples, Lands, and Resources; Urban Systems, Infrastructure, and Vulnerability; Land Use and Land Cover Change; and Rural Communities. The assessment also includes discussions of how climate change impacts cascade through different sectors such as water and energy, and affect and are affected by land-use decisions. These and other interconnections greatly stress society's capacity to respond to climate-related crises that occur simultaneously or in rapid sequence.

Societal Choices

Because environmental, cultural, and socioeconomic systems are tightly coupled, climate change impacts can either be amplified or reduced by cultural and socioeconomic decisions. In many arenas, it is clear that societal decisions have substantial influence on the vulnerability of valued resources to climate change. For example, rapid population growth and development in coastal areas tends to amplify climate change related impacts. Recognition of these couplings, together with recognition of multiple sources of vulnerability, helps identify what information decision-makers need as they manage risks.

International Context

Climate change is a global phenomenon; the causes and the impacts involve energy-use, economic, and risk-management decisions across the globe. Impacts, vulnerabilities, and opportunities in the U.S. are related in complex and interactive ways with changes outside the United States, and vice versa. In order for U.S. concerns related to climate change to be addressed comprehensively, the international context must be considered. Foreign assistance, health, environmental quality objectives, and economic interests are all affected by climate changes experienced in other parts of the world. Although there is significantly more work to be done in this area, this report identifies some initial implications of global and international trends that can be more fully investigated in future assessments.

Thresholds, Tipping Points, and Surprises

While some climate changes will occur slowly and relatively gradually, others could be rapid and dramatic, leading to unexpected breaking points in natural and social systems. Although they have potentially large impacts, these breaking points or tipping points are difficult to predict, as there are many uncertainties about future conditions. These uncertainties and potential surprises come from a number of sources, including insufficient data associated with low probability/high consequence events, models that are not yet able to represent all the interactions of multiple stresses, incomplete understanding of physical climate mechanisms related to tipping points, and a multitude of issues associated with human behavior, risk management, and decision-making. Improving our ability to anticipate thresholds and tipping points can be helpful in developing effective climate change mitigation and adaptation strategies (Ch. 2: Our Changing Climate; Ch. 29: Research Needs; and Appendices 3 and 4).

RISK MANAGEMENT FRAMEWORK

Authors were asked to consider the science and information needs of decision-makers facing climate change risks to infrastructure, natural ecosystems, resources, communities, and other things of societal value. They were also asked to consider opportunities that climate change might present. For each region and sector, they were asked to assess a small number of key climate-related vulnerabilities of concern based on the risk (considering likelihood and consequence) of impacts. They were also asked to address the most important information needs of stakeholders, and to consider the decisions stakeholders are facing. The criteria provided for identifying key vulnerabilities in each sector or region included magnitude, timing, persistence/reversibility, scale, and distribution of impacts, likelihood whenever possible, importance of impacts (based on the perceptions of relevant parties), and the potential for adaptation. Authors were encouraged to think about these topics from both a quantitative and qualitative perspective and to consider the influence of multiple stresses whenever possible.

RESPONDING TO CLIMATE CHANGE

While the primary focus of this report is on the impacts of climate change in the United States, it also documents some of the actions society is taking or can take to respond. Responses to climate change fall into two broad categories. The first involves "mitigation" measures to reduce future climate change by reducing emissions of heat-trapping gases and particles, or increasing removal of carbon dioxide from the atmosphere. The second involves "adaptation" measures to improve society's ability to cope with or avoid harmful impacts and take advantage of beneficial ones, now and in the future. At this point, both of these response activities are necessary to limit the magnitude and impacts of global climate change on the United States.

More effective mitigation measures can reduce the amount of climate change, and therefore reduce the need for future adaptation. This report underscores the effects of mitigation measures by comparing impacts resulting from higher versus lower emissions scenarios. This shows that choices made about emissions in the next few decades will have far-reaching consequences for climate change impacts throughout this century. Lower emissions will reduce the rate and lessen the magnitude of climate change and its impacts. Higher emissions will do the opposite.

While the report demonstrates the importance of mitigation as an essential part of the nation's climate change strategy, it does not evaluate mitigation technologies or policies or undertake an analysis of the effectiveness of various approaches. The range of mitigation responses being studied includes, but is not limited to, policies and technologies that lead to more efficient production and use of energy, increased use of non-carbon-emitting energy sources such as wind and solar power, and carbon capture and storage.

Adaptation actions are complementary to mitigation actions. They are focused on moderating harmful impacts of current and future climate variability and change and taking advantage of possible opportunities. While this report assesses the current state of adaptation actions and planning across the country in a general way, the implementation of adaptive actions is still nascent. A comprehensive assessment of actions taken, and of their effectiveness, is not yet possible. This report documents some of the actions currently being pursued to address impacts such as increased urban heat extremes and air pollution, and describes the challenges decision-makers face in planning for and implementing adaptation responses.

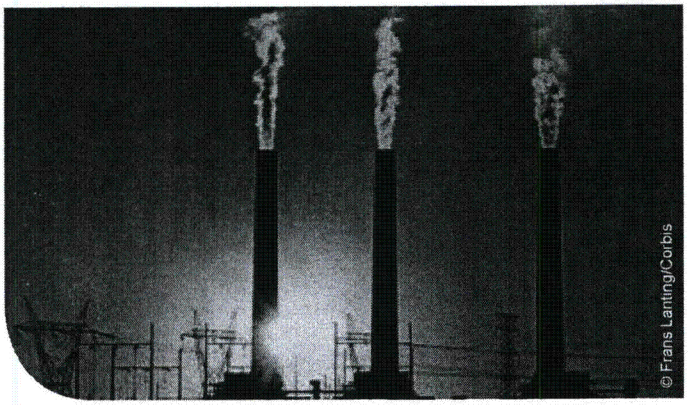
TRACEABLE ACCOUNTS: PROCESS AND CONFIDENCE

The "traceable accounts" that accompany each chapter: 1) document the process the authors used to reach the conclusions in their key messages; 2) provide additional information to reviewers and other readers about the quality of the information used; 3) allow traceability to resources; and 4) provide the level of confidence the authors have in the main findings of the chapters. The authors have assessed a wide range of information in the scientific literature and various technical reports. In assessing confidence, they have considered the strength and consistency of the observed evidence, the skill, range, and consistency of model projections, and insights from peer-reviewed sources.

When it is considered scientifically justified to report the likelihood of particular impacts within the range of possible outcomes, this report takes a plain-language approach to expressing the expert judgment of the author team based on the best available evidence. For example, an outcome termed "likely" has at least a two-thirds chance of occurring; an outcome termed "very likely" has more than a 90% chance. Key sources of information used to develop these characterizations are referenced.

1 OVERVIEW AND REPORT FINDINGS

Climate change is already affecting the American people in far-reaching ways. Certain types of extreme weather events with links to climate change have become more frequent and/or intense, including prolonged periods of heat, heavy downpours, and, in some regions, floods and droughts. In addition, warming is causing sea level to rise and glaciers and Arctic sea ice to melt, and oceans are becoming more acidic as they absorb carbon dioxide. These and other aspects of climate change are disrupting people's lives and damaging some sectors of our economy.



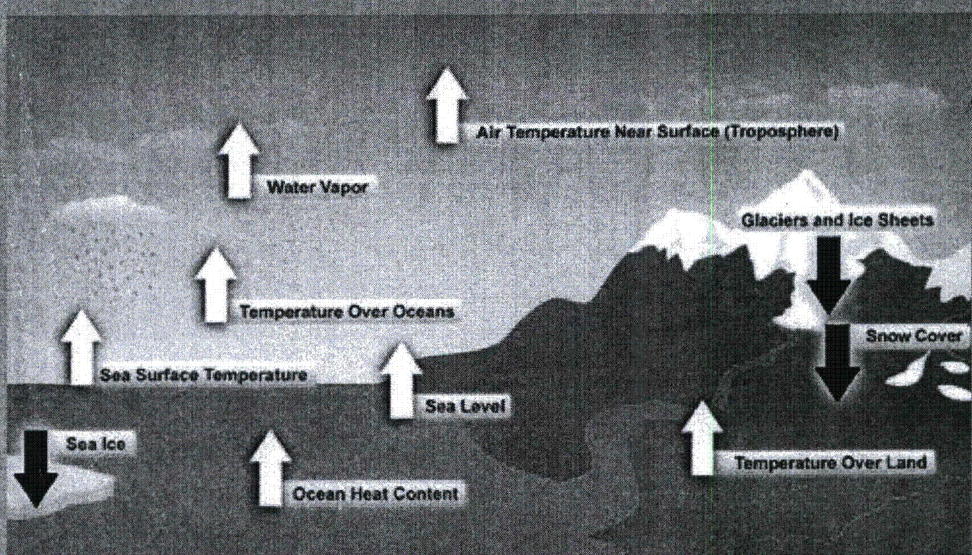
Coal-fired power plants emit heat-trapping carbon dioxide to the atmosphere.

Climate Change: Present and Future

Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans. Scientists and engineers from around the world have meticulously collected this evidence, using satellites and networks of weather balloons, thermometers, buoys, and other observing systems. Evidence of climate change is also visible in the observed and measured changes in location and behavior of species and functioning of ecosystems. Taken together, this evidence tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity.

Multiple lines of independent evidence confirm that human activities are the primary cause of the global warming of the past 50 years. The burning of coal, oil, and gas, and clearing of forests have increased the concentration of carbon dioxide in the atmosphere by more than 40% since the Industrial Revolution, and it has been known for almost two centuries that this carbon dioxide traps heat. Methane and nitrous oxide emissions from agriculture and other human activities add to the atmospheric burden of heat-trapping gases. Data show that natural factors like the sun and volcanoes cannot have caused the warming observed over the past 50 years. Sensors on satellites have measured the sun's output with great accuracy and found no overall increase during the past half century. Large volcanic eruptions during this period, such as Mount Pinatubo in 1991, have exerted a short-term *cooling* influence. In fact, if not for human activities, global climate would actually have cooled slightly over the past 50 years. The pattern of temperature change through the layers of the atmosphere, with warming near the surface and cooling higher up in the stratosphere, further confirms that it is the buildup of heat-trapping gases (also known as "greenhouse gases") that has caused most of the Earth's warming over the past half century.

Ten Indicators of a Warming World

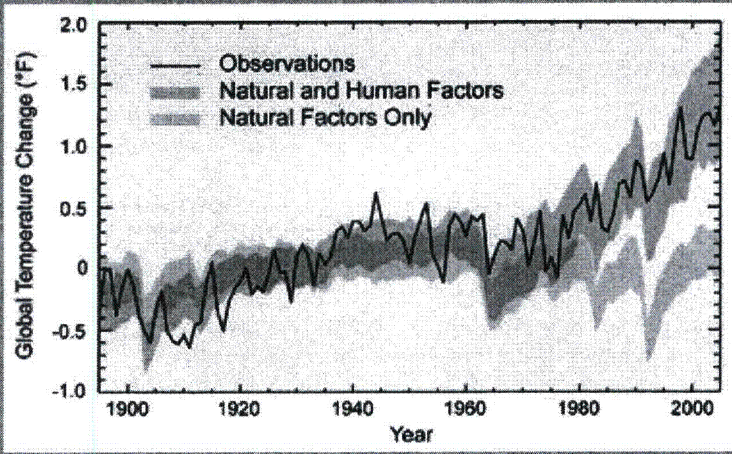


These are just some of the indicators measured globally over many decades that show that the Earth's climate is warming. White arrows indicate increasing trends; black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are increasing, and all those expected to decrease in a warming world are decreasing. (Figure source: NOAA NCDC, based on data updated from Kennedy et al. 2010[3]).

Because human-induced warming is superimposed on a background of natural variations in climate, warming is not uniform over time. Short-term fluctuations in the long-term upward trend are thus natural and expected. For example, a recent slowing in the rate of surface air temperature rise appears to be related to cyclic changes in the oceans and in the sun's energy output, as well as a series of small volcanic eruptions and other factors. Nonetheless, global temperatures are still on the rise and are expected to rise further.

U.S. average temperature has increased by 1.3°F to 1.9°F since 1895, and most of this increase has occurred since 1970. The most recent decade was the nation's and the world's hottest on record, and 2012 was the hottest year on record in the continental United States. All U.S. regions have experienced warming in recent decades, but the extent of warming has not been uniform. In general, temperatures are rising more quickly in the north. Alaskans have experienced some of the largest increases in temperature between 1970 and the present. People living in the Southeast have experienced some of the smallest temperature increases over this period.

Separating Human and Natural Influences on Climate

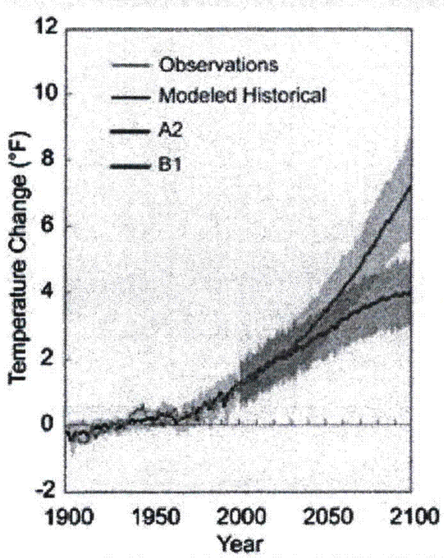


The green band shows how global average temperature would have changed over the last century due to natural forces alone, as simulated by climate models. The blue band shows model simulations of the effects of human and natural forces (including solar and volcanic activity) combined. The black line shows the actual observed global average temperatures. Only with the inclusion of human influences can models reproduce the observed temperature changes. (Figure source: adapted from Huber and Knutti 2012[5]).

Temperatures are projected to rise another 2°F to 4°F in most areas of the United States over the next few decades. Reductions in some short-lived human-induced emissions that contribute to warming, such as black carbon (soot) and methane, could reduce some of the projected warming over the next couple of decades, because, unlike carbon dioxide, these gases and particles have relatively short atmospheric lifetimes.

The amount of warming projected beyond the next few decades is directly linked to the cumulative global emissions of heat-trapping gases and particles. By the end of this century, a roughly 3°F to 5°F rise is projected under a lower emissions scenario, which would require substantial reductions in emissions (referred to as the "B1 scenario"), and a 5°F to 10°F rise for a higher emissions scenario assuming continued increases in emissions, predominantly from fossil fuel combustion (referred to as the "A2 scenario"). These projections are based on results from 16 climate models that used the two emissions scenarios in a formal intermodel comparison study. The range of model projections for each emissions scenario is the result of the differences in the ways the models represent key factors such as water vapor, ice and snow reflectivity, and clouds, which can either dampen or amplify the initial effect of human influences on temperature. The net effect of these feedbacks is expected to amplify warming. More information about the models and scenarios used in this report can be found in Appendix 5 of the full report.[1]

Projected Global Temperature Change



Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. The lines on the graph represent a central estimate of global average temperature rise (relative to the 1901-1960 average) for the two main scenarios used in this report. A2 assumes continued increases in emissions throughout this century, and B1 assumes significant emissions reductions, though not due explicitly to climate change policies. Shading indicates the range (5th to 95th percentile) of results from a suite of climate models. In both cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. (Figure source: NOAA NCDC / CICS-NC).

Prolonged periods of high temperatures and the persistence of high nighttime temperatures have increased in many locations (especially in urban areas) over the past half century. High nighttime temperatures have widespread impacts because people, livestock, and wildlife get no respite from the heat. In some regions, prolonged periods of high temperatures associated with droughts contribute to conditions that lead to larger wildfires and longer fire seasons. As expected in a warming climate, recent trends show that extreme heat is becoming more common, while extreme cold is becoming less common. Evidence indicates that the human influence on climate has already roughly doubled the probability of extreme heat events such as the record-breaking summer heat experienced in 2011 in Texas and Oklahoma. The incidence of record-breaking high temperatures is projected to rise.[2]

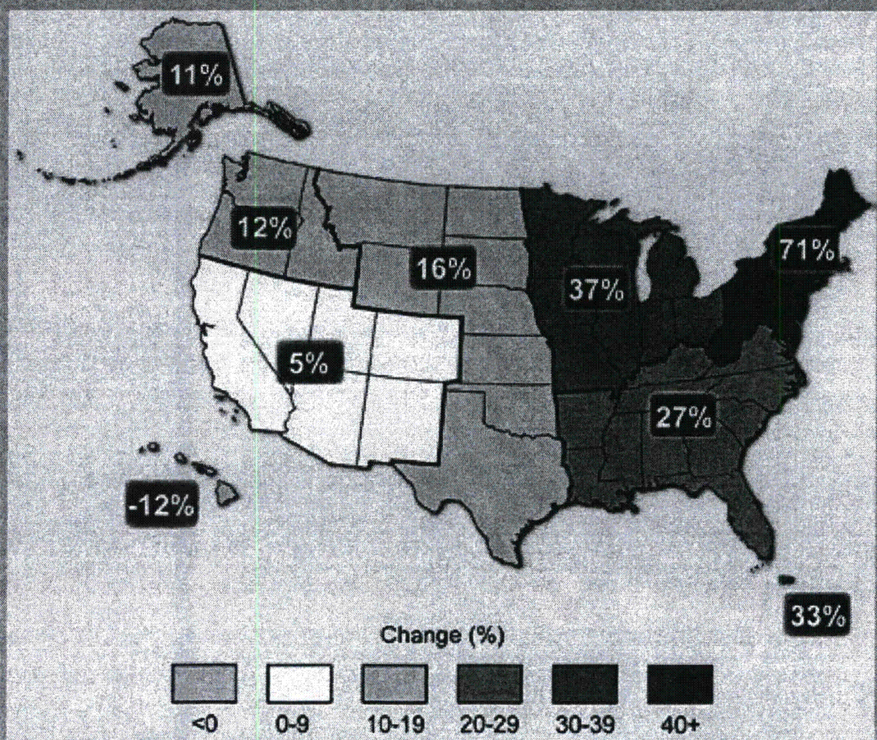
Human-induced climate change means much more than just hotter weather. Increases in ocean and freshwater temperatures, frost-free days, and heavy downpours have all been documented. Global sea level has risen, and there have been large reductions in snow-cover extent, glaciers, and sea ice. These changes and other climatic changes have affected and will continue to affect human health, water supply, agriculture, transportation, energy, coastal areas, and many other sectors of society, with increasingly adverse impacts on the American economy and quality of life.[3]

Some of the changes discussed in this report are common to many regions. For example, large increases in heavy precipitation have occurred in the Northeast, Midwest, and Great Plains, where heavy downpours have frequently led to runoff that exceeded the capacity of storm drains and levees, and caused flooding events and accelerated erosion. Other impacts, such as those associated with the rapid thawing of permafrost in Alaska, are unique to a particular U.S. region. Permafrost thawing is causing extensive damage to infrastructure in our nation's largest state.[4]

Some impacts that occur in one region ripple beyond that region. For example, the dramatic decline of summer sea ice in the Arctic – a loss of ice cover roughly equal to half the area of the continental United States – exacerbates global warming by reducing the reflectivity of Earth's surface and increasing the amount of heat absorbed. Similarly, smoke from wildfires in one location can contribute to poor air quality in faraway regions, and evidence suggests that particulate matter can affect atmospheric properties and therefore weather patterns. Major storms and the higher storm surges exacerbated by sea level rise that hit the Gulf Coast affect the entire country through their cascading effects on oil and gas production and distribution.[5]

Water expands as it warms, causing global sea levels to rise; melting of land-based ice also raises sea level by adding water to the oceans. Over the past century, global average sea level has risen by about 8 inches. Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, providing evidence of acceleration. Sea level rise, combined with coastal storms, has increased the risk of erosion, storm surge damage, and flooding for coastal communities, especially along the Gulf Coast, the Atlantic seaboard, and in Alaska. Coastal infrastructure, including roads, rail lines, energy infrastructure, airports, port facilities, and military bases, are increasingly at risk from sea level rise and damaging storm surges. Sea level is projected to rise by another 1 to 4 feet in this century, although the rise in sea level in specific regions is expected to vary from this global average for a number of reasons. A wider range of scenarios,

Observed Change in Very Heavy Precipitation

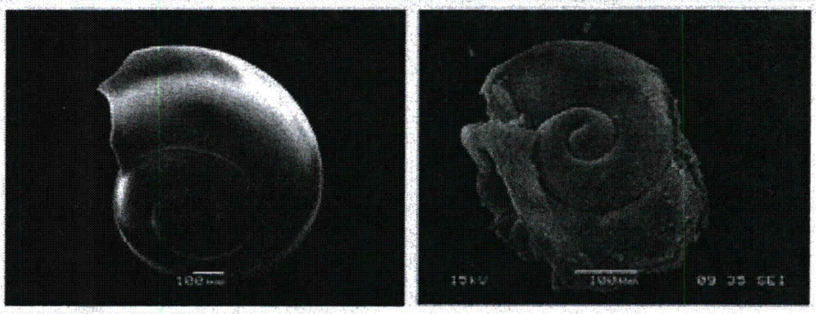


Percent changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012 for each region. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. (Figure source: updated from Karl et al. 2009[7]).

from 8 inches to more than 6 feet by 2100, has been used in risk-based analyses in this report. In general, higher emissions scenarios that lead to more warming would be expected to lead to higher amounts of sea level rise. The stakes are high, as nearly five million Americans and hundreds of billions of dollars of property are located in areas that are less than four feet above the local high-tide level.[6]

In addition to causing changes in climate, increasing levels of carbon dioxide from the burning of fossil fuels and other human activities have a direct effect on the world's oceans. Carbon dioxide interacts with ocean water to form carbonic acid, increasing the ocean's acidity. Ocean surface waters have become 30% more acidic over the last 250 years as they have absorbed large amounts of carbon dioxide from the atmosphere. This ocean acidification makes water more corrosive, reducing the capacity of marine organisms with shells or skeletons made of calcium carbonate (such as corals, krill, oysters, clams, and crabs) to survive, grow, and reproduce, which in turn will affect the marine food chain.[7]

Shells Dissolve in Acidified Ocean Water

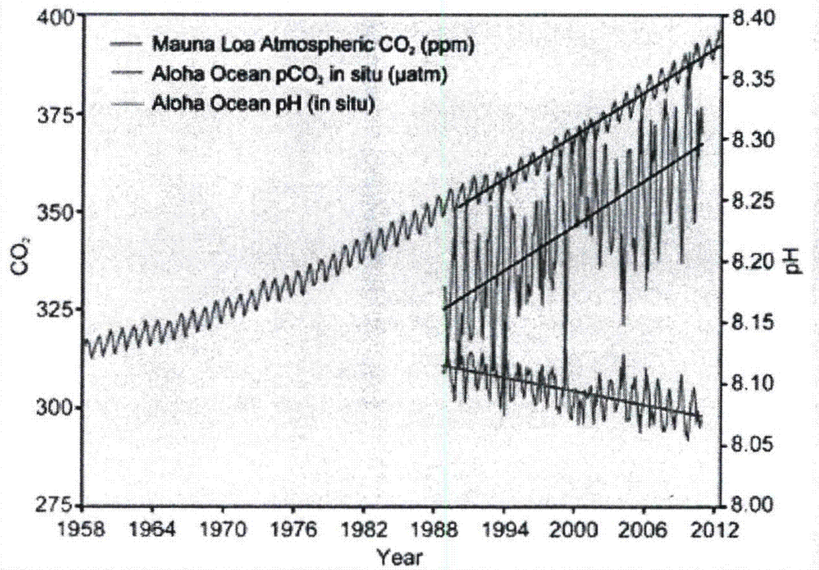


Pteropods, or "sea butterflies," are eaten by a variety of marine species ranging from tiny krill to salmon to whales. The photos show what happens to a pteropod's shell in seawater that is too acidic. On the left is a shell from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod in a region where the water is more acidic. (Figure source: (left) Bednaršek et al. 2012[8] (right) Nina Bednaršek).

Widespread Impacts

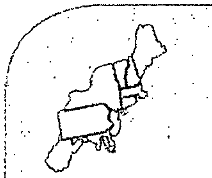
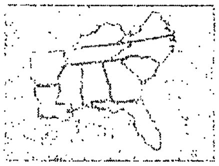
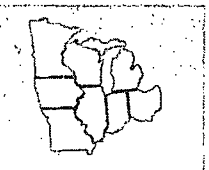
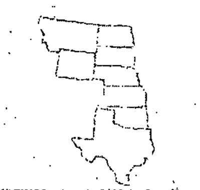
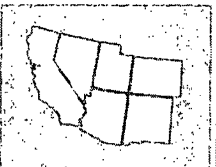
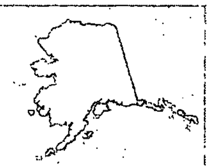
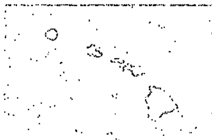
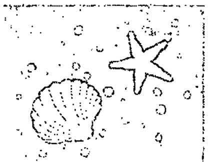
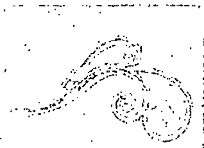
Impacts related to climate change are already evident in many regions and sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond. Climate changes interact with other environmental and societal factors in ways that can either moderate or intensify these impacts.

As Oceans Absorb CO_2 They Become More Acidic



The correlation between rising levels of carbon dioxide in the atmosphere (red) with rising carbon dioxide levels (blue) and falling pH in the ocean (green). As carbon dioxide accumulates in the ocean, the water becomes more acidic (the pH declines). (Figure source: modified from Feely et al. 2009[9]).

Observed and projected climate change impacts vary across the regions of the United States. Selected impacts emphasized in the regional chapters are shown below, and many more are explored in detail in this report.

	Northeast	Communities are affected by heat waves, more extreme precipitation events, and coastal flooding due to sea level rise and storm surge.
	Southeast and Caribbean	Decreased water availability, exacerbated by population growth and land-use change, causes increased competition for water. There are increased risks associated with extreme events such as hurricanes.
	Midwest	Longer growing seasons and rising carbon dioxide levels increase yields of some crops, although these benefits have already been offset in some instances by occurrence of extreme events such as heat waves, droughts, and floods.
	Great Plains	Rising temperatures lead to increased demand for water and energy and impacts on agricultural practices.
	Southwest	Drought and increased warming foster wildfires and increased competition for scarce water resources for people and ecosystems.
	Northwest	Changes in the timing of streamflow related to earlier snowmelt reduce the supply of water in summer, causing far-reaching ecological and socioeconomic consequences.
	Alaska	Rapidly receding summer sea ice, shrinking glaciers, and thawing permafrost cause damage to infrastructure and major changes to ecosystems. Impacts to Alaska Native communities increase.
	Hawai'i and Pacific Islands	Increasingly constrained freshwater supplies, coupled with increased temperatures, stress both people and ecosystems and decrease food and water security.
	Coasts	Coastal lifelines, such as water supply infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.
	Oceans	The oceans are currently absorbing about a quarter of human-caused carbon dioxide emissions to the atmosphere and over 90% of the heat associated with global warming, leading to ocean acidification and the alteration of marine ecosystems.

Some climate changes currently have beneficial effects for specific sectors or regions. For example, current benefits of warming include longer growing seasons for agriculture and longer ice-free periods for shipping on the Great Lakes. At the same time, however, longer growing seasons, along with higher temperatures and carbon dioxide levels, can increase pollen production, intensifying and lengthening the allergy season. Longer ice-free periods on the Great Lakes can result in more lake-effect snowfalls.

Sectors affected by climate changes include agriculture, water, human health, energy, transportation, forests, and ecosystems. Climate change poses a major challenge to U.S. agriculture because of the critical dependence of agricultural systems on climate. Climate change has the potential to both positively and negatively affect the location, timing, and productivity of crop, livestock, and fishery systems at local, national, and global scales. The United States produces nearly $330 billion per year in agricultural commodities. This productivity is vulnerable to direct impacts on crops and livestock from changing climate conditions and extreme weather events and indirect impacts through increasing pressures from pests and pathogens. Climate change will also alter the stability of food supplies and create new food security challenges for the United States as the world seeks to feed nine billion people by 2050. While the agriculture sector has proven to be adaptable to a range of stresses, as evidenced by continued growth in production and efficiency across the United States, climate change poses a new set of challenges.[8]

Climate change can exacerbate respiratory and asthma-related conditions through increases in pollen, ground-level ozone, and wildfire smoke.

Water quality and quantity are being affected by climate change. Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. Water quality is also diminishing in many areas, particularly due to sediment and contaminant concentrations after heavy downpours. Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands. In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed with existing practices.[9]

Certain groups of people are more vulnerable to the range of climate change related health impacts, including the elderly, children, the poor, and the sick.

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease water quality in many ways. Here, middle school students in Colorado test water quality.

Climate change affects human health in many ways. For example, increasingly frequent and intense heat events lead to more heat-related illnesses and deaths and, over time, worsen drought and wildfire risks, and intensify air pollution. Increasingly frequent extreme precipitation and associated flooding can lead to injuries and increases in waterborne disease. Rising sea surface temperatures have been linked with increasing levels and ranges of diseases. Rising sea levels intensify coastal flooding and storm surge, and thus exacerbate threats to public safety during storms. Certain groups of people are more vulnerable to the range of climate change related health impacts, including the elderly, children, the poor, and the sick. Others are vulnerable because of where they live, including those in floodplains, coastal zones, and some urban areas. Improving and properly supporting the public health infrastructure will be critical to managing the potential health impacts of climate change.[10]

Climate change also affects the living world, including people, through changes in ecosystems and biodiversity. Ecosystems provide a rich array of benefits and services to humanity, including habitat for fish and wildlife, drinking water storage and filtration, fertile soils for growing crops, buffering against a range of stressors including climate change impacts, and aesthetic and cultural values. These benefits are not always easy to quantify, but they support jobs, economic growth, health, and human well-being. Climate change driven disruptions to ecosystems have direct and indirect human impacts, including reduced water supply and quality, the loss of iconic species and landscapes, effects on food chains and the timing and success of species migrations, and the potential for extreme weather and climate events to destroy or degrade the ability of ecosystems to provide societal benefits.[11]

> The amount of future climate change will still largely be determined by choices society makes about emissions.

Human modifications of ecosystems and landscapes often increase their vulnerability to damage from extreme weather events, while simultaneously reducing their natural capacity to moderate the impacts of such events. For example, salt marshes, reefs, mangrove forests, and barrier islands defend coastal ecosystems and infrastructure, such as roads and buildings, against storm surges. The loss of these natural buffers due to coastal development, erosion, and sea level rise increases the risk of catastrophic damage during or after extreme weather events. Although floodplain wetlands are greatly reduced from their historical extent, those that remain still absorb floodwaters and reduce the effects of high flows on river-margin lands. Extreme weather events that produce sudden increases in water flow, often carrying debris and pollutants, can decrease the natural capacity of ecosystems to cleanse contaminants.[12]

The climate change impacts being felt in the regions and sectors of the United States are affected by global trends and economic decisions. In an increasingly interconnected world, U.S. vulnerability is linked to impacts in other nations. It is thus difficult to fully evaluate the impacts of climate change on the United States without considering consequences of climate change elsewhere.

Response Options

As the impacts of climate change are becoming more prevalent, Americans face choices. Especially because of past emissions of long-lived heat-trapping gases, some additional climate change and related impacts are now unavoidable. This is due to the long-lived nature of many of these gases, as well as the amount of heat absorbed and retained by the oceans and other responses within the climate system. The amount of future climate change, however, will still largely be determined by choices society makes about emissions. Lower emissions of heat-trapping gases and particles mean less future warming and less-severe impacts; higher emissions mean more warming and more severe impacts. Efforts to limit emissions or increase carbon uptake fall into a category of response options known as "mitigation," which refers to reducing the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere.[13]

The other major category of response options is known as "adaptation," and refers to actions to prepare for and adjust to new conditions, thereby reducing harm or taking advantage of new opportunities. Mitigation and adaptation actions are linked in multiple ways, including that effective mitigation reduces the need for adaptation in the future. Both are essential parts of a comprehensive climate change response strategy. The threat of irreversible impacts makes the timing of mitigation efforts particularly critical. This report includes chapters on Mitigation, Adaptation, and Decision Support that offer an overview of the options and activities being planned or implemented around the country as local, state, federal, and tribal governments, as well as businesses, organizations, and individuals begin to respond to climate change. These chapters conclude that while response actions are under development, current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.[14]

Large reductions in global emissions of heat-trapping gases, similar to the lower emissions scenario (B1) analyzed in this assessment, would reduce the risks of some of the worst impacts of climate change. Some targets called for in international climate negotiations to date would require even larger reductions than those outlined in the B1 scenario. Meanwhile, global emissions are still rising and are on a path to be even higher than the high emissions scenario (A2) analyzed in this report. The recent U.S. contribution to annual global emissions is about 18%, but the U.S. contribution to cumulative global emissions over the last century is much higher. Carbon dioxide lasts for a long time in the atmosphere, and it is the cumulative carbon emissions that determine the amount of global climate change. After decades of increases, U.S. 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. Governmental actions in city, state, regional, and federal programs to promote energy efficiency have also contributed to reducing U.S. carbon emissions. Many, if not most of these programs are motivated by other policy objectives, but some are directed specifically at greenhouse gas emissions.

These U.S. actions and others that might be undertaken in the future are described in the Mitigation chapter of this report. 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.[15]

With regard to adaptation, the pace and magnitude of observed and projected changes emphasize the need to be prepared for a wide variety and intensity of impacts. Because of the growing influence of human activities, the climate of the past is not a good basis for future planning. For example, building codes and landscaping ordinances could be updated to improve energy efficiency, conserve water supplies, protect against insects that spread disease (such as dengue fever), reduce susceptibility to heat stress, and improve protection against extreme events. The fact that climate change impacts are increasing points to the urgent need to develop and refine approaches that enable decision-making and increase flexibility and resilience in the face of ongoing and future impacts. Reducing non-climate-related stresses that contribute to existing vulnerabilities can also be an effective approach to climate change adaptation.[16]

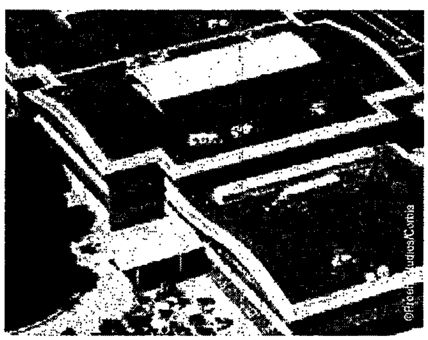
Adaptation can involve considering local, state, regional, national, and international jurisdictional objectives. For example, in managing water supplies to adapt to a changing climate, the implications of international treaties should be considered in the context of managing the Great Lakes, the Columbia River, and the Colorado River to deal with increased drought risk. Both "bottom up" community planning and "top down" national strategies may help regions deal with impacts such as increases in electrical brownouts, heat stress, floods, and wildfires.[17]

Proactively preparing for climate change can reduce impacts while also facilitating a more rapid and efficient response to changes as they happen. Such efforts are beginning at the federal, regional, state, tribal, and local levels, and in the corporate and non-governmental sectors, to build adaptive capacity and resilience to climate change impacts. Using scientific information to prepare for climate changes in advance can provide economic opportunities, and proactively managing the risks can reduce impacts and costs over time.[18]

There are a number of areas where improved scientific information or understanding would enhance the capacity to estimate future climate change impacts. For example, knowledge of the mechanisms controlling the rate of ice loss in Greenland and Antarctica is limited, making it difficult for scientists to narrow the range of expected future sea level rise. Improved understanding of ecological and social responses to climate change is needed, as is understanding of how ecological and social responses will interact.[19]

A sustained climate assessment process could more efficiently collect and synthesize the rapidly evolving science and help supply timely and relevant information to decision-makers. Results from all of these efforts could continue to deepen our understanding of the interactions of human and natural systems in the context of a changing climate, enabling society to effectively respond and prepare for our future.[20]

The cumulative weight of the scientific evidence contained in this report confirms that climate change is affecting the American people now, and that choices we make will affect our future and that of future generations.




Cities providing transportation options including bike lanes, buildings designed with energy saving features such as green roofs, and houses elevated to allow storm surges to pass underneath are among the many response options being pursued around the country.

Report Findings

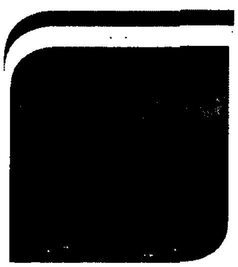
These findings distill important results that arise from this National Climate Assessment. They do not represent a full summary of all of the chapters' findings, but rather a synthesis of particularly noteworthy conclusions.

1. Global climate is changing and this is apparent across the United States in a wide range of observations. The global warming of the past 50 years is primarily due to human activities, predominantly the burning of fossil fuels.

Many independent lines of evidence confirm that human activities are affecting climate in unprecedented ways. U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the warmest on record. Because human-induced warming is superimposed on a naturally varying climate, rising temperatures are not evenly distributed across the country or over time.[21] See page 18.

2. Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities.

Changes in extreme weather events are the primary way that most people experience climate change. Human-induced climate change has already increased the number and strength of some of these extreme events. Over the last 50 years, much of the United States has seen an increase in prolonged periods of excessively high temperatures, more heavy downpours, and in some regions, more severe droughts.[22] See page 24.

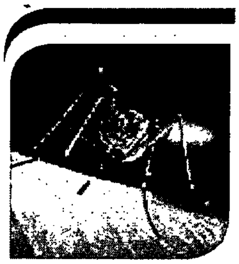


3. Human-induced climate change is projected to continue, and it will accelerate significantly if global emissions of heat-trapping gases continue to increase.

Heat-trapping gases already in the atmosphere have committed us to a hotter future with more climate-related impacts over the next few decades. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases that human activities emit globally, now and in the future.[23] See page 28.

4. Impacts related to climate change are already evident in many sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond.

Climate change is already affecting societies and the natural world. Climate change interacts with other environmental and societal factors in ways that can either moderate or intensify these impacts. The types and magnitudes of impacts vary across the nation and through time. Children, the elderly, the sick, and the poor are especially vulnerable. There is mounting evidence that harm to the nation will increase substantially in the future unless global emissions of heat-trapping gases are greatly reduced.[24] See page 32.



5. Climate change threatens human health and well-being in many ways, including through more extreme weather events and wildfire, decreased air quality, and diseases transmitted by insects, food, and water.

Climate change is increasing the risks of heat stress, respiratory stress from poor air quality, and the spread of waterborne diseases. Extreme weather events often lead to fatalities and a variety of health impacts on vulnerable populations, including impacts on mental health, such as anxiety and post-traumatic stress disorder. Large-scale changes in the environment due to climate change and extreme weather events are increasing the risk of the emergence or reemergence of health threats that are currently uncommon in the United States, such as dengue fever.[25] See page 34.

6. Infrastructure is being damaged by sea level rise, heavy downpours, and extreme heat; damages are projected to increase with continued climate change.

Sea level rise, storm surge, and heavy downpours, in combination with the pattern of continued development in coastal areas, are increasing damage to U.S. infrastructure including roads, buildings, and industrial facilities, and are also increasing risks to ports and coastal military installations. Flooding along rivers, lakes, and in cities following heavy downpours, prolonged rains, and rapid melting of snowpack is exceeding the limits of flood protection infrastructure designed for historical conditions. Extreme heat is damaging transportation infrastructure such as roads, rail lines, and airport runways.[26] See page 38.

7. Water quality and water supply reliability are jeopardized by climate change in a variety of ways that affect ecosystems and livelihoods.

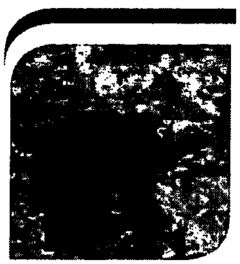
Surface and groundwater supplies in some regions are already stressed by increasing demand for water as well as declining runoff and groundwater recharge. In some regions, particularly the southern part of the country and the Caribbean and Pacific Islands, climate change is increasing the likelihood of water shortages and competition for water among its many uses. Water quality is diminishing in many areas, particularly due to increasing sediment and contaminant concentrations after heavy downpours.[27] See page 42.

8. Climate disruptions to agriculture have been increasing and are projected to become more severe over this century.

Some areas are already experiencing climate-related disruptions, particularly due to extreme weather events. While some U.S. regions and some types of agricultural production will be relatively resilient to climate change over the next 25 years or so, others will increasingly suffer from stresses due to extreme heat, drought, disease, and heavy downpours. From mid-century on, climate change is projected to have more negative impacts on crops and livestock across the country – a trend that could diminish the security of our food supply.[28] See page 46.

9. Climate change poses particular threats to Indigenous Peoples' health, well-being, and ways of life.

Chronic stresses such as extreme poverty are being exacerbated by climate change impacts such as reduced access to traditional foods, decreased water quality, and increasing exposure to health and safety hazards. In parts of Alaska, Louisiana, the Pacific Islands, and other coastal locations, climate change impacts (through erosion and inundation) are so severe that some communities are already relocating from historical homelands to which their traditions and cultural identities are tied. Particularly in Alaska, the rapid pace of temperature rise, ice and snow melt, and permafrost thaw are significantly affecting critical infrastructure and traditional livelihoods.[29] See page 48.

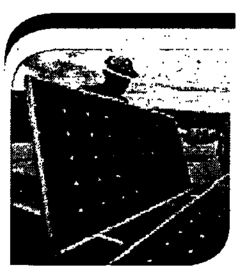


10. Ecosystems and the benefits they provide to society are being affected by climate change. The capacity of ecosystems to buffer the impacts of extreme events like fires, floods, and severe storms is being overwhelmed.

Climate change impacts on biodiversity are already being observed in alteration of the timing of critical biological events such as spring bud burst and substantial range shifts of many species. In the longer term, there is an increased risk of species extinction. These changes have social, cultural, and economic effects. Events such as droughts, floods, wildfires, and pest outbreaks associated with climate change (for example, bark beetles in the West) are already disrupting ecosystems. These changes limit the capacity of ecosystems, such as forests, barrier beaches, and wetlands, to continue to play important roles in reducing the impacts of these extreme events on infrastructure, human communities, and other valued resources.[30] See page 50.

11. Ocean waters are becoming warmer and more acidic, broadly affecting ocean circulation, chemistry, ecosystems, and marine life.

More acidic waters inhibit the formation of shells, skeletons, and coral reefs. Warmer waters harm coral reefs and alter the distribution, abundance, and productivity of many marine species. The rising temperature and changing chemistry of ocean water combine with other stresses, such as overfishing and coastal and marine pollution, to alter marine-based food production and harm fishing communities.[31] See page 58.



12. Planning for adaptation (to address and prepare for impacts) and mitigation (to reduce future climate change, for example by cutting emissions) is becoming more widespread, but current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.

Actions to reduce emissions, increase carbon uptake, adapt to a changing climate, and increase resilience to impacts that are unavoidable can improve public health, economic development, ecosystem protection, and quality of life.[32] See page 62.

REFERENCES

Numbered references for the Overview indicate the chapters that provide supporting evidence for the reported conclusions.

1. Ch. 2.
2. Ch. 2, 3, 6, 9, 20.
3. Ch. 2, 3, 4, 5, 6, 9, 10, 12, 16, 20, 24, 25.
4. Ch. 2, 12, 16, 18, 19, 20, 21, 22, 23.
5. Ch. 2, 4, 12, 16, 17, 18, 19, 20, 22, 25.
6. Ch. 2, 4, 5, 10, 12, 16, 17, 20, 22, 25.
7. Ch. 2, 12, 23, 24, 25.
8. Ch. 2, 12, 13, 14, 18, 19.
9. Ch. 2, 3, 12, 16, 17, 18, 19, 20, 21, 23.
10. Ch. 2, 9, 11, 12, 13, 16, 18, 19, 20, 25.
11. Ch. 3, 6, 8, 12, 14, 23, 24, 25.
12. Ch. 3, 7, 8, 25.
13. Ch. 2, 26, 27.
14. Ch. 26, 27, 28.
15. Ch. 2, 4, 27.
16. Ch. 2, 3, 5, 9, 11, 12, 13, 25, 26, 27, 28.
17. Ch. 3, 7, 9, 10, 12, 18, 20, 21, 26, 28.
18. Ch. 28.
19. Ch. 29, Appendix 6.
20. Ch. 30.
21. Ch. 2, Appendices 3 and 4.
22. Ch. 2, 16, 17, 18, 19, 20, 23, Appendices 3 and 4.
23. Ch. 2, 27, Appendices 3 and 4.
24. Ch. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25.
25. Ch. 2, 6, 9, 11, 12, 16, 19, 20, 22, 23.
26. Ch. 2, 3, 5, 6, 11, 12, 16, 17, 18, 19, 20, 21, 22, 23, 25.
27. Ch. 2, 3, 12, 16, 17, 18, 19, 20, 21, 23.
28. Ch. 2, 6, 12, 13, 14, 18, 19.
29. Ch. 12, 17, 20, 21, 22, 23, 25.
30. Ch. 2, 3, 6, 7, 8, 10, 11, 14, 15, 19, 25.
31. Ch. 2, 12, 23, 24, 25.
32. Ch. 6, 7, 8, 9, 10, 13, 15, 25, 26, 27, 28.

Letter references refer to external sources

a. Kennedy, J. J., P. W. Thorne, T. C. Peterson, R. A. Reudy, P. A. Stott, D. E. Parker, S. A. Good, H. A. Titchner, and K. M. Willett, 2010: How do we know the world has warmed? State of the Climate in 2009. *Bulletin of the American Meteorological Society,* **91,** S26-27, doi:10.1175/BAMS-91-7-StateoftheClimate. [Available online at http://journals.ametsoc.org/doi/abs/10.1175/BAMS-91-7-StateoftheClimate]

b. Huber, M., and R. Knutti, 2012: Anthropogenic and natural warming inferred from changes in Earth's energy balance. *Nature Geoscience,* **5,** 31-36, doi:10.1038/ngeo1327. [Available online at http://www.nature.com/ngeo/journal/v5/n1/pdf/ngeo1327.pdf]

c. Karl, T. R., J. T. Melillo, and T. C. Peterson, Eds., 2009: *Global Climate Change Impacts in the United States.* Cambridge University Press, 189 pp. [Available online at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf]

d. Feely, R. A., S. C. Doney, and S. R. Cooley, 2009: Ocean acidification: Present conditions and future changes in a high-CO_2 world. *Oceanography,* **22,** 36-47, doi:10.5670/oceanog.2009.95. [Available online at http://www.tos.org/oceanography/archive/22-4_feely.pdf]

e. Bednaršek, N., G. A. Tarling, D. C. E. Bakker, S. Fielding, E. M. Jones, H. J. Venables, P. Ward, A. Kuzirian, B. Lézé, R. A. Feely, and E. J. Murphy, 2012: Extensive dissolution of live pteropods in the Southern Ocean. *Nature Geoscience,* **5,** 881-885, doi:10.1038/ngeo1635

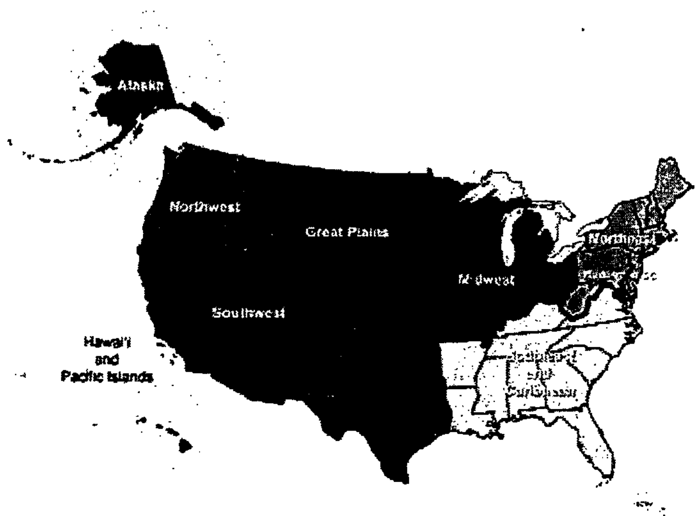
PHOTO CREDITS

pg. 23–Person pumping gas: Charles Minshew/KOMU; People cooling off during heatwave: ©Julie Jacobson/AP/Corbis; Smog over city: ©iStockPhoto.com DanielStein; Child blowing nose: ©Stockbyte/Getty Images

pg. 24–Mosquito: ©James Gathany, CDC; Road washed out due to flooding: ©John Wark/AP/Corbis; Mountain stream: ©Dan Sherwood/Design Pics/Corbis; Farmer with corn: ©iStockPhoto.com/ValentinRussanov

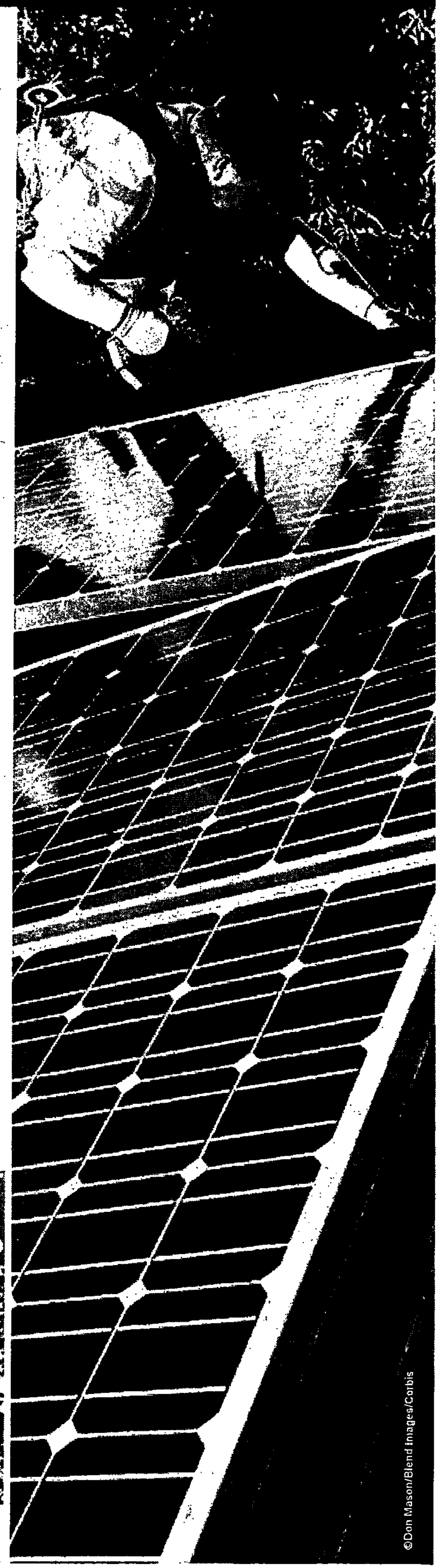
pg. 25–Person building house: ©Aaron Huey/National Geographic Society/Corbis; Bear: ©Chase Swift/Corbis; Manatee: US Fish and Wildlife Service; Person with solar panels: ©Dennis Schroeder, NREL

CONTENTS



Northwest
Great Plains
Southwest
Hawai'i and Pacific Islands

RESPONSE STRATEGIES


©Don Mason/Blend Images/Corbis

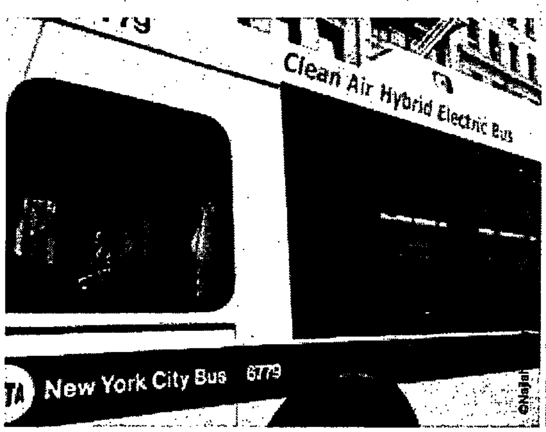
People make choices every day about risks and benefits in their lives, weighing experience, information, and judgment as they consider the impacts of their decisions on themselves and the people around them. Similarly, people make choices that alter the magnitude of impacts resulting from current and future climate change. Using science-based information to anticipate future changes can help society make better decisions about how to reduce risks and protect people, places, and ecosystems from climate change impacts. Decisions made now and in the future will influence society's resilience to impacts of future climate change.

In recognition of the significance of these decisions, the National Climate Assessment presents information that is useful for a wide variety of decisions across regions and sectors, at multiple scales, and over multiple time frames. For the first time, the National Climate Assessment includes chapters on Decision Support, Mitigation, and Adaptation, in addition to identifying research needs associated with these topics.

As with other sections of this report, the linkages across and among these chapters are extremely important. There are direct connections between mitigation decisions (about whether and how to manage emissions of heat-trapping gases) and how much climate will change in the future. The amount of change that occurs will in turn dictate the amount of adaptation that will be required.

In the Decision Support chapter, a variety of approaches to bridge the gap between scientific understanding and decision-making are discussed, leading to the conclusion that there are many opportunities to help scientists understand the needs of decision-makers, and also to help decision-makers use available tools and information to reduce the risks of climate change. The Mitigation chapter describes emissions trajectories and assesses the state of mitigation activities. Policies already enacted and other factors lowered U.S. emissions in recent years, but achievement of a global emissions path consistent with the lower scenario (B1) analyzed in this assessment will require strenuous action by all major emitters. The Adaptation chapter assesses current adaptation activities across the United States in the public and private sectors, and concludes that although a lot of adaptation planning is being done, implementation lags significantly behind the scale of anticipated changes.

This report concludes with chapters on Research Needs to improve future climate and global change assessments and on the Sustained Assessment Process, which describes the rationale for ongoing assessment activity to achieve greater efficiency and better scientific and societal outcomes.



Climate Change Impacts in the United States

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

Recommended Citation for Chapter

Jacoby, H. D., A. C. Janetos, R. Birdsey, J. Buizer, K. Calvin, F. de la Chesnaye, D. Schimel, I. Sue Wing, R. Detchon, J. Edmonds, L. Russell, and J. West, 2014: Ch. 27: Mitigation. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 648-669. doi:10.7930/J0C8276J.

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

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-

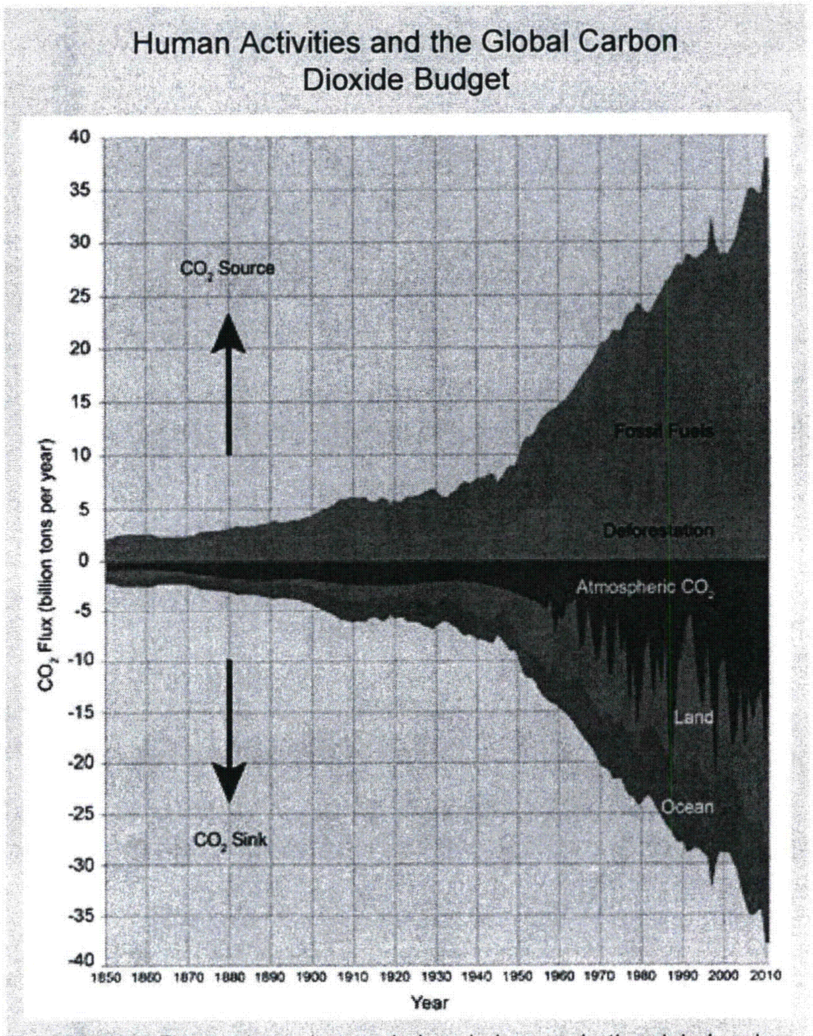


Figure 27.1. Figure shows human-induced changes in the global carbon dioxide budget roughly since the beginning of the Industrial Revolution. Emissions from fossil fuel burning are the dominant cause of the steep rise shown here from 1850 to 2012. (Global Carbon Project 2010, 2012[10]).

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.

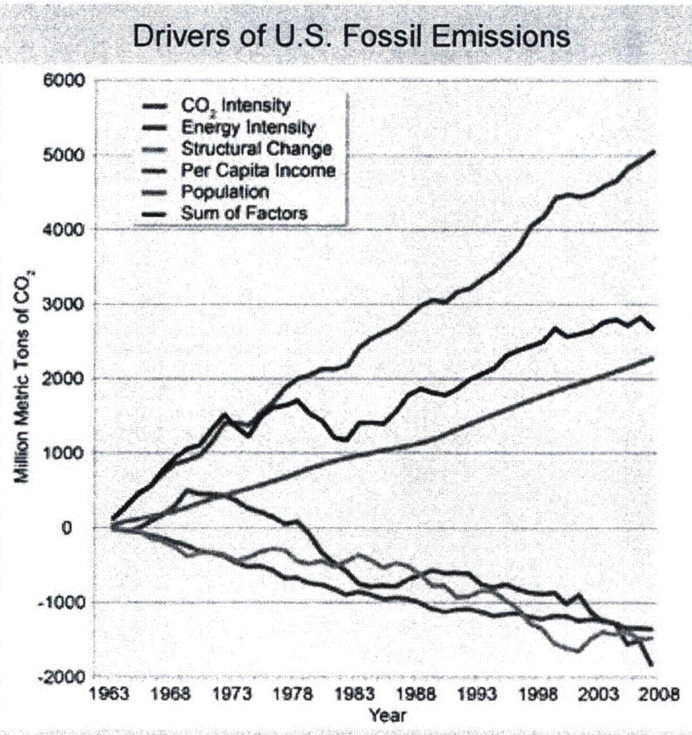


Figure 27.2. This graph depicts the changes in carbon dioxide (CO_2) emissions over time as a function of five driving forces: 1) the amount of CO_2 produced per unit of energy (CO_2 intensity); 2) the amount of energy used per unit of gross domestic product (energy intensity); 3) structural changes 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]).

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.

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]

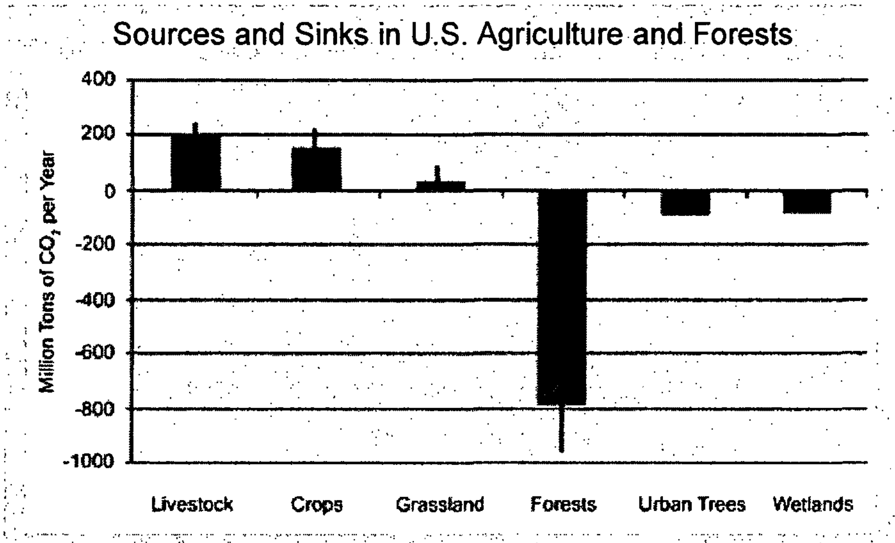


Figure 27.3 Graph shows annual average greenhouse gas emissions from land use including livestock and crop production, but does not include fossil fuels used in agricultural production. Forests are a significant "sink" that absorbs carbon dioxide from the atmosphere. All values shown are for 2008, except 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 bio-energy), 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.

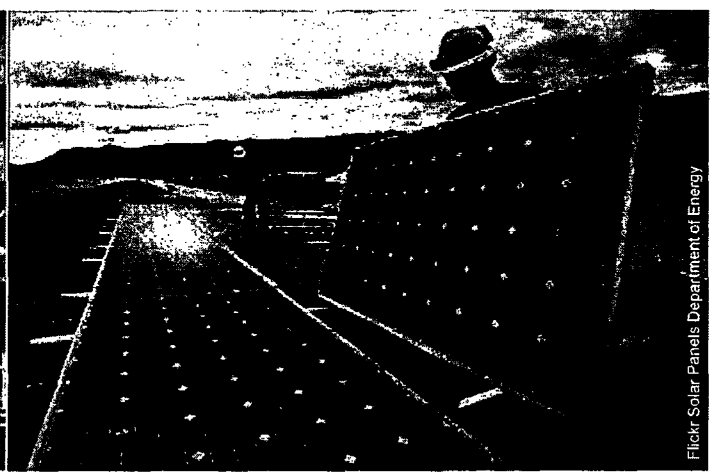
Programs underway that reduce carbon dioxide emissions include the promotion of solar, nuclear, and wind power and efficient vehicles

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

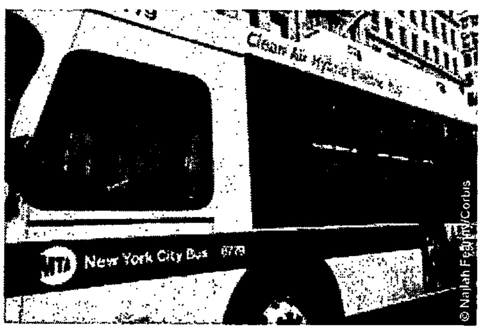
Corporations, individuals, and non-profit organizations have initiated a host of voluntary actions. The following examples give the flavor of the range of efforts:

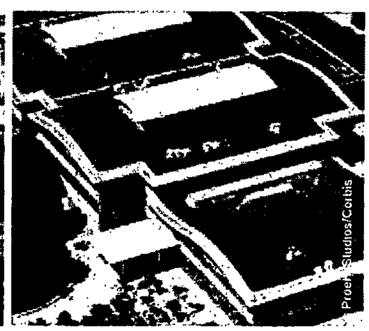
- The Carbon Disclosure Project has the largest global collection of self-reported climate change and water-use information. The system enables companies to measure, disclose, manage, and share climate change and water-use information. Some 650 U.S. signatories include banks, pension funds, asset managers,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

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]

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 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]

References

1. NRC, 2010: Limiting the Magnitude of Future Climate Change. America's Climate Choices. Panel on Limiting the Magnitude of Future Climate Change. National Research Council, Board on Atmospheric Sciences and Climate, Division of Earth and Life Studies. The National Academies Press, 276 pp. [Available online at http://www.nap.edu/catalog.php?record_id=12785]

2. DOE, 2011: Report of the First Quadrennial Technology Review, 168 pp., U.S. Department of Energy, Washington, D.C. [Available online at http://energy.gov/sites/prod/files/QTR_report.pdf]

3. IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds. Cambridge University Press, 996 pp. [Available online at http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm]

4. Plattner, G. K., R. Knutti, F. Joos, T. F. Stocker, W. von Bloh, V. Brovkin, D. Cameron, E. Driesschaert, S. Dutkiewicz, M. Eby, N. R. Edwards, T. Fichefet, J. C. Hargreaves, C. D. Jones, M. F. Loutre, H. D. Matthews, A. Mouchet, S. A. Müller, S. Nawrath, A. Price, A. Sokolov, K. M. Strassmann, and A. J. Weaver, 2008: Long-term climate commitments projected with climate-carbon cycle models. *Journal of Climate*, **21,** 2721-2751, doi:10.1175/2007jcli1905.1. [Available online at http://journals.ametsoc.org/doi/pdf/10.1175/2007JCLI1905.1]

5. Denman, K. L., G. Brasseur, A. Chidthaisong, P. Ciais, P. M. Cox, R. E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. L. da Silva Dias, S. C. Wofsy, and X. Zhang, 2007: Ch. 7: Couplings between changes in the climate system and biogeochemistry. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., Cambridge University Press, 499-587. [Available online at http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter7.pdf]

6. Cicerone, R. J., and R. S. Oremland, 1988: Biogeochemical aspects of atmospheric methane. *Global Biogeochemical Cycles,* **2,** 299-327, doi:10.1029/GB002i004p00299.

7. IPCC, 1995: *The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers and Technical Summary.* Cambridge University Press.

8. Moore, B., III, and B. H. Braswell, 1994: The lifetime of excess atmospheric carbon dioxide. *Global Biogeochemical Cycles,* **8,** 23-38, doi:10.1029/93GB03392.

9. Schimel, D. S., 1995: Terrestrial ecosystems and the carbon cycle. *Global Change Biology,* **1,** 77-91, doi:10.1111/j.1365-2486.1995.tb00008.x.

10. GCP, 2010: Ten Years of Advancing Knowledge on the Global Carbon Cycle and its Management. L. Poruschi, S. Dhakal, and J. Canadel, Eds., Global Carbon Project, Tsukuba, Japan. [Available online at http://www.globalcarbonproject.org/global/pdf/GCP_10years_med_res.pdf]

    ——: Carbon Budget 2012: An Annual Update of the Global Carbon Budget and Trends. Global Carbon Project. [Available online at http://www.globalcarbonproject.org/carbonbudget/]

11. Archer, D., 2010: *The Global Carbon Cycle.* Princeton University Press, 205 pp.

12. Grieshop, A. P., C. C. O. Reynolds, M. Kandlikar, and H. Dowlatabadi, 2009: A black-carbon mitigation wedge. *Nature Geoscience,* **2,** 533-534, doi:10.1038/ngeo595.

13. Moss, R. H., J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. van Vuuren, T. R. Carter, S. Emori, M. Kainuma, T. Kram, G. A. Meehl, J. F. B. Mitchell, N. Nakicenovic, K. Riahi, S. J. Smith, R. J. Stouffer, A. M. Thomson, J. P. Weyant, and T. J. Willbanks, 2010: The next generation of scenarios for climate change research and assessment. *Nature,* **463,** 747-756, doi:10.1038/nature08823.

14. van Vuuren, D. P., J. Cofala, H. E. Eerens, R. Oostenrijk, C. Heyes, Z. Klimont, M. G. J. Den Elzen, and M. Amann, 2006: Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe. *Energy Policy,* **34,** 444-460, doi:10.1016/j.enpol.2004.06.012.

15. Shepherd, J. G., 2009: *Geoengineering the Climate: Science, Governance and Uncertainty.* Royal Society, 82 pp. [Available online at http://eprints.soton.ac.uk/156647/1/Geoengineering_the_climate.pdf]

16. American Physical Society, 2011: Direct Air Capture of CO_2 with Chemicals: A Technology Assessment for the APS Panel on Public Affairs, 100 pp., American Physical Society. [Available online at http://www.aps.org/policy/reports/assessments/upload/dac2011.pdf]

17. Russell, L. M., P. J. Rasch, G. M. Mace, R. B. Jackson, J. Shepherd, P. Liss, M. Leinen, D. Schimel, N. E. Vaughan, A. C. Janetos, P. W. Boyd, R. J. Norby, K. Caldeira, J. Merikanto, P. Artaxo, J. Melillo, and M. G. Morgan, 2012: Ecosystem impacts of geoengineering: A review for developing a science plan. *AMBIO: A Journal of the Human Environment*, **41,** 350-369, doi:10.1007/s13280-012-0258-5. [Available online at http://www.bz.duke.edu/jackson/ambio2012.pdf]

18. Parson, E. A., and D. W. Keith, 2013: End the deadlock on governance of geoengineering research. *Science*, **339,** 1278-1279, doi:10.1126/science.1232527.

19. EIA, 2013: June 2013 Monthly Energy Review. DOE/EIA-0035(2013/06), 201 pp., U.S. Department of Energy, U.S. Energy Information Administration, Washington, D.C. [Available online at http://www.eia.gov/totalenergy/data/monthly/archive/00351306.pdf]

20. EPA, 2013: Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2011. U.S. Environmental Protection Agency, Washington, D.C. [Available online at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf]

21. Baldwin, J. G., and I. Sue Wing, 2013: The spatiotemporal evolution of U.S. carbon dioxide emissions: Stylized facts and implications for climate policy. *Journal of Regional Science*, **in press**, doi:10.1111/jors.12028.

22. EIA, 2013: Annual Energy Outlook 2013 with Projections to 2040. DOE/EIA-0383(2013), 244 pp., U.S. Energy Information Administration, Washington, D.C. [Available online at http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf]

23. UNEP, 2009: *The Montreal Protocol on Substances that Deplete the Ozone Layer.* United Nations Environment Programme Ozone Secretariat, 572 pp. [Available online at http://ozone.unep.org/Publications/MP_Handbook/MP-Handbook-2009.pdf]

24. EPA, 2012: Report to Congress on Black Carbon. EPA-450/R-12-001, 388 pp., U.S. Environmental Protection Agency, Washington, D.C. [Available online at http://www.epa.gov/blackcarbon/2012report/fullreport.pdf]

25. ——, 2010: Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2008, 407 pp., U.S. Environmental Protection Agency, Washington, D.C. [Available online at http://www.epa.gov/climatechange/Downloads/ghgemissions/508_Complete_GHG_1990_2008.pdf]

26. USDA, 2011: U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008. Technical Bulletin No. 1930., 159 pp., U.S. Department of Agriculture, Climate Change Program Office, Office of the Chief Economist, Washington, D.C. [Available online at http://www.usda.gov/oce/climate_change/AFGG_Inventory/USDA_GHG_Inv_1990-2008_June2011.pdf]

27. Pacala, S., R. A. Birdsey, S. D. Bridgham, R. T. Conant, K. Davis, B. Hales, R. A. Houghton, J. C. Jenkins, M. Johnston, G. Marland, and K. Paustian, 2007: Ch. 3: The North American carbon budget past and present. *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle*, A. W. King, L. Dillling, G. P. Zimmerman, D. M. Fairman, R. A. Houghton, G. Marland, A. Z. Rose, and T. J. Wilbanks, Eds., 29-170. [Available online at http://nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_pacala_001.pdf]

28. Birdsey, R., K. Pregitzer, and A. Lucier, 2006: Forest carbon management in the United States: 1600–2100. *Journal of Environmental Quality*, **35,** 1461–1469, doi:10.2134/jeq2005.0162.

29. Masek, J. G., W. B. Cohen, D. Leckie, M. A. Wulder, R. Vargas, B. de Jong, S. Healey, B. Law, R. Birdsey, R. A. Houghton, D. Mildrexler, S. Goward, and W. B. Smit, 2011: Recent rates of forest harvest and conversion in North America. *Journal of Geophysical Research*, **116,** G00K03, doi:10.1029/2010JG001471. [Available online at http://onlinelibrary.wiley.com/doi/10.1029/2010JG001471/pdf]

30. Zheng, D., L. S. Heath, M. J. Ducey, and J. E. Smith, 2011: Carbon changes in conterminous US forests associated with growth and major disturbances: 1992–2001. *Environmental Research Letters*, **6,** 014012, doi:10.1088/1748-9326/6/1/014012.

31. Zhang, F., J. M. Chen, Y. Pan, R. A. Birdsey, S. Shen, W. Ju, and L. He, 2012: Attributing carbon changes in conterminous US forests to disturbance and non-disturbance factors from 1901 to 2010. *Journal of Geophysical Research*, **117,** doi:10.1029/2011JG001930.

32. Richardson, A. D., T. Andy Black, P. Ciais, N. Delbart, M. A. Friedl, N. Gobron, D. Y. Hollinger, W. L. Kutsch, B. Longdoz, S. Luyssaert, M. Migliavacca, L. Montagnani, J. William Munger, E. Moors, S. Piao, C. Rebmann, M. Reichstein, N. Saigusa, E. Tomelleri, R. Vargas, and A. Varlagin, 2010: Influence of spring and autumn phenological transitions on forest ecosystem productivity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **365,** 3227-3246, doi:10.1098/rstb.2010.0102. [Available online at http://rstb.royalsocietypublishing.org/content/365/1555/3227.full.pdf+html]

33. Pan, Y., J. M. Chen, R. Birdsey, K. McCullough, L. He, and F. Deng, 2011: Age structure and disturbance legacy of North American forests. *Biogeosciences*, **8,** 715–732, doi:10.5194/bg-8-715-2011. [Available online at http://www.biogeosciences.net/8/715/2011/bg-8-715-2011.pdf]

Williams, C. A., G. J. Collatz, J. Masek, and S. N. Goward, 2012: Carbon consequences of forest disturbance and recovery across the conterminous United States. *Global Biogeochemical Cycles*, **26**, GB1005, doi:10.1029/2010gb003947.

34. Caspersen, J. P., S. W. Pacala, J. C. Jenkins, G. C. Hurtt, P. R. Moorcroft, and R. A. Birdsey, 2000: Contributions of land-use history to carbon accumulation in U.S. forests. *Science*, **290**, 1148-1151, doi:10.1126/science.290.5494.1148.

Pan, Y., R. Birdsey, J. Hom, and K. McCullough, 2009: Separating effects of changes in atmospheric composition, climate and land-use on carbon sequestration of US Mid-Atlantic temperate forests. *Forest Ecology and Management*, **259**, 151-164, doi:10.1016/j.foreco.2009.09.049. [Available online at http://treesearch.fs.fed.us/pubs/34188]

35. The White House, 2010: Economic Report of the President, Council of Economic Advisors, 462 pp., The White House, Washington, D.C. [Available online at http://www.whitehouse.gov/sites/default/files/microsites/economic-report-president.pdf]

——, 2010: Federal Climate Change Expenditures: Report to Congress. Office of Management and Budget, 34 pp.

——, 2012: A Secure Energy Future: Progress Report. The White House. [Available online at http://www.whitehouse.gov/sites/default/files/email-files/the_blueprint_for_a_secure_energy_future_oneyear_progress_report.pdf]

CCCSTI, 2009: Strategies of the Commercialization and Deployment of Greenhouse Gas Intensity-Reducing Technologies and Practices. DOE/PI-000, 190 pp., The Committee on Climate Change Science and Technology Integration [Available online at http://www.climatetechnology.gov/Strategy-Intensity-Reducing-Technologies.pdf]

GAO, 2011: Climate Change: Improvements Needed to Clarify National Priorities and Better Align Them with Federal Funding Decisions. GAO-11-317, 95 pp., U.S. Government Accountability Office. [Available online at http://www.gao.gov/assets/320/318556.pdf]

36. Massachusetts v. Environmental Protection Agency, 2007: 549 U.S. 497. [Available online at http://www.supremecourt.gov/opinions/06pdf/05-1120.pdf]

37. The White House, cited 2013: The President's Climate Action Plan. The White House. [Available online at http://www.whitehouse.gov/share/climate-action-plan]

38. Krause, R. M., 2011: Symbolic or substantive policy? Measuring the extent of local commitment to climate protection. *Environment and Planning C: Government and Policy*, **29**, 46-62, doi:10.1068/c09185.

Pitt, D. R., 2010: Harnessing community energy: The keys to climate mitigation policy adoption in US municipalities. *Local Environment*, **15**, 717-729, doi:10.1080/13549839.2010.509388.

39. U.S. Mayors Climate Protection Agreement, cited 2012: List of Participating Mayors. U.S. Mayors Climate Protection Center, The U.S. Conference of Mayors. [Available online at http://www.usmayors.org/climateprotection/list.asp]

40. Paltsev, S., J. M. Reilly, H. D. Jacoby, and J. F. Morris, 2009: The cost of climate policy in the United States. *Energy Economics*, **31**, S235-S243, doi:10.1016/j.eneco.2009.06.005.

EIA, 2009: Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009, 82 pp., U.S. Energy Information Administration, Washington, D.C. [Available online at http://www.eia.gov/oiaf/servicerpt/hr2454/pdf/sroiaf%282009%2905.pdf]

41. CBO, 2009: The Costs of Reducing Greenhouse-Gas Emissions, 12 pp., Congressional Budget Office, Washington, D.C. [Available online at http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/104xx/doc10458/11-23-greenhousegasemissions_brief.pdf]

42. Fischer, C., and R. G. Newell, 2008: Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management*, **55**, 142-162, doi:10.1016/j.jeem.2007.11.001.

Karplus, V. J., S. Paltsev, M. Babiker, and J. M. Reilly, 2013: Should a vehicle fuel economy standard be combined with an economy-wide greenhouse gas emissions constraint? Implications for energy and climate policy in the United States. *Energy Economics*, **36**, 322-333, doi:10.1016/j.eneco.2012.09.001.

43. Janetos, A., and A. Wagener, 2002: Understanding the Ancillary Effects of Climate Change Policies: A Research Agenda. World Resources Institute Policy Brief, Washington, D.C. [Available online at http://pdf.wri.org/climate_janetos_ancillary.pdf]

44. Haines, A., K. R. Smith, D. Anderson, P. R. Epstein, A. J. McMichael, I. Roberts, P. Wilkinson, J. Woodcock, and J. Woods, 2007: Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. *The Lancet*, **370**, 1264-1281, doi:10.1016/S0140-6736(07)61257-4.

45. Bell, M., D. Davis, L. Cifuentes, A. Krupnick, R. Morgenstern, and G. Thurston, 2008: Ancillary human health benefits of improved air quality resulting from climate change mitigation. *Environmental Health*, **7**, 1-18, doi:10.1186/1476-069x-7-41.

46. Charlson, R. J., and T. M. L. Wigley, 1994: Sulfate aerosol and climatic change. *Scientific American*, **270**, 48-57.

47. Davis, D. L., 1997: Short-term improvements in public health from global-climate policies on fossil-fuel combustion: An interim report. *The Lancet*, **350,** 1341-1349, doi:10.1016/S0140-6736(97)10209-4.

48. Nemet, G. F., T. Holloway, and P. Meier, 2010: Implications of incorporating air-quality co-benefits into climate change policymaking. *Environmental Research Letters*, **5,** 014007, doi:10.1088/1748-9326/5/1/014007. [Available online at http://iopscience.iop.org/1748-9326/5/1/014007/pdf/1748-9326_5_1_014007.pdf]

49. Burtraw, D., A. Krupnick, K. Palmer, A. Paul, M. Toman, and C. Bloyd, 2003: Ancillary benefits of reduced air pollution in the US from moderate greenhouse gas mitigation policies in the electricity sector. *Journal of Environmental Economics and Management*, **45,** 650-673, doi:10.1016/S0095-0696(02)00022-0.

50. West, J. J., A. M. Fiore, L. W. Horowitz, and D. L. Mauzerall, 2006: Global health benefits of mitigating ozone pollution with methane emission controls. *Proceedings of the National Academy of Sciences*, **103,** 3998-3993, doi:10.1073/pnas.0600201103. [Available online at http://www.pnas.org/content/103/11/3988.full.pdf+html]

51. Shindell, D., J. C. I. Kuylenstierna, E. Vignati, R. van Dingenen, M. Amann, Z. Klimont, S. C. Anenberg, N. Muller, G. Janssens-Maenhout, F. Raes, J. Schwartz, G. Faluvegi, L. Pozzoli, K. Kupiainen, L. Hoglund-Isaksson, L. Emberson, D. Streets, V. Ramanathan, K. Hicks, N. T. K. Oanh, G. Milly, M. Williams, V. Demkine, and D. Fowler, 2012: Simultaneously mitigating near-term climate change and improving human health and food security. *Science*, **335,** 183-189, doi:10.1126/science.1210026.

Wang, X., and K. R. Smith, 1999: Secondary benefits of greenhouse gas control: Health impacts in China. *Environmental Science & Technology*, **33,** 3056-3061, doi:10.1021/es981360d. [Available online at http://pubs.acs.org/doi/abs/10.1021/es981360d]

Ramanathan, V., H. Rodhe, M. Agrawal, H. Akimoto, M. Auffhammer, U. K. Chopra, L. Emberson, S. I. Hasnain, M. Iyngararasan, A. Jayaraman, M. Lawrence, T. Nakajima, M. Ruchirawat, A. K. Singh, J. R. Vincent, and Y. Zhang, 2008: Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia, 367 pp., United Nations Environment Programme, Nairobi, Kenya.

52. van Vuuren, D. P., S. Deetman, M. G. J. den Elzen, A. Hof, M. Isaac, K. Klein Goldewijk, T. Kram, A. Mendoza Beltran, E. Stehfest, and J. van Vliet, 2011: RCP2.6: Exploring the possibility to keep global mean temperature increase below 2° C. *Climatic Change*, **109,** 95-116, doi:10.1007/s10584-011-0152-3. [Available online at http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0152-3.pdf]

53. Thomson, A. M., K. V. Calvin, S. J. Smith, G. P. Kyle, A. Volke, P. Patel, S. Delgado-Arias, B. Bond-Lamberty, M. A. Wise, and L. E. Clarke, 2011: RCP4.5: A pathway for stabilization of radiative forcing by 2100. *Climatic Change*, **109,** 77-94, doi:10.1007/s10584-011-0151-4.

54. Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels, 2007: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations–US Climate Change Science Program Synthesis and Assessment Product 2.1a. Sub-report 2.1A of Synthesis and Assessment Product 2.1, 154 pp., U.S. Department of Energy, Office of Biological & Environmental Research, Washington, D.C. [Available online at http://downloads.globalchange.gov/sap/sap2-1a/sap2-1a-final-all.pdf]

55. Clarke, L., J. Edmonds, V. Krey, R. Richels, S. Rose, and M. Tavoni, 2009: International climate policy architectures: Overview of the EMF 22 International Scenarios. *Energy Economics*, **31,** S64-S81, doi:10.1016/j.eneco.2009.10.013.

56. Clarke, L., A. Fawcett, J. McFarland, J. Weyant, Y. Zhou, and V. Chaturvedi, 2013: Technology and US emissions reductions goals: Results of the EMF 24 modeling exercise. *The Energy Journal*, **In press**.

Fawcett, A., L. Clarke, S. Rausch, and J. Weyant, 2013: Overview of EMF 24 policy scenarios. *The Energy Journal*, **In press**.

Fawcett, A. A., K. V. Calvin, F. C. de la Chesnaye, J. M. Reilly, and J. P. Weyant, 2009: Overview of EMF 22 U.S. transition scenarios. *Energy Economics*, **31, Supplement 2,** S198-S211, doi:10.1016/j.eneco.2009.10.015.

57. NRC, 2010: *Adapting to Impacts of Climate Change. America's Climate Choices: Report of the Panel on Adapting to the Impacts of Climate Change.* National Research Council. The National Academies Press, 292 pp. [Available online at http://www.nap.edu/catalog.php?record_id=12783]

58. OMB, 2012: Fiscal Year 2013 Budget of the U.S. Government, 256 pp., Office of Management and Budget, Washington, D.C. [Available online at http://www.whitehouse.gov/sites/default/files/omb/budget/fy2013/assets/budget.pdf]

59. Edmonds, J. A., T. Wilson, R. Rosenzweig, R. Benedick, E. L. Malone, J. F. Clarke, J. J. Dooley, and S. H. Kim, 2000: Global Energy Technology Strategy: Addressing Climate Change. Initial Findings from an International Public-Private Collaboration. The Global Energy Technology Strategy Program, Washington, D.C. [Available online at http://www.globalchange.umd.edu/data/gtsp/docs/GTSP-indfind.pdf]

Edmonds, J. A., M. A. Wise, J. J. Dooley, S. H. Kim, S. J. Smith, P. J. Runci, L. E. Clarke, E. L. Malone, and G. M. Stokes, 2007: Global Energy Technology Strategy: Addressing Climate Change. Phase 2 Findings from an International Public-Private Sponsored Research Program. The Global Energy Technology Strategy Program, Washington, D.C. [Available online at http://www.globalchange.umd.edu/data/gtsp/docs/gtsp_2007_final.pdf]

60. DOE, 2009: The National Energy Modeling System: An Overview 2009, 83 pp., Energy Information Administration, Office of Integrated Analysis and Forecasting, Washington, D.C. [Available online at http://www.eia.doe.gov/oiaf/aeo/overview/]

Janetos, A. C., L. Clarke, B. Collins, K. Ebi, J. Edmonds, I. Foster, J. Jacoby, K. Judd, R. Leung, and R. Newell, 2009: Science Challenges and Future Directions: Climate Change Integrated Assessment Research. Report PNNL-18417, 80 pp., U.S. Department of Energy, Office of Science. [Available online at http://science.energy.gov/~/media/ber/pdf/ia_workshop_low_res_06_25_09.pdf]

Prinn, R. G., 2013: Development and application of earth system models. *Proceedings of the National Academy of Sciences*, **110,** 3673-3680, doi:10.1073/pnas.1107470109. [Available online at http://www.pnas.org/content/110/suppl.1/3673.full.pdf+html]

61. EIA, 2012: Annual Energy Outlook 2012 with Projections to 2035. DOE/EIA-0383(2012), 239 pp., U.S. Energy Information Administration, Washington, D.C. [Available online at http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf]

62. DeFries, R., and C. Rosenzweig, 2010: Toward a whole-landscape approach for sustainable land use in the tropics. *Proceedings of the National Academy of Sciences*, **107,** 19627-19632, doi:10.1073/pnas.1011163107. [Available online at http://www.pnas.org/content/107/46/19627.full.pdf+html]

Melillo, J. M., J. M. Reilly, D. W. Kicklighter, A. C. Gurgel, T. W. Cronin, S. Paltsev, B. S. Felzer, X. Wang, A. P. Sokolov, and C. A. Schlosser, 2009: Indirect emissions from biofuels: How important? *Science*, **326,** 1397-1399, doi:10.1126/science.1180251. [Available online at http://globalchange.mit.edu/hold/restricted/MITJPSPGC_Reprint09-20.pdf]

Thomson, A. M., K. V. Calvin, L. P. Chini, G. Hurtt, J. A. Edmonds, B. Bond-Lamberty, S. Frolking, M. A. Wise, and A. C. Janetos, 2010: Climate mitigation and the future of tropical landscapes. *Proceedings of the National Academy of Sciences*, **107,** 19633-19638, doi:10.1073/pnas.0910467107. [Available online at http://www.pnas.org/content/107/46/19633.short]

63. Dietz, T., G. T. Gardner, J. Gilligan, P. C. Stern, and M. P. Vandenbergh, 2009: Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences*, **106,** 18452-18456, doi:10.1073/pnas.0908738106. [Available online at http://www.pnas.org/content/106/44/18452.full.pdf+html]

64. Vandenbergh, M. P., P. C. Stern, G. T. Gardner, T. Dietz, and J. M. Gilligan, 2010: Implementing the behavioral wedge: Designing and adopting effective carbon emissions reduction programs. Vanderbilt public law research paper no. 10-26. *Environmental Law Reporter*, **40,** 10547.

65. C2ES, cited 2013: Greenhouse Gas Reporting and Registries. Center for Climate and Energy Solutions. [Available online at http://www.c2es.org/us-states-regions/policy-maps/ghg-reporting]

66. ——, cited 2013: Greenhouse Gas Emissions Targets. Center for Climate and Energy Solutions. [Available online at http://www.c2es.org/us-states-regions/policy-maps/emissions-targets]

67. EDF, 2012: States Have Led the Way in Curbing Carbon Pollution from New Power Plants, 1 pp., Environmental Defense Fund. [Available online at http://www.edf.org/sites/default/files/state-ghg-standards-03132012.pdf]

68. C2ES, cited 2013: Low Carbon Fuel Standard. Center for Climate and Energy Solutions. [Available online at http://www.c2es.org/us-states-regions/policy-maps/low-carbon-fuel-standard]

69. ——, cited 2013: Climate Action Plans. Center for Climate and Energy Solutions. [Available online at http://www.c2es.org/us-states-regions/policy-maps/action-plan]

70. CEPA, cited 2013: Cap-and-Trade Program. California Environmental Protection Agency. [Available online at http://arb.ca.gov/cc/capandtrade/capandtrade.htm]

71. C2ES, cited 2013: Multi-State Climate Initiatives. Center for Climate and Energy Solutions. [Available online at http://www.c2es.org/us-states-regions/regional-climate-initiatives#WCI]

72. EPA, cited 2013: Tribal Climate and Energy Information. U.S. Environmental Protection Agency. [Available online at http://www.epa.gov/statelocalclimate/tribal]

73. DOE, 2013: Database of State Incentives for Renewables & Efficiency. Renewable Portfolio Standard Policies, 1 pp., U.S. Department of Energy. [Available online at http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf]

74. ——, 2013: Database of State Incentives for Renewables & Efficiency. Energy Efficiency Resource Standards., 1 pp., U.S. Department of Energy. [Available online at http://www.dsireusa.org/documents/summarymaps/EERS_map.pdf]

75. ——, 2013: Database of State Incentives for Renewables & Efficiency. Property Tax Incentives for Renewables, 1 pp., U.S. Department of Energy. [Available online at http://www.dsireusa.org/documents/summarymaps/PropertyTax_map.pdf]

76. NRC, 2011: *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia.* National Research Council. The National Academies Press, 298 pp. [Available online at http://www.nap.edu/catalog.php?record_id=12877]

77. van Vuuren, D. P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G. C. Hurtt, T. Kram, V. Krey, and J. F. Lamarque, 2011: The representative concentration pathways: An overview. *Climatic Change*, **109,** 5-31, doi:10.1007/s10584-011-0148-z. [Available online at http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0148-z.pdf]

78. EIA, 2011: International Energy Outlook 2011. U.S. Energy Information Administration, Washington, D.C. [Available online at http://www.eia.gov/forecasts/archive/ieo11/]

79. Metcalf, G. E., 2008: An empirical analysis of energy intensity and its determinants at the state level. *The Energy Journal*, **29,** 1-26, doi:10.5547/ISSN0195-6574-EJ-Vol29-No3-1. [Available online at http://works.bepress.com/cgi/viewcontent.cgi?article=1005&context=gilbert_metcalf]

Sue Wing, I., 2008: Explaining the declining energy intensity of the US economy. *Resource and Energy Economics*, **30,** 21-49, doi:10.1016/j.reseneeco.2007.03.001.

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.

Climate Change Impacts in the United States

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

Recommended Citation for Chapter

Bierbaum, R., A. Lee, J. Smith, M. Blair, L. M. Carter, F. S. Chapin, III, P. Fleming, S. Ruffo, S. McNeeley, M. Stults, L. Verduzco, and E. Seyller, 2014: Ch. 28: Adaptation. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 670-706. doi:10.7930/J07H1GGT.

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

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).

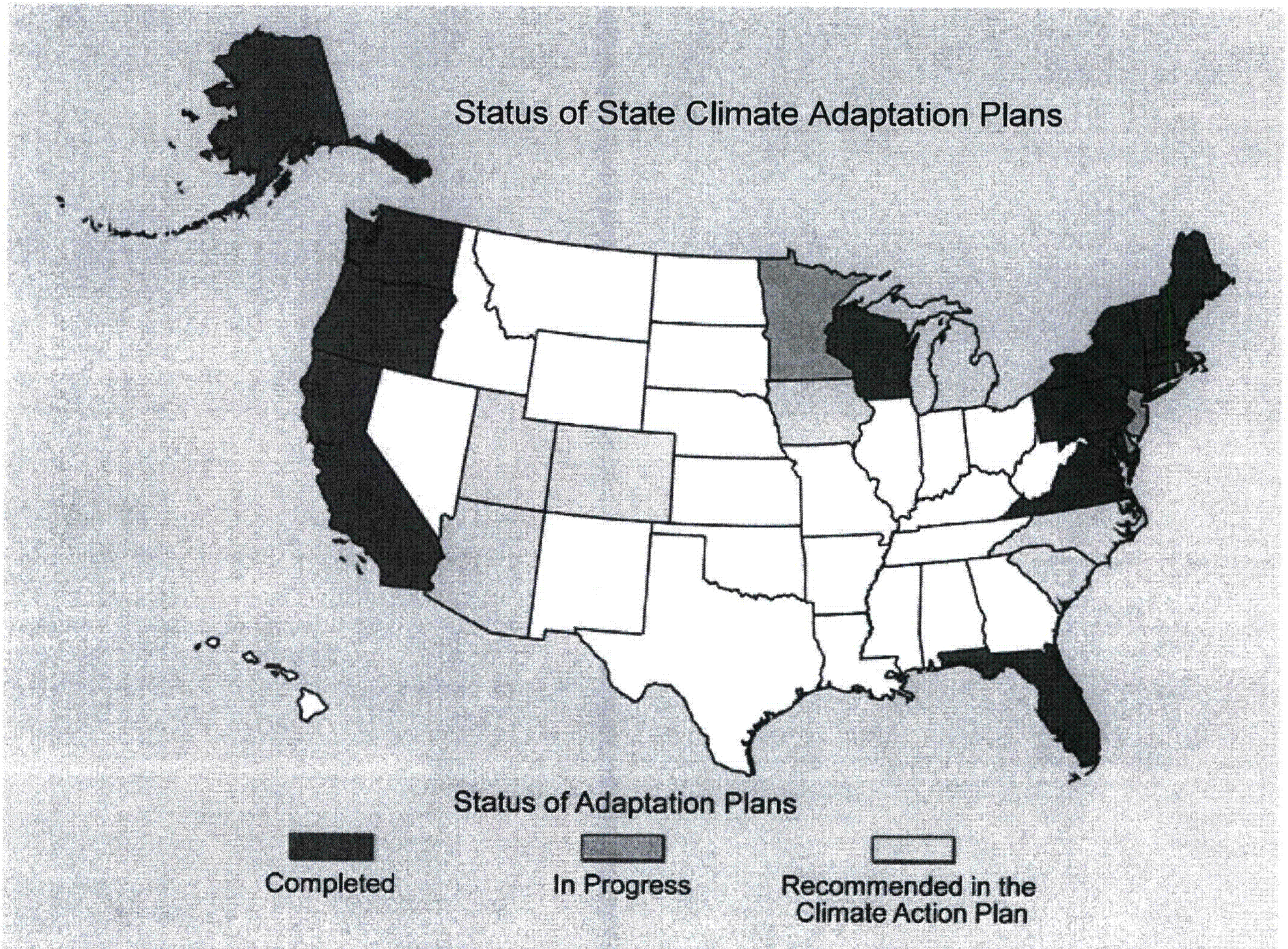


Figure 28.1. Status of State Climate Adaptation Plans. (Figure source: redrawn from C2ES 2013[37]).

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).[51]

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]

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.

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]

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.

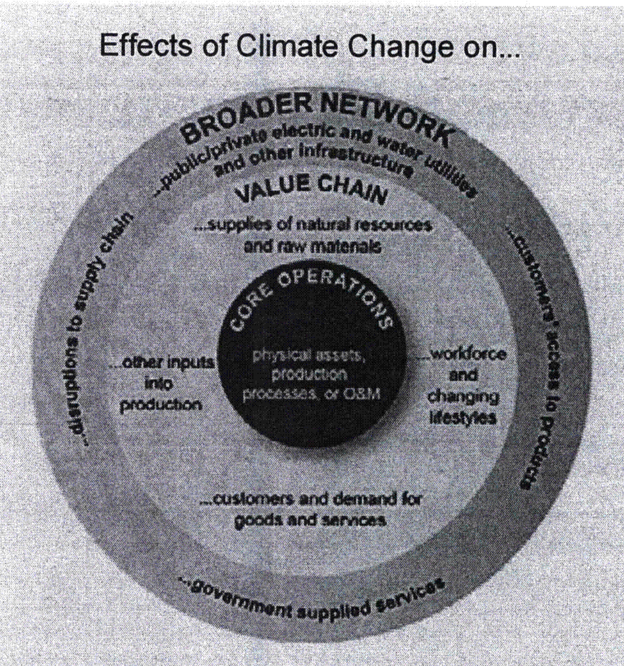


Figure 28.2. "Risk Disk" depicts three pathways by which risks posed by climate change can affect business, such as through core operations, the value chain, and broader changes in the economy and infrastructure. (Figure source: redrawn from C2ES 2008[74]).

Section 1: Adaptation Process

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

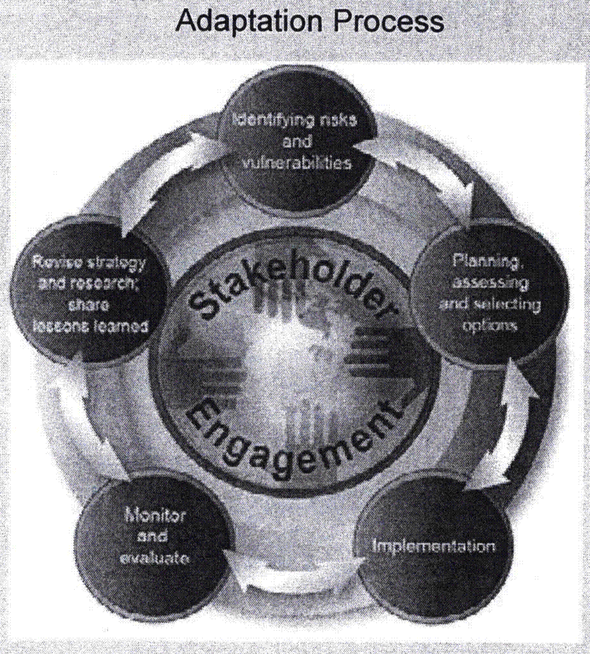


Figure 28.3. Generalized Adaptation Process (Figure source: adapted from NRC 2010[11]).

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

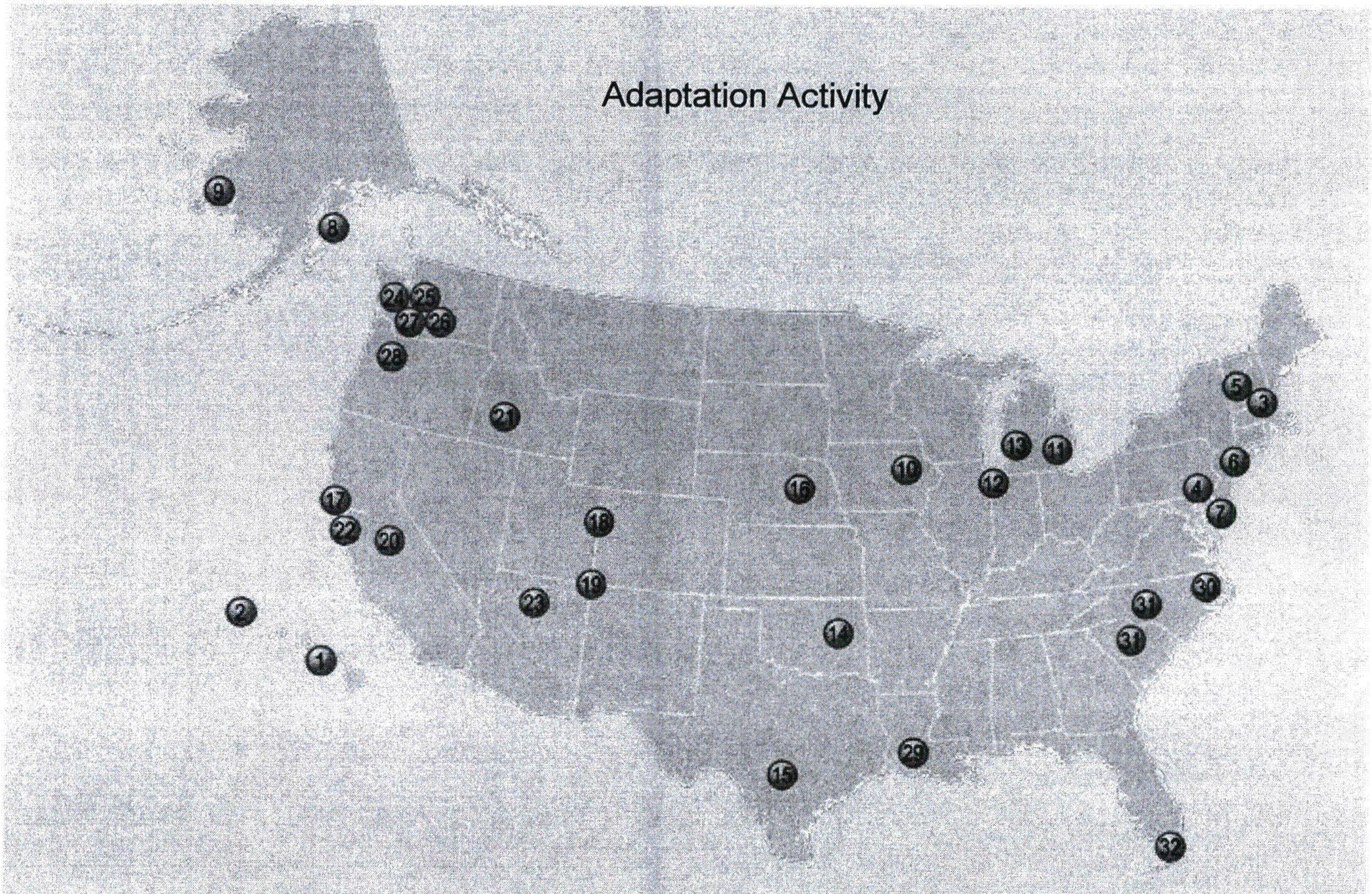
Table 28.6. Summary of Adaptation Barriers

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]

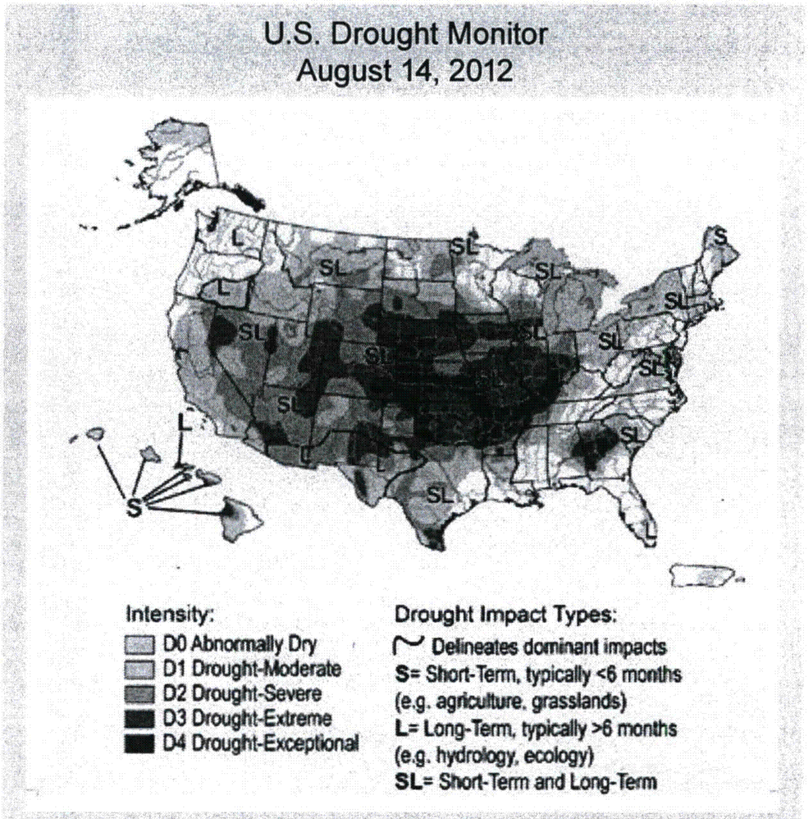


Figure 28.5. U.S. Drought Monitor Map accessed on August 20, 2012. The U.S. Drought Monitor is produced in partnership between the national Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration.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

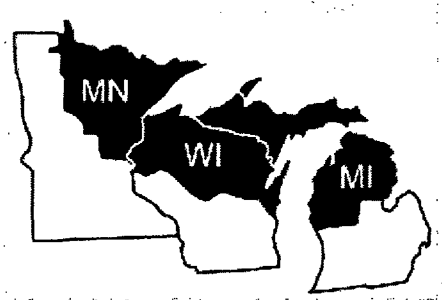


Figure 28.6. Northwoods Climate Change Response Framework Region (Figure Source: USDA Forest Service 2012[159]).

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).

REFERENCES

1. Bierbaum, R. M., D. G. Brown, and J. L. McAlpine, 2008: *Coping with Climate Change: National Summit Proceedings.* University of Michigan Press, 256 pp.

2. SEGCC, 2007: Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable. Report Prepared for the United Nations Commission on Sustainable Development. R. Bierbaum, J. P. Holdren, M. MacCracken, R. H. Moss, P. H. Raven, and H. J. Schellnhuber, Eds., 144 pp., Scientific Expert Group on Climate Change, Sigma Xi and the United Nations Foundation, Research Triangle Park, NC and Washington, D.C. [Available online at http://www.globalproblems-globalsolutions-files.org/unf_website/PDF/climate%20_change_avoid_unmanagable_manage_unavoidable.pdf]

3. McMullen, C. P., and J. R. Jabbour, 2009: *Climate Change Science Compendium 2009.* United Nations Environment Programme.

4. Skaggs, R., T. C. Janetos, K. A. Hibbard, and J. S. Rice, 2012: Climate and Energy-Water-Land System Interactions Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment, 152 pp., Pacific Northwest National Laboratory, Richland, Washington. [Available online at http://climatemodeling.science.energy.gov/f/PNNL-21185_FINAL_REPORT.pdf]

   Wilbanks, T., D. Bilello, D. Schmalzer, and M. Scott, 2012: Climate Change and Energy Supply and Use. Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment, 79 pp., Oak Ridge National Laboratory, U.S. Department of Energy, Office of Science, Oak Ridge, TN. [Available online at http://www.esd.ornl.gov/eess/EnergySupplyUse.pdf]

5. Wilbanks, T., S. Fernandez, G. Backus, P. Garcia, K. Jonietz, P. Kirshen, M. Savonis, B. Solecki, and L. Toole, 2012: Climate Change and Infrastructure, Urban Systems, and Vulnerabilities. Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment, 119 pp., Oak Ridge National Laboratory. U.S Department of Energy, Office of Science, Oak Ridge, TN. [Available online at http://www.esd.ornl.gov/eess/Infrastructure.pdf]

6. Karl, T. R., J. T. Melillo, and T. C. Peterson, Eds., 2009: *Global Climate Change Impacts in the United States.* Cambridge University Press, 189 pp. [Available online at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf]

7. Kareiva, P., C. Enquist, A. Johnson, S. H. Julius, J. Lawler, B. Petersen, L. Pitelka, R. Shaw, and J. M. West, 2008: Ch. 9: Synthesis and conclusions. *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, S. H. Julius, and J. M. West Eds., U.S. Environmental Protection Agency, 9-1 to 9-66. [Available online at http://library.globalchange.gov/products/sap-4-4-preliminary-review-of-adaptation-options-for-climate-sensitive-ecosystems-and-resources]

8. Staudinger, M. D., N. B. Grimm, A. Staudt, S. L. Carter, F. S. Chapin, III, P. Kareiva, M. Ruckelshaus, and B. A. Stein, 2012: Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services. Technical Input to the 2013 National Climate Assessment 296 pp., U.S. Geological Survey, Reston, VA. [Available online at http://downloads.usgcrp.gov/NCA/Activities/Biodiversity-Ecosystems-and-Ecosystem-Services-Technical-Input.pdf]

9. Solecki, W., and C. Rosenzweig, Eds., 2012: *U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues, Technical Input Report Series, U.S. National Climate Assessment.* U.S. Global Change Research Program.

10. Kerr, R. A., 2011: Time to adapt to a warming world, but where's the science? *Science*, **334**, 1052-1053, doi:10.1126/science.334.6059.1052.

11. NRC, 2010: *Adapting to Impacts of Climate Change. America's Climate Choices: Report of the Panel on Adapting to the Impacts of Climate Change.* National Research Council. The National Academies Press, 292 pp. [Available online at http://www.nap.edu/catalog.php?record_id=12783]

12. PCAST, 2011: Report to the President: Sustainability Environmental Capital: Protecting Society and the Economy 145 pp., President's Council of Advisors on Science and Technology, Executive Office of the President, Washington, D.C. [Available online at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_sustaining_environmental_capital_report.pdf]

    Wilby, R. L., and S. Dessai, 2010: Robust adaptation to climate change. *Weather*, **65**, 180-185, doi:10.1002/wea.543.

13. Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, Eds., 2013: *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment.* Island press, 528 pp. [Available online at http://swccar.org/sites/all/themes/files/SW-NCA-color-FINALweb.pdf]

14. Winkler, J., J. Andresen, and J. Hatfield, Eds., 2012: *Midwest Technical Input Report: Prepared for the US National Climate Assessment.* 236 pp.

15. Lamb, H. H., 1982: *Climate, History, and the Modern World.* Methuen.

16. IPCC, 2007: Appendix I: Glossary. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., Cambridge University Press. [Available online at http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-app.pdf]

17. NRC, 2007: *Understanding Multiple Environmental Stresses: Report of a Workshop.* National Research Council. The National Academy Press, 154 pp. [Available online at http://www.nap.edu/catalog.php?record_id=11748]

18. C2ES, 2012: Climate Change Adaptation: What Federal Agencies are Doing, February 2012 Update 71 pp., Center for Climate and Energy Solutions, Arlington, VA. [Available online at http://www.c2es.org/docUploads/federal-agencies-adaptation.pdf]

19. CEQ, 2011: Federal Actions for a Climate Resilient Nation: Progress Report of the Interagency Climate Change Adaptation Task Force, 32 pp., The White House Council on Environmental Quality, Office of Science and Technology Policy, Climate Change Adaptation Task Force, Washington, D.C. [Available online at http://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_adaptation_progress_report.pdf]

20. NRC, 2010: *Informing an Effective Response to Climate Change. America's Climate Choices: Panel on Informing Effective Decisions and Actions Related to Climate Change.* National Research Council, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, National Academies Press, 348 pp. [Available online at http://www.nap.edu/catalog.php?record_id=12784]

21. U.S. Government, 2009: Executive Order 13514. Federal Leadership in Environmental, Energy, and Economic Performance. *Federal Register,* **74,** 52117-52127. [Available online at http://www.whitehouse.gov/assets/documents/2009fedleader_eo_rel.pdf]

22. The White House, cited 2013: The President's Climate Action Plan. The White House. [Available online at http://www.whitehouse.gov/share/climate-action-plan]

23. ——, 2013: Executive Order 13653. Preparing the United States for the Impacts of Climate Change. The White House, Washington, D.C. [Available online at http://www.whitehouse.gov/the-press-office/2013/11/01/executive-order-preparing-united-states-impacts-climate-change]

24. ICATF, 2011: National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate, 76 pp., U.S. Interagency Climate Change Adaptation Task Force,. [Available online at http://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf]

25. National Fish Wildlife and Plants Climate Adaptation Partnership, 2012: National Fish, Wildlife and Plants Climate Adaptation Strategy, 120 pp., Association of Fish and Wildlife agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service., Washington, D.C. [Available online at http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf]

26. NOC, 2013: National Ocean Policy Implementation Plan, 32 pp., National Ocean Council, Washington, D.C. [Available online at http://www.whitehouse.gov//sites/default/files/national_ocean_policy_implementation_plan.pdf]

27. USGCRP, 2012: The National Global Change Research Plan 2012–2021: A Strategic Plan for the U.S. Global Change Research Program. 132 pp., The U.S. Global Change Research Program, Washington, D.C. [Available online at http://downloads.globalchange.gov/strategic-plan/2012/usgcrp-strategic-plan-2012.pdf]

28. NPS, 2010: National Park Service Climate Change Response Strategy, 36 pp., U.S. National Park Service Climate Change Response Program, Fort Collins, Colorado. [Available online at http://www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf]

29. Rosenzweig, C., R. Horton, I. S. Higuchi, and C. Hudson, 2011: NASA's CASI Building climate-resilient NASA centers. *Livebetter Magazine,* December 22, 2011. [Available online at http://livebettermagazine.com/article/nasas-casi-building-climate-resilient-nasa-centers/]

30. Smith, J. B., J. M. Vogel, T. L. Cruce, S. Seidel, and H. A. Holsinger, 2010: Adapting to Climate Change: A Call for Federal Leadership. Pew Center on Global Climate Change, Arlington, VA. [Available online at http://www.c2es.org/docUploads/adaptation-federal-leadership.pdf]

31. National Climate Adaptation Summit Committee, 2010: National Climate Adaptation Summit Report, 26 pp., University Corporation for Atmospheric Research (UCAR), Boulder, CO. [Available online at 15cbac88-03de-4015-aa61-d63a10050686]

32. OTA, 1993: Preparing for an Uncertain Climate. Volume I and II (OTA-O-567; OTA-O-568). U. S. Congress, Ed., 365 pp., Office of Technology Assessment, US Government Printing Office, Washington, D.C. [Available online at www.fas.org/ota/reports/9338.pdf]

33. CEQ, 2010: Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy 72 pp., The White House Council on Environmental Quality (CEQ), Washington, D.C. [Available online at http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf]

34. Goulder, L. H., and R. N. Stavins, 2011: Challenges from state-federal interactions in US climate change policy. *The American Economic Review*, **101,** 253-257, doi:10.1257/aer.101.3.253.

Morsch, A., and R. Bartlett, 2011: Policy Brief: State Strategies to Plan for and Adapt to Climate Change - NI PB 11-08, 11 pp., Nicholas Institute for Environmental Policy Solutions – Duke University, Durham, NC. [Available online at http://nicholasinstitute.duke.edu/sites/default/files/publications/state-strategies-to-plan-for-and-adapt-to-climate-change-paper.pdf]

35. Feldman, I. R., and J. H. Kahan, 2007: Preparing for the day after tomorrow: Frameworks for climate change adaptation. *Sustainable Development Law & Policy*, **8,** 31-39, 87-89. [Available online at http://digitalcommons.wcl.american.edu/cgi/viewcontent.cgi?article=1162&context=sdlp]

36. Moser, S. C., 2009: Good Morning America! The Explosive Awakening of the US to Adaptation, 39 pp., California Energy Commission, NOAA-Coastal Services Center, Sacramento, CA and Charleston, SC. [Available online at http://www.preventionweb.net/files/11374_MoserGoodMorningAmericaAdaptationin.pdf]

37. C2ES, cited 2013: State and Local Climate Adaptation. Center for Climate and Energy Solutions. [Available online at http://www.c2es.org/us-states-regions/policy-maps/adaptation]

38. AFWA, 2011: State Climate Adaptation Summary Report, 90 pp., Association of Fish and Wildlife Agencies, Washington, D.C.

39. Immediate Action Workgroup, 2008: Recommendations Report to the Governor's Subcabinet on Climate Change. Final Report from the Immediate Action Workgroup, April 17, 2008, 86 pp., Immediate Action Workgroup, State of Alaska Juneau, AK. [Available online at http://www.climatechange.alaska.gov/docs/iaw_rpt_17apr08.pdf]

40. EPA, cited 2012: State and Local Climate and Energy Program. U.S. Environmental Protection Agency. [Available online at http://www.epa.gov/statelocalclimate/index.html]

41. Salkin, P. E., 2009: Sustainability and land use planning: Greening. State and local land use plans and regulations to address climate change challenges and preserve resources for future generations. *William and Mary Environmental Law and Policy Review*, **34,** 121-170. [Available online at http://scholarship.law.wm.edu/cgi/viewcontent.cgi?article=1003&context=wmelpr]

42. Keener, V., J. J. Marra, M. L. Finucane, D. Spooner, and M. H. Smith, Eds., 2012: *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA).* Island Press, 170 pp. [Available online at http://www.pacificrisa.org/projects/pirca/]

43. KDFWR, 2010: Action Plan to Respond to Climate Change in Kentucky: A Strategy of Resilience, 37 pp., Kentucky Department of Fish and Wildlife Resources. [Available online at http://fw.ky.gov/kfwis/stwg/2010Update/Climate_Change_Chapter.pdf]

44. State of Louisiana, 2012: Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority, State of Louisiana, Baton Rouge, LA. [Available online at http://www.coastalmasterplan.louisiana.gov/2012-master-plan/final-master-plan/]

45. Grannis, J., 2011: Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use. How Governments Can Use Land-Use Practices to Adapt to Sea-Level Rise, 100 pp., Georgetown Climate Center, Washington, D.C. [Available online at http://www.georgetownclimate.org/sites/default/files/Adaptation_Tool_Kit_SLR.pdf]

46. Feifel, K., 2010: Implementation of Maryland's Climate Action Plan: Case Study on a Project of the Maryland Department of Natural Resources, 2 pp., EcoAdapt, Island Press. [Available online at http://www.cakex.org/printpdf/case-studies/2829]

47. Propst, S. C., cited 2012: Innovative Approaches for Adapting to Water Variability in the West. Georgetown Climate Center. [Available online at http://www.georgetownclimate.org/resources/innovative-approaches-for-adapting-to-water-variability-in-the-west]

48. SCIPP, 2012: Southern Climate Impacts and Planning Program Regional Integrated Sciences and Assessments Program 4th Annual Report: May 1, 2011 - April 30, 2012: Norman, OK and Baton Rouge, LA, 20 pp., Southern Climate Impacts and Planning Program (SCIPP), Oklahoma Climatological Survey, University of Oklahoma and Louisiana State University, and the National Oceanic and Atmospheric Administration. [Available online at http://www.southernclimate.org/publications/SCIPP_2011-2012_Annual_Report.pdf]

49. Brubaker, M., J. Berner, J. Bell, J. Warren, and A. Rolin, 2010: Climate Change in Point Hope, Alaska: Strategies for Community Health: Anchorage, AK, Alaska Native Tribal Health Consortium, 44 pp., Center for Climate and Health. [Available online at http://www.anthc.org/chs/ces/climate/upload/Climate-Change-and-Health-Effects-in-Point-Hope-Alaska.pdf]

50. Bronen, R., 2011: Climate-induced community relocations: Creating an adaptive governance framework based in human rights doctrine. *NYU Review Law & Social Change*, **35**, 357-408. [Available online at http://socialchangenyu.files.wordpress.com/2012/08/climate-induced-migration-bronen-35-2.pdf]

51. Simmonds, J., 2011: Resource for Consideration by the NCA Teams Addressing the Impacts of Climate Change on Native Communities. Native Communities and Climate Change Project of the University of Colorado Law School and the Cooperative Institute for Research in Environmental Science.

52. Lamb, R., and M. V. Davis, 2011: Promoting Generations of Self Reliance: Stories and Examples of Tribal Adaptation to Change, 27 pp., U.S. Environmental Protection Agency Region 10, Seattle, WA. [Available online at http://www.epa.gov/region10/pdf/tribal/stories_and_examples_of_tribal_adaptation_to_change.pdf]

53. Anguelovski, I., and J. Carmin, 2011: Something borrowed, everything new: Innovation and institutionalization in urban climate governance. *Current Opinion in Environmental Sustainability*, **3**, doi:10.1016/J.cosust.2010.12017.

54. Gregg, R. M., L. J. Hansen, K. M. Feifel, J. L. Hitt, J. M. Kershner, A. Score, and J. R. Hoffman, 2011: The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas. A report for the Gordon and Betty Moore Foundation: Bainbridge Island, WA, EcoAdapt., 145 pp. [Available online at http://ecoadapt.org/documents/marine-adaptation-report.pdf]

55. Rabe, B. G., 2009: Second-generation climate policies in the states: Proliferation, diffusion, and regionalization. *Changing Climates in North American Politics: Institutions, Policymaking, and Multilevel Governance*, H. Selin, and S. D. VanDeveer, Eds., MIT Press, 67-86.

Wheeler, S. M., 2008: State and municipal climate change plans: The first generation. *Journal of the American Planning Association*, **74**, 481-496, doi:10.1080/01944360802377973.

56. Tang, Z., S. D. Brody, C. Quinn, L. Chang, and T. Wei, 2010: Moving from agenda to action: Evaluating local climate change action plans. *Journal of Environmental Planning and Management*, **53**, 41-62, doi:10.1080/09640560903399772.

57. Colson, M., K. Heery, and A. Wallis, 2011: A Survey Of Regional Planning For Climate Adaptation, 20 pp., The National Association of Regional Councils, Washington, DC. [Available online at http://narc.org/wp-content/uploads/NOAA_White_Paper-FINAL2.pdf]

58. Dierwechter, Y., 2010: Metropolitan geographies of US climate action: Cities, suburbs, and the local divide in global responsibilities. *Journal of Environmental Policy & Planning*, **12**, 59-82, doi:10.1080/15239081003625960.

Kahn, M. E., 2009: Urban growth and climate change. *Annual Review of Resource Economics*, **1**, 333-350, doi:10.1146/annurev.resource.050708.144249.

Selin, H., and S. D. VanDeveer, 2007: Political science and prediction: What's next for U.S. climate change policy? *Review of Policy Research*, **24**, 1-27, doi:10.1111/j.1541-1338.2007.00265.x. [Available online at http://pubpages.unh.edu/~sdv/US-Climate-Policy.pdf]

59. Carmin, J., N. Nadkarni, and C. Rhie, 2012: Progress and Challenges in Urban Climate Adaptation Planning: Results of a Global Survey, 30 pp., Massachussetts Institute of Technology, ICLEI - Local Governments for Sustainability, Cambridge, MA. [Available online at http://web.mit.edu/jcarmin/www/urbanadapt/Urban%20Adaptation%20Report%20FINAL.pdf]

60. Binder, L. C. W., J. K. Barcelos, D. B. Booth, M. Darzen, M. M. Elsner, R. Fenske, T. F. Graham, A. F. Hamlet, J. Hodges-Howell, J. E. Jackson, C. Karr, P. W. Keys, J. S. Littell, N. Mantua, J. Marlow, D. McKenzie, M. Robinson-Dorn, E. A. Rosenberg, C. O. Stöckle, and J. A. Vano, 2010: Preparing for climate change in Washington State. *Climatic Change*, **102**, 351-376, doi:10.1007/s10584-010-9850-5.

61. EPA, 2010: Climate Change Vulnerability Assessments: A Review of Water Utility Practices. EPA 800-R-10-001, 32 pp., U.S. Environmental Protection Agency, Washington, D.C. [Available online at http://water.epa.gov/scitech/climatechange/upload/Climate-Change-Vulnerability-Assessments-Sept-2010.pdf]

62. City of Lewes, 2011: The City of Lewes Hazard Mitigation and Climate Adaptation Action Plan, 164 pp., Delaware Sea Grant College Program, ICLEI-Local Governments for Sustainability, and University of Delaware Sustainable Coastal Communities Program. [Available online at http://www.deseagrant.org/sites/default/files/attachments/Lewes%20Hazard%20Mitigation%20and%20Climate%20Adaptation%20Action%20Plan.pdf]

63. Stults, M., and J. Pagach, 2011: Preparing for Climate Change in Groton, Connecticut: A Model Process for Communities in the Northeast. U.S. Environmental Protection Agency Climate Ready Estuaries Program and the Long Island Sound Study, Washington, D.C. [Available online at http://www.groton-ct.gov/depts/plandev/docs/Final%20Report_Groton%20Coastal%20Climate%20Change%20ProjectJP.pdf]

64. City of Chicago, 2008: City of Chicago Climate Action Plan: Our City. Our Future, 57 pp. [Available online at http://www.chicagoclimateaction.org/filebin/pdf/finalreport/CCAPREPORTFINALv2.pdf]

65. Wolf, K., 2009: Adapting to climate change: Strategies from King County, Washington. *PAS Memo*, March/April, 11. [Available online at http://www.planning.org/pas/memo/previous.htm]

66. City of New York, 2012: PlaNYC Progress Report 2012. A Greener, Greater New York, 48 pp., New York. [Available online at http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/planyc_progress_report_2012.pdf]

67. SFRCCC, 2012: A Region Responds to a Changing Climate. Southeast Florida Regional Climate Change Compact Counties. Regional Climate Action Plan, 80 pp., South Florida Regional Climate Change Compact Broward, Miami-Dade, Monroe, and Palm Beach Counties, FL. [Available online at http://southeastfloridaclimatecompact.org/pdf/Regional%20Climate%20Action%20Plan%20FINAL%20ADA%20Compliant.pdf]

68. Horton, R., W. Solecki, and C. Rosenzweig, 2012: Climate Change in the Northeast: A Sourcebook. Draft Technical Input Report prepared for the U.S. National Climate Assessment. [Available online at http://downloads.usgcrp.gov/NCA/Activities/nca_ne_full_report_v2.pdf]

69. White-Newsome, J. L., B. N. Sánchez, E. A. Parker, J. T. Dvonch, Z. Zhang, and M. S. O'Neill, 2011: Assessing heat-adaptive behaviors among older, urban-dwelling adults. *Maturitas*, **70,** 85-91, doi:10.1016/j.maturitas.2011.06.015.

70. Agrawal, A., 2008: The Role of Local Institutions in Adaptation to Climate Change. International Forestry Research and Institutions Program (IFRI) Working Paper # W081-3, 47 pp., Natural Resources and Environment, University of Michigan. [Available online at http://www.worldfishcenter.org/sites/default/files/The%20role%20of%20local%20institutions%20in%20adaptation%20to%20climate%20change.pdf]

Guston, D. H., W. Clark, T. Keating, D. Cash, S. Moser, C. Miller, and C. Powers, 2000: Report of the Workshop on Boundary Organizations in Environmental Policy and Science. Belfer Center for Science and International Affairs (BCSIA) Discussion Paper 2000-32. Bloustein School of Planning and Public Policy, Rutgers University, New Brunswick, NJ, Environmental and Occupational Health Sciences Institute at Rutgers University and UMDNJ-RWJMS, Global Environmental Assessment Project, Environment and Natural Resources Program, Kennedy School of Government, Harvard University, 41 pp. [Available online at http://www.hks.harvard.edu/gea/pubs/huru1.pdf]

71. Van Aalst, M. K., T. Cannon, and I. Burton, 2008: Community level adaptation to climate change: The potential role of participatory community risk assessment. *Global Environmental Change*, **18,** 165-179, doi:10.1016/j.gloenvcha.2007.06.002.

72. Vose, J. M., D. L. Peterson, and T. Patel-Weynand, Eds., 2012: *Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector. General Technical Report PNW-GTR-870.* U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 265 pp. [Available online at http://www.usda.gov/oce/climate_change/effects_2012/FS_Climate1114%20opt.pdf]

73. CDP, 2011: CDP S&P 500 Report: Strategic Advantage Through Climate Change Action, 49 pp., Carbon Disclosure Project, New York, NY and London, UK. [Available online at https://www.cdproject.net/CDPResults/CDP-2011-SP500.pdf]

74. C2ES, 2008: Adapting to Climate Change: A Business Approach. F. G. Sussman, and J. R. Freed, Eds., 41 pp., Center for Climate and Energy Solutions (C2ES), Arlington, VA. [Available online at http://www.c2es.org/docUploads/Business-Adaptation.pdf]

75. PWC, 2010: Business Leadership on Climate Change Adaptation: Encouraging Engagement and Action, 36 pp., PricewaterhouseCoopers LLP London, UK. [Available online at http://www.ukmediacentre.pwc.com/imagelibrary/downloadMedia.ashx?MediaDetailsID=1837]

76. WBCSD, 2009: Adaptation: An Issue Brief for Business, 24 pp., World Business Council for Sustainable Development, Geneva, Switzerland and Washington, D.C. [Available online at http://www.preventionweb.net/files/7781_Adaptation1.pdf]

77. Agrawala, S., M. Carraro, N. Kingsmill, E. Lanzi, M. Mullan, and G. Prudent-Richard, 2011: Private sector engagement in adaptation to climate change: Approaches to managing climate risks. *OECD Environment Working Papers*, **39,** doi:10.1787/5kg221jkf1g7-en.

Oxfam America, cited 2012: The New Adaptation Marketplace: Climate Change and Opportunities for Green Economic Growth. Oxfam America. [Available online at http://www.usclimatenetwork.org/resource-database/the-new-adaptation-marketplace.pdf]

78. Dell, J., and P. Pasteris, 2010: Adaptation in the Oil and Gas Industry to Projected Impacts of Climate Change. Society of Petroleum Engineers, 16 pp.

79. Means, E., III, M. Laugier, J. Daw, L. Kaatz, and M. Waage, 2010: Decision Support Planning Methods: Incorporating Climate Change Uncertainties Into Water Planning. Water Utility Climate Alliance White Paper, 113 pp., Water Utility Alliance, San Francisco, CA. [Available online at http://www.wucaonline.org/assets/pdf/pubs_whitepaper_012110.pdf]

80. Glick, P., B. A. Stein, and N. A. Edelson, 2011: *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment.* National Wildlife Federation, 176 pp.

Rowland, E. L., J. E. Davison, and L. J. Graumlich, 2011: Approaches to evaluating climate change impacts on species: A guide to initiating the adaptation planning process. *Environmental Management*, **47,** 322-337, doi:10.1007/s00267-010-9608-x.

West, J. M., S. H. Julius, P. Kareiva, C. Enquist, J. J. Lawler, B. Petersen, A. E. Johnson, and M. R. Shaw, 2009: US natural resources and climate change: Concepts and approaches for management adaptation. *Environmental Management*, **44,** 1001-1021, doi:10.1007/s00267-009-9345-1.

81. Ingram, K., K. Dow, L. Carter, and J. Anderson, Eds., 2013: *Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability.* Island Press, 342 pp. [Available online at http://www.seclimate.org/pdfpubs/2013/SE-NCA-draft8-color.pdf]

82. Lackstrom, K., K. Dow, B. Haywood, A. Brennan, N. Kettle, and A. Brosius, 2012: Engaging Climate-Sensitive Sectors in the Carolinas. Technical Report: CISA-2012-03: Carolinas Integrated Sciences and Assessments, 180 pp., Carolinas Integrated Sciences and Assessments (CISA), University of South Carolina, Columbia, SC. [Available online at http://www.cisa.sc.edu/Pubs_Presentations_Posters/Reports/2012_Lackstrom%20et%20al_Engaging%20Climate-Sensitive%20Sectors%20in%20the%20Carolinas.pdf]

83. Barrett, J., J. Rose, A. Deonarine, A. Clemetson, J. Pagach, M. Parker, and M. Tedesco, 2011: Sentinel Monitoring for Climate Change in the Long Island Sound Estuarine and Coastal Ecosystems of New York and Connecticut, 139 pp., U.S. Environmental Protection Agency, Stamford, CT.

Ford, J. D., E. C. H. Keskitalo, T. Smith, T. Pearce, L. Berrang-Ford, F. Duerden, and B. Smit, 2010: Case study and analogue methodologies in climate change vulnerability research. *Wiley Interdisciplinary Reviews: Climate Change*, **1,** 374-392, doi:10.1002/wcc.48. [Available online at http://onlinelibrary.wiley.com/doi/10.1002/wcc.48/pdf]

Füssel, H. M., 2007: Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, **17,** 155-167, doi:10.1016/j.gloenvcha.2006.05.002.

Heller, N. E., and E. S. Zavaleta, 2009: Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation*, **142,** 14-32, doi:10.1016/j.biocon.2008.10.006.

Hulme, M., and S. Dessai, 2008: Predicting, deciding, learning: Can one evaluate the 'success' of national climate scenarios? *Environmental Research Letters*, **3,** 045013, doi:10.1088/1748-9326/3/4/045013. [Available online at http://iopscience.iop.org/1748-9326/3/4/045013]

Pahl-Wostl, C., P. Jeffrey, N. Isendahl, and M. Brugnach, 2011: Maturing the new water management paradigm: Progressing from aspiration to practice. *Water Resources Management*, **25,** 837-856, doi:10.1007/s11269-010-9729-2. [Available online at http://www.evergladeshub.com/lit/pdf11/Pahl11watResMgmt25-837-56-WatMgmt.pdf]

84. EPA, 2011: Climate Change Vulnerability Assessments: Four Case Studies of Water Utility Practices. U.S. Environmental Protection Agency, Washington, DC. [Available online at http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=233808]

85. Fazey, I., J. G. P. Gamarra, J. Fischer, M. S. Reed, L. C. Stringer, and M. Christie, 2010: Adaptation strategies for reducing vulnerability to future environmental change. *Frontiers in Ecology and the Environment*, **8,** 414-422, doi:10.1890/080215.

Few, R., K. Brown, and E. L. Tompkins, 2007: Public participation and climate change adaptation: Avoiding the illusion of inclusion. *Climate Policy*, **7,** 46-59, doi:10.1080/14693062.2007.9685637.

Smit, B., and J. Wandel, 2006: Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, **16,** 282-292, doi:10.1016/j.gloenvcha.2006.03.008.

86. Preston, B. L., R. M. Westaway, and E. J. Yuen, 2011: Climate adaptation planning in practice: An evaluation of adaptation plans from three developed nations. *Mitigation and Adaptation Strategies for Global Change*, **16,** 407-438, doi:10.1007/s11027-010-9270-x.

87. Brunner, R. D., T. A. Steelman, L. Coe-Juell, C. M. Cromley, C. M. Edwards, and D. W. Tucker, 2005: *Adaptive Governance: Integrating Science, Policy, and Decision Making.* Columbia University Press, 326 pp.

Stern, P. C., H. V. Fineberg, and I. Ebrary, 1996: *Understanding Risk: Informing Decisions in a Democratic Society.* National Academy Press, 250 pp. [Available online at http://www.nap.edu/openbook.php?isbn=030905396X]

The World Bank, 2008: *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disaster.* The World Bank 157 pp.

88. ICLEI, 2012: Sea Level Rise Adaptation Strategy for San Diego Bay. D. Hirschfeld, and B. Holland, Eds., 133 pp., ICLEI-Local Governments for Sustainability USA San Diego, CA. [Available online at http://www.icleiusa.org/static/San_Diego_Bay_SLR_Adaptation_Strategy_Complete.pdf]

Moser, S. C., and J. A. Ekstrom, 2010: A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences*, **107,** 22026-22031, doi:10.1073/pnas.1007887107. [Available online at http://www.pnas.org/content/107/51/22026.full.pdf+html]

Pyke, C., M. Bennett, M. Johnston, R. Najjar, M. Raub, K. Sellner, S. Stiles, and D. Wardrop, 2012: Adapting to Climate Change in the Chesapeake Bay: A STAC workshop to monitor progress in addressing climate change across the Chesapeake Bay. STAC Publication 12-001. Philadelphia, PA, 14 pp. [Available online at http://www.chesapeakebay.net/channel_files/18086/(attachment_vi.b)_adapting_to_climate_change_in_the_chesapeake_bay.pdf]

89. Sutaria, S., A. Kulungara, K. Wyss, and J. Blumenstock, 2012: 3rd National Climate Assessment Feedback Report. Reference Number 2011-0059, 7 pp., Association of State and Territorial Health Officials (ASTHO), Arlington, VA.

90. Burkett, V., and M. Davidson, 2012: *Coastal Impacts, Adaptation and Vulnerabilities: A Technical Input to the 2013 National Climate Assessment.* Island Press, 216 pp.

91. Federspiel, S., 2012: Climate Change Adaptation Planning, Implementation, and Evaluation: Needs, Resources, and Lessons for the 2013 National Climate Assessment, 62 pp., University of Michigan School of Natural Resources and Environment, Ann Arbor, MI.

Hammill, A., and T. Tanner, 2011: Harmonising climate risk management: Adaptation screening and assessment tools for development co-operation. *OECD Environment Working Papers*, **36**, 53, doi:10.1787/5kg706918zvl-en.

92. Wilby, R. L., and K. Vaughan, 2011: Hallmarks of organisations that are adapting to climate change. *Water and Environment Journal*, **25**, 271-281, doi:10.1111/j.1747-6593.2010.00220.x.

93. Groves, D. G., and R. J. Lempert, 2007: A new analytic method for finding policy-relevant scenarios. *Global Environmental Change*, **17**, 73-85, doi:10.1016/j.gloenvcha.2006.11.006.

94. Lempert, R. J., D. G. Groves, S. W. Popper, and S. C. Bankes, 2006: A general, analytic method for generating robust strategies and narrative scenarios. *Management Science*, **52**, 514-528, doi:10.1287/mnsc.1050.0472.

Williams, B. K., and E. D. Brown, 2012: Adaptive Management: The U.S. Department of the Interior Applications Guide 136 pp., U.S. Department of the Interior, Adaptive Management Working Group, Washington, D.C. [Available online at http://www.doi.gov/ppa/upload/DOI-Adaptive-Management-Applications-Guide-WebOptimized.pdf]

95. Moore, S., E. Zavaleta, and R. Shaw, 2012: Decision-Making Under Uncertainty: An Assessment of Adaptation Strategies and Scenario Development for Resource Managers. Publication number: CEC-500-2012-027., California Energy Commission. University of California, Santa Cruz, Sacramento, CA. [Available online at http://www.energy.ca.gov/2012publications/CEC-500-2012-027/CEC-500-2012-027.pdf]

96. Moser, S. C., 2012: Adaptation, mitigation, and their disharmonious discontents: An essay. *Climatic Change*, **111**, 165-175, doi:10.1007/s10584-012-0398-4. [Available online at http://www.susannemoser.com/documents/Moser_essay_accepted_clean_11-1-2011_withTablesFigures.pdf]

97. NRC, 2004: *Adaptive Management for Water Resources Project Planning.* National Research Council, Panel on Adaptive Management for Resource Stewardship. The National Academies Press, 113 pp. [Available online at http://www.nap.edu/catalog.php?record_id=10972]

98. Ford, J. D., L. Berrang-Ford, and J. Paterson, 2011: A systematic review of observed climate change adaptation in developed nations. *Climatic Change*, **106**, 327-336, doi:10.1007/s10584-011-0045-5. [Available online at http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0045-5]

99. Dovers, S. R., and A. A. Hezri, 2010: Institutions and policy processes: The means to the ends of adaptation. *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 212-231, doi:10.1002/wcc.29.

100. Janetos, A. C., R. S. Chen, D. Arndt, M. A. Kenney, D. Abbasi, T. Armstrong, A. Bartuska, M. Blair, J. Buizer, T. Dietz, D. Easterling, J. Kaye, M. Kolian, M. McGeehin, R. O'Connor, R. Pulwarty, S. Running, R. Schmalensee, R. Webb, J. Weltzin, S. Baptista, C. A. F. Enquist, J. Hatfield, M. Hayes, K. B. Jones, C. McNutt, W. Meier, M. D. Schwartz, and M. Svoboda, 2012: National Climate Assessment Indicators: Background, Development, and Examples. A Technical Input to the 2013 National Climate Assessment Report., 59 pp. [Available online at http://downloads.usgcrp.gov/NCA/Activities/NCA-Indicators-Technical-Input-Report-FINAL--3-1-12.pdf]

101. EPA, 2010: Climate Resilience Evaluation and Awareness Tool, 2 pp., U.S. Environmental Protection Agency, Office of Water. [Available online at http://water.epa.gov/infrastructure/watersecurity/climate/upload/epa817f12011.pdf]

——, 2012: National Water program 2012 Strategy: Response to Climate Change, 132 pp., U.S. Environmental Protection Agency. [Available online at http://water.epa.gov/scitech/climatechange/upload/epa_2012_climate_water_strategy_full_report_final.pdf]

102. Parry, M., N. Arnell, P. Berry, D. Dodman, S. Fankhauser, C. Hope, S. Kovats, R. Nicholls, D. Satterthwaite, R. Tiffin, and T. Wheeler, 2009: Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates, 116 pp., International Institute for Environment and Development, London, UK. [Available online at http://pubs.iied.org/pdfs/11501IIED.pdf]

Sussman, F., N. Krishnan, K. Maher, R. Miller, C. Mack, P. Stewart, K. Shouse, and B. Perkins, 2014: Climate change adaptation cost in the US: What do we know? *Climate Policy*, **14,** 242-282, doi:10.1080/14693062.2013.777604.

103. Ruth, M., D. Coelho, and D. Karetnikox, 2007: The US Economic Impacts of Climate Change and the Costs of Inaction. A Review and Assessment by the Center for Integrative Environmental Research (CIER) at the University of Maryland, 52 pp., College Park, MD. [Available online at http://www.cier.umd.edu/climateadaptation/]

104. McCollum, D. W., J. A. Tanaka, J. A. Morgan, J. E. Mitchell, K. A. Maczko, L. Hidinger, W. E. Fox, and C. S. Duke, 2011: Climate Change Effects on Rangelands: Affirming the Need for Monitoring. RMRS Human Dimensions Research Program: Discussion Paper, 27 pp., USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. [Available online at http://gis.fs.fed.us/rm/value/docs/climate_change_effects_rangelands.pdf]

105. Bjerklie, D. M., J. R. Mullaney, J. R. Stone, B. J. Skinner, and M. A. Ramlow, 2012: Preliminary Investigation of the Effects of Sea-Level Rise on Groundwater Levels in New Haven, Connecticut. U.S. Geological Survey Open-File Report 2012-1025, 56 pp., U.S. Department of the Interior and U.S. Geological Survey. [Available online at http://pubs.usgs.gov/of/2012/1025/pdf/ofr2012-1025_report_508.pdf]

106. Ekstrom, J. A., S. C. Moser, and M. Torn, 2011: Barriers to Climate Change Adaptation: A Diagnostic Framework. Final Project Report. Publication Number: CEC-500-2011-004, 94 pp., California Energy Commission, Sacramento, CA. [Available online at http://www.energy.ca.gov/2011publications/CEC-500-2011-004/CEC-500-2011-004.pdf]

107. Bierbaum, R., J. B. Smith, A. Lee, L. Carter, F. S. Chapin, III, P. Fleming, S. Ruffo, S. McNeeley, M. Stults, E. Wasley, and L. Verduzco, 2013 A comprehensive review of climate adaptation in the United States: More than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change*, **18,** 361-406, doi:10.1007/s11027-012-9423-1. [Available online at http://link.springer.com/article/10.1007%2Fs11027-012-9423-1]

108. Adger, W. N., S. Agrawala, M. M. Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit, and K. Takahashi, 2007: Ch. 17: Assessment of adaptation practices, options, constraints and capacity. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, Eds., Cambridge University Press, 717-743.

McIlgorm, A., S. Hanna, G. Knapp, P. Le Floc'H, F. Millerd, and M. Pan, 2010: How will climate change alter fishery governance? Insights from seven international case studies. *Marine Policy*, **34,** 170-177, doi:10.1016/j.marpol.2009.06.004.

109. Barsugli, J. J., J. M. Vogel, L. Kaatz, J. B. Smith, M. Waage, and C. Anderson, 2012: Two faces of uncertainty: Climate science and water utility planning methods. *Journal of Water Resources Planning and Management* **138,** 389-395, doi:10.1061/(ASCE)WR.1943-5452.0000188.

Dilling, L., and M. C. Lemos, 2011: Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change*, **21,** 680-689, doi:10.1016/j.gloenvcha.2010.11.006.

Fowler, H. J., and R. L. Wilby, 2007: Beyond the downscaling comparison study. *International Journal of Climatology*, **27,** 1543-1545, doi:10.1002/joc.1616. [Available online at http://onlinelibrary.wiley.com/doi/10.1002/joc.1616/pdf]

Larsen, L., A. L. Steiner, E. S. Mallen, N. Kahn, S. Kalafatis, M. Ryen, P. Sotherland, and A. B. Tawfik, 2011: Climate downscaling and urban planning implications in three Great Lakes cities. *Journal of the American Planning Association*, **submitted.**

McNie, E. C., 2007: Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environmental Science & Policy*, **10,** 17-38, doi:10.1016/j.envsci.2006.10.004.

Mitchell, J. E., Ed., 2010: *Criteria and Indicators of Sustainable Rangeland Management.* University of Wyoming Extension Publication No. SM-56, 227 pp. [Available online at http://www.sustainablerangeland.org/pdf/SM56.pdf]

Romsdahl, R. J., L. Atkinson, and J. Schultz, 2013: Planning for climate change across the US Great Plains: Concerns and insights from government decision-makers. *Journal of Environmental Studies and Sciences*, **3,** 1-14, doi:10.1007/s13412-012-0078-8.

110. Hauser, R., and J. Jadin, 2012: Rural Communities Workshop Technical Report to the 2013 National Climate Assessment, 38 pp. [Available online at http://downloads.globalchange.gov/nca/technical_inputs/rural-communities-workshop-technical-input.pdf]

Lebow, B., T. Patel-Weynand, T. Loveland, and R. Cantral, 2012: Land Use and Land Cover National Stakeholder Workshop Technical Report. Report prepared for 2013 National Climate Assessment, 73 pp. [Available online at http://downloads.usgcrp.gov/NCA/Activities/final_nca_lulc_workshop_report.pdf]

111. Needham, H. F., L. Carter, and B. D. Keim, 2012: Gulf Coast Climate Needs Assessment Interviews, 20 pp., Southern Climate Impacts Planning Program (SCIPP). [Available online at http://www.southernclimate.org/publications/Gulf_Coast_Assessment_Final.pdf]

112. Schramm, P. J., 2012: National Climate Assessment Health Sector Workshop Report: Northwest Region, 28 pp., Seattle, Washington. [Available online at http://www.joss.ucar.edu/ohhi/nw_nca_health_sector_feb12/Health_and_CC_NW_Report.pdf]

113. Brugger, J., and M. Crimmins, 2011: Weather, Climate, and Rural Arizona: Insights and Assessment Strategies. A Technical Input to the U.S. National Climate Assessment, 80 pp., U.S. Global Climate Research Program, Washington, D.C. [Available online at http://www.climas.arizona.edu/files/climas/project-documents/public/1400/nca-report-final.pdf]

114. GAO, 2009: Alaska Native Villages: Limited Progress Has Been Made on Relocating Villages Threatened By Flooding and Erosion. Government Accountability Office Report GAO-09-551, 53 pp., U.S. Government Accountability Office. [Available online at http://www.gao.gov/new.items/d09551.pdf]

115. Levin, S. A., and W. C. Clark, 2010: Toward a Science of Sustainability: Report from Toward a Science of Sustainability Conference *Toward a Science of Sustainability*, Airlie Center, Warrenton, Virginia Center for International Development Working Papers. [Available online at http://www.nsf.gov/mps/dms/documents/SustainabilityWorkshop2009Report.pdf]

116. NRC, 2009: A Transportation Research Program for Mitigation and Adapting to Climate Change and Conserving Energy. Special Report 299, 136 pp., National Research Council, Committee for Study on Transportation Research Programs to Address Energy and Climate Change, Transportation Research Board of the National Academies, Washington, D.C. [Available online at http://www.nap.edu/catalog.php?record_id=12801]

117. Adger, W. N., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. R. Nelson, L. O. Naess, J. Wolf, and A. Wreford, 2009: Are there social limits to adaptation to climate change? *Climatic Change*, **93,** 335-354, doi:10.1007/s10584-008-9520-z.

McNeeley, S. M., 2012: Examining barriers and opportunities for sustainable adaptation to climate change in Interior Alaska. *Climate Change*, **111,** 835-857, doi:10.1007/s10584-011-0158-x. [Available online at http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0158-x]

118. Carpenter, S. R., and W. A. Brock, 2008: Adaptive capacity and traps. *Ecology and Society*, **13,** 40. [Available online at http://www.ecologyandsociety.org/vol13/iss2/art40/]

Craig, R. K., 2008: Climate change, regulatory fragmentation, and water triage. *FSU College of Law, Public Law Research Paper No. 288.*

Folke, C., 2006: Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, **16,** 253-267, doi:10.1016/j.gloenvcha.2006.04.002. [Available online at http://www.sciencedirect.com/science/article/pii/S0959378006000379]

Jantarasami, L. C., J. J. Lawler, and C. W. Thomas, 2010: Institutional barriers to climate change adaptation in US national parks and forests. *Ecology and Society*, **15,** 33. [Available online at http://www.ecologyandsociety.org/vol15/iss4/art33/]

Lee, K. N., 1993: *Compass and Gyroscope: Integrating Science and Politics for the Environment.* Island Press, 255 pp.

Nelson, D. R., W. N. Adger, and K. Brown, 2007: Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources*, **32,** 395-419, doi:10.1146/annurev.energy.32.051807.090348. [Available online at http://eprints.icrisat.ac.in/4245/1/AnnualReviewofEnvResources_32_395-419_2007.pdf]

119. Moser, S. C., and J. A. Ekstrom, 2012: Identifying and Overcoming Barriers to Climate Change Adaptation in San Francisco Bay: Results from Case Studies. Publication number: CEC-500-2012-034, 186 pp., California Energy Commission, Sacramento, CA. [Available online at http://www.energy.ca.gov/2012publications/CEC-500-2012-034/CEC-500-2012-034.pdf]

120. Ding, D., E. W. Maibach, X. Zhao, C. Roser-Renouf, and A. Leiserowitz, 2011: Support for climate policy and societal action are linked to perceptions about scientific agreement. *Nature Climate Change*, doi:10.1038/nclimate1295.

121. Leiserowitz, A., E. Maibach, C. Roser-Renouf, and N. Smith, 2012: Climate Change in the American Mind: Public Support for Climate & Energy Policies in March 2012. Yale Project on Climate Change Communication., Yale University and George Mason University, New Haven, CT. [Available online at http://environment.yale.edu/climate/files/Policy-Support-March-2012.pdf]

Smith, J. B., J. M. Vogel, and J. E. Cromwell, III, 2009: An architecture for government action on adaptation to climate change. An editorial comment. *Climatic Change*, **95,** 53-61, doi:10.1007/s10584-009-9623-1.

122. Doria, M. F., E. Boyd, E. L. Tompkins, and W. N. Adger, 2009: Using expert elicitation to define successful adaptation to climate change. *Environmental Science & Policy*, **12,** 810-819, doi:10.1016/j.envsci.2009.04.001.

Gifford, R., 2011: The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. *American Psychologist*, **66,** 290-302, doi:10.1037/a0023566.

Kahan, D. M., H. Jenkins-Smith, and D. Braman, 2011: Cultural cognition of scientific consensus. *Journal of Risk Research*, **14**, 147-174, doi:10.1080/13669877.2010.511246.

Leiserowitz, A., 2006: Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Climatic Change*, **77**, 45-72, doi:10.1007/s10584-006-9059-9.

Renn, O., 2011: The social amplification/attenuation of risk framework: Application to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **2**, 154-169, doi:10.1002/wcc.99. [Available online at http://onlinelibrary.wiley.com/doi/10.1002/wcc.99/pdf]

Renn, O., A. Klinke, and M. van Asselt, 2011: Coping with complexity, uncertainty and ambiguity in risk governance: A synthesis. *AMBIO: A Journal of the Human Environment*, **40**, 231-246, doi:10.1007/s13280-010-0134-0.

Verweij, M., M. Douglas, R. Ellis, C. Engel, F. Hendriks, S. Lohmann, S. Ney, S. Rayner, and M. Thompson, 2006: Clumsy solutions for a complex world: The case of climate change. *Public Administration*, **84**, 817-843, doi:10.1111/j.1540-8159.2005.09566.x-i1.

Weber, E. U., and P. C. Stern, 2011: Public understanding of climate change in the United States. *American Psychologist*, **66**, 315-328, doi:10.1037/a0023253.

Kahan, D., D. Braman, P. Slovic, J. Gastil, and G. Cohen, 2007: The Second National Risk and Culture Study: Making Sense of - and Making Progress In - The American Culture War of Fact (October 3, 2007). GWU Legal Studies Research Paper No. 370; Yale Law School, Public Law Working Paper No. 154; GWU Law School Public Law Research Paper No. 370; Harvard Law School Program on Risk Regulation Research Paper No. 08-26, 23 pp. [Available online at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1017189]

123. NOAA, 2010: Adapting to Climate Change: A Planning Guide for State Coastal Managers, 133 pp., NOAA Office of Ocean and Coastal Resource Management, Silver Spring, MD. [Available online at http://coastalmanagement.noaa.gov/climate/docs/adaptationguide.pdf]

124. HDLNR, 2011: The Rain Follows The Forest: A Plan to Replenish Hawaii's Source of Water, 24 pp., Department of Land and Natural Resources, State of Hawai`i. [Available online at http://dlnr.hawaii.gov/rain/files/2014/02/The-Rain-Follows-the-Forest.pdf]

125. EPA, cited 2013: Adaptation Efforts: EPA New England: New England Federal Partners. U.S. Environmental Protection Agency. [Available online at http://www.epa.gov/region1/eco/energy/adaptation-efforts-epanc.html]

126. PWD, cited 2013: Green City, Clean Waters. Philadelphia Water Department. [Available online at http://www.phillywatersheds.org/ltcpu/]

127. City of Keene, 2010: Keene Comprehensive Master Plan. City of Keene, Keene, New Hampshire. [Available online at http://www.ci.keene.nh.us/sites/default/files/CMPprint-final-1027-fullversion_2.pdf]

128. NYCDEP, cited 2013: Green Infrastructure Plan and Annual Reports. New York City Department of Environmental Protection [Available online at http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml]

129. ICLEI, cited 2013: Homer, Alaska's Climate Adaptation Progress Despite Uncertainties. ICLEI. [Available online at http://www.cakex.org/virtual-library/2555]

130. State of Alaska Division of Community and Regional Affairs Planning and Land Management, cited 2012: Newtok Planning Group. State of Alaska. [Available online at http://www.commerce.state.ak.us/dca/planning/npg/Newtok_Planning_Group.htm]

131. Maus, E., 2013: Case Studies in Floodplain Regulation, 14 pp. [Available online at http://www.georgetownclimate.org/sites/default/files/Case%20Studies%20in%20Floodplain%20Regulation%206-3-final.pdf]

132. Cameron, L., M. Stanbury, R. Wahl, and S. Manente, 2011: Michigan Climate and Health Adaptation Plan (MICHAP) 2010 – 2015 Strategic Plan, 14 pp., Division of Environmental Health: Michigan Department of Community Health. [Available online at http://www.michigan.gov/documents/mdch/MDCH_climate_change_strategicPlan_final_1-24-2011__343856_7.pdf]

133. City of Grand Rapids, cited 2013: The Office of Energy and Sustainability. City of Grand Rapids, MI. [Available online at http://grcity.us/enterprise-services/officeofenergyandsustainability/Pages/default.aspx/]

134. City of Tulsa, cited 2013: Rooftop to River. The Tulsa Program. City of Tulsa, OK. [Available online at http://www.smartcommunities.ncat.org/articles/rooftop/program.shtml]

135. TFS, cited 2013: Wildland Urban Interface: Texas Firewise Communities. Texas A&M Forest Sevice. [Available online at http://texasforestservice.tamu.edu/main/article.aspx?id=1602]

136. Carter, L., 2012: personal communication.

137. Gregg, R. M., cited 2013: Estero de Limantour Coastal Watershed Restoration Project [Case Study on a Project of the Point Reyes National Seashore]. Product of EcoAdapt's State of Adaptation Program. [Available online at http://www.cakex.org/case-studies/1083]

138. Sustainable Communities Leadership Academy, cited 2013: Front Range, Intermountain & Desert Southwest Region: A Regional Climate Leadership Academy For The Western Adaptation Alliance. Sustainable Communities Leadership Academy. [Available online at http://sustainablecommunitiesleadershipacademy.org/workshops/regional-western-adaptation-alliance]

139. Navajo Nation Department of Water Resources, 2003: Navajo Nation Drought Contingency Plan, 163 pp., Division of Natural Resources, Department of Water Resources, Water Management Branch, Fort Defiance, AZ, Navajo Nation. [Available online at http://www.frontiernet.net/~nndwr_wmb/PDF/drought/drghtcon_plan2003_final.pdf]

140. English, P., K. Fitzsimmons, S. Hoshiko, T. Kim, H. G. Margolis, T. E. McKone, M. Rotkin-Ellman, G. Solomon, R. Trent, and Z. Ross, 2007: Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies. Report No. 1: Heat-Related Illness and Mortality. California Department of Public Health and the Public Health Institute. [Available online at http://www.ehib.org/papers/Heat_Vulnerability_2007.pdf]

141. SFBCDC: An International Competition for Ideas Responding to Sea Level Rise in San Francisco Bay and Beyond. San Francisco Bay Conservation and Development Commission [Available online at http://www.risingtidescompetition.com/risingtides/Home.html]

142. City of Flagstaff, 2012: City of Flagstaff Resiliency and Preparedness Study, 57 pp., City of Flagstaff Climate and Adaptation Management. [Available online at http://flagstaff.az.gov/index.aspx?nid=1732]

143. USFS, 2011: Adapting to Climate Change at Olympic National Forest and Olympic National Park, 144 pp., U.S. Forest Service, Pacific Northwest Research Station. [Available online at http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf]

144. Wolf, K., 2009: Adapting to Climate Change: Strategies from King County, Washington, 11 pp., American Planning Association. [Available online at http://www.nerrs.noaa.gov/doc/pdf/training/strategies_king_county.pdf]

145. City of Portland, 2009: Climate action plan 2009, 63 pp., City of Portland Bureau of Planning and Sustainability and Multnomah County Sustainability Program, Portland, Oregon. [Available online at http://www.portlandoregon.gov/bps/article/268612]

146. LRAP, cited 2013: Louisiana Resiliency Assistance Program. The Office of Community Development – Disaster Recovery Unit and Lousiana State University Coastal Sustainability Studio. [Available online at http://resiliency.lsu.edu/]

147. The Nature Conservancy, 2011: Alligator River National Wildlife Refuge grows. *North Carolina Afield*, 12 pp., The North Carolina Chapter of The Nature Conservancy. [Available online at http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/northcarolina/afield-spring-2011.pdf]

148. Bloetscher, F., B. Heimlich, and D. E. Meeroff, 2011: Development of an adaptation toolbox to protect southeast Florida water supplies from climate change. *Environmental Reviews*, **19**, 397-417, doi:10.1139/a11-011. [Available online at http://www.nrcresearchpress.com/doi/pdf/10.1139/a11-011]

149. NAST, 2000: Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Report for the US Global Change Research Program, 163 pp., U.S. Global Climate Research Program, National Assessment Synthesis Team, Cambridge, UK. [Available online at http://library.globalchange.gov/downloads/download.php?id=124]

150. IPCC, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* C. B. Field, V. Barros, T.F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P. M. Midgley, Eds. Cambridge University Press, 582 pp. [Available online at http://ipcc-wg2.gov/SREX/images/uploads/SREX-All_FINAL.pdf]

Kates, R. W., W. R. Travis, and T. J. Wilbanks, 2012: Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences*, **109**, 7156-7161, doi:10.1073/pnas.1115521109. [Available online at www.pnas.org/content/109/19/7156.full.pdf+html]

151. McNutt, C. A., M. J. Hayes, L. S. Darby, J. P. Verdin, and R. S. Pulwarty, 2013: Ch. 10: Developing early warning and drought risk reduction strategies. *Drought, Risk Management, and Policy: Decision-Making Under Uncertainty*, L. C. Botterill, and G. C. Cockfield, Eds., CRC Press, 151-170.

152. NOAA, 2012: State of the climate: Drought Annual 2012, December 2012. National Oceanic and Atmospheric Administration. [Available online at http://www.ncdc.noaa.gov/sotc/drought/]

Schwalm, C. R., C. A. Williams, and K. Schaefer, 2012: Hundred-year forecast: Drought. *The New York Times*, August 11, 2012. [Available online at http://www.nytimes.com/2012/08/12/opinion/sunday/extreme-weather-and-drought-are-here-to-stay.html?_r=0]

153. Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov, 2010: Future dryness in the southwest US and the hydrology of the early 21st century drought. *Proceedings of the National Academy of Sciences*, **107,** 21271-21276, doi:10.1073/pnas.0912391107. [Available online at http://www.pnas.org/content/early/2010/12/06/0912391107.full.pdf+html]

Christensen, N., and D. P. Lettenmaier, 2006: A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. *Hydrology and Earth System Sciences*, **3,** 3727-3770, doi:10.5194/hessd-3-3727-2006.

Hidalgo, H. G., T. Das, M. D. Dettinger, D. R. Cayan, D. W. Pierce, T. P. Barnett, G. Bala, A. Mirin, A. W. Wood, C. Bonfils, B. D. Santer, and T. Nozawa, 2009: Detection and attribution of streamflow timing changes to climate change in the western United States. *Journal of Climate*, **22,** 3838-3855, doi:10.1175/2009jcli2470.1. [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2009JCLI2470.1]

Pierce, D. W., T. P. Barnett, H. G. Hidalgo, T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. R. Cayan, A. Mirin, A. W. Wood, and T. Nozawa, 2008: Attribution of declining western US snowpack to human effects. *Journal of Climate*, **21,** 6425-6444, doi:10.1175/2008JCLI2405.1. [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2008JCLI2405.1]

Seager, R., and G. A. Vecchi, 2010: Greenhouse warming and the 21st century hydroclimate of southwestern North America. *Proceedings of the National Academy of Sciences*, **107,** 21277-21282, doi:10.1073/pnas.0910856107. [Available online at http://www.pnas.org/content/107/50/21277.full.pdf]

154. Gray, S. T., J. J. Lukas, and C. A. Woodhouse, 2011: Millennial-length records of streamflow from three major Upper Colorado River tributaries. *JAWRA Journal of the American Water Resources Association*, **47,** 702-712, doi:10.1111/j.1752-1688.2011.00535.x. [Available online at http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2011.00535.x/pdf]

Woodhouse, C. A., S. T. Gray, and D. M. Meko, 2006: Updated streamflow reconstructions for the Upper Colorado River Basin. *Water Resources Research*, **42,** doi:10.1029/2005WR004455.

155. Brown, C., 2010: The end of reliability. *Journal of Water Resources Planning and Management*, **136,** 143-145, doi:10.1061/(ASCE)WR.1943-5452.65.

156. Western Governors' Association, 2006: Water Needs and Strategies for a Sustainable Future 26 pp., Western Governors' Association, Western States Water Council, Denver, CO.

——, 2008: *Water Needs and Strategies for a Sustainable Future: Next Steps.* Western Governors' Association, 37 pp.

——, 2010: Water Needs and Strategies for a Sustainable Future: 2010 Progress Report. Western Governors' Association and Western States Water Council, Denver, CO. [Available online at http://www.westgov.org/wswc/wswc_2010_complete%20-compressed.pdf]

157. USACE, 2009: Western States Watershed Study: Report to the Western States Water Council 42 pp., U.S. Army Corps of Engineers. [Available online at http://www.westgov.org/wswc/wsws%20main%20report_jan09.pdf]

158. Reclamation, 2011: Reclamation Managing Water in the West. SECURE Water Act Section 9503(c) - Reclamation Climate Change and Water 2011. P. Alexander, L. Brekke, G. Davis, S. Gangopadhyay, K. Grantz, C. Hennig, C. Jerla, D. Llewellyn, P. Miller, T. Pruitt, D. Raff, T. Scott, M. Tansey, and T. Turner, Eds., 226 pp., U.S. Department of the Interior, U.S. Bureau of Reclamation, Denver, CO. [Available online at http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf]

——, 2011: Reclamation Managing Water in the West: Interim Report No. 1, Colorado River Basin Water Supply and Demand Study, Status Report. U.S Department of the Interior, Bureau of Reclamation, Denver, CO. [Available online at http://www.usbr.gov/lc/region/programs/crbstudy/Report1/StatusRpt.pdf]

159. USFS, cited 2012: Northern Institute of Applied Climate Science: Climate Change Response Framework. U.S. Department of Agriculture, U.S. Forest Service. [Available online at http://nrs.fs.fed.us/niacs/climate/framework/]

160. Swanston, C. W., M. Janowiak, L. R. Iverson, L. R. Parker, D. J. Mladenoff, L. Brandt, P. Butler, M. St. Pierre, A. M. Prasad, S. Matthews, M. P. Peters, and D. Higgins, 2011: Ecosystem Vulnerability Assessment and Synthesis: A Report From the Climate Change Response Framework Project in Northern Wisconsin. Gen. Tech. Rep. NRS-82, 142 pp., U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. [Available online at http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs82.pdf]

161. Joyce, L. A., G. M. Blate, S. G. McNulty, C. I. Millar, S. Moser, R. P. Neilson, and D. L. Peterson, 2009: Managing for multiple resources under climate change: National forests. *Environmental Management*, **44,** 1022-1032, doi:10.1007/s00267-009-9324-6.

Miles, P. D., 2010: Forest Inventory EVALIDator web-application version 4.01 beta. U.S. Department of Agriculture, Forest Service, Northern Research Station Forest Inventory and Analysis, St. Paul, MN. [Available online at http://fiatools.fs.fed.us/Evalidator4/tmattribute.jsp]

WDNR, 2009: Forest Ownership and Parcelization. Wisconsin Department of Natural Resources, Madison, WI.

162. Swanston, C., and M. Janowiak, Eds., 2012: Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers. General Technical Report NRS-87, 121 pp., U.S. Department of Agriculture, Forest Service, Newtown Square, PA. [Available online at http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs87.pdf]

163. Butler, P., M. Janowiak, L. Brandt, and C. Swanston, 2011: Lessons learned from the Climate Change Response Framework Project in Northern Wisconsin: Newtown Square, PA, USDA Forest Service. 24 pp. [Available online at http://www.nrs.fs.fed.us/niacs/local-resources/docs/LESSONS_LEARNED_from_the_CCRFP.pdf]

Janowiak, M. K., P. R. Butler, C. W. Swanston, L. R. Parker, M. J. St. Pierre, and L. A. Brandt, 2012: Adaptation workbook. *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers. General Technical Report NRS-87*, C. Swanston, and M. Janowiak, Eds., U.S. Department of Agriculture, Forest Service, 35-56. [Available online at http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs87.pdf]

164. DOT, 2011: Interagency Transportation, Land Use, and Climate Change Cape Cod Pilot Project: Cape Cod Commission Action Plan, 22 pp., U.S. Department of Transportation: Federal Highway Administration, John A. Volpe National Transportation Systems Center. [Available online at http://www.volpe.dot.gov/sites/volpe.dot.gov/files/docs/ccc_action_plan.pdf]

165. ——, 2011: Interagency Transportation, Land Use, and Climate Change Cape Cod Pilot Project. One-Pager., 20 pp., U.S. Department of Transportation: Federal Highway Administration, John A. Volpe National Transportation Systems Center, Washington, D.C. [Available online at http://www.volpe.dot.gov/sites/volpe.dot.gov/files/docs/Cape%20Cod%20Pilot%20Project%20One%20Pager_092811.pdf]

166. Commonwealth of Massachusetts, 2004: Massachusetts Climate Protection Plan, 54 pp., Boston, MA.

167. Esri, 2011: Climate Change Scenario Planning for Cape Cod: A Collaborative Exercise in GeoDesign. *ArcNews*. [Available online at http://www.esri.com/news/arcnews/fall11articles/climate-change-scenario-planning-for-cape-cod.html]

168. Lennertz, B., 2011: High-touch/high-tech charrettes. *Planning*, American Planning Association, 26 pp. [Available online at http://www.planning.org/planning/2011/oct/]

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

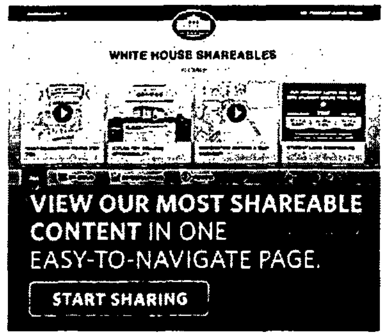
The key message and supporting text summarize extensive evidence documented in the peer-reviewed literature as well as the more than 130 technical inputs received and reviewed as part of the Federal Register Notice solicitation for public input.

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



The White House

Office of the Press Secretary

For Immediate Release June 25, 2013

FACT SHEET: President Obama's Climate Action Plan

President Obama's Plan to Cut Carbon Pollution

Taking Action for Our Kids

We have a moral obligation to leave our children a planet that's not polluted or damaged, and by taking an all- of-the-above approach to develop homegrown energy and steady, responsible steps to cut carbon pollution, we can protect our kids' health and begin to slow the effects of climate change so we leave a cleaner, more stable environment for future generations. Building on efforts underway in states and communities across the country, the President's plan cuts carbon pollution that causes climate change and threatens public health. Today, we have limits in place for arsenic, mercury and lead, but we let power plants release as much carbon pollution as they want – pollution that is contributing to higher rates of asthma attacks and more frequent and severe floods and heat waves.

Cutting carbon pollution will help keep our air and water clean and protect our kids. The President's plan will also spark innovation across a wide variety of energy technologies, resulting in cleaner forms of American- made energy and cutting our dependence on foreign oil. Combined with the President's other actions to increase the efficiency of our cars and household appliances, the President's plan will help American families cut energy waste, lowering their gas and utility bills. In addition, the plan steps up our global efforts to lead on climate change and invests to strengthen our roads, bridges, and shorelines so we can better protect people's homes, businesses, and way of life from severe weather.

While no single step can reverse the effects of climate change, we have a moral obligation to act on behalf of future generations. Climate change represents one of the major challenges of the 21st century, but as a nation of innovators, we can and will meet this challenge in a way that advances our economy, our environment, and public health all at the same time. That is why the President's comprehensive plan takes action to:

Cuts Carbon Pollution in America. In 2012, U.S. carbon pollution from the energy sector fell to the lowest level in two decades even as the economy continued to grow. To build on this progress, the Obama Administration is putting in place tough new rules to cut carbon pollution—just like we have for other toxins like mercury and arsenic —so we protect the health of our children and move our economy toward American-made clean energy sources that will create good jobs and lower home energy bills. For example, the plan:

- Directs EPA to work closely with states, industry and other stakeholder to establish carbon pollution standards for both new and existing power plants;
- Makes up to $8 billion in loan guarantee authority available for a wide array of advanced fossil energy and efficiency projects to support investments in innovative technologies;
- Directs DOI to permit enough renewables project—like wind and solar – on public lands by 2020 to power more than 6 million homes; designates the first-ever hydropower project for priority permitting; and sets a new goal to install 100 megawatts of renewables on federally assisted housing by 2020; while maintaining the commitment to deploy renewables on military installations;
- Expands the President's Better Building Challenge, focusing on helping commercial, industrial, and multi-family buildings cut waste and become at least 20 percent more energy efficient by 2020;
- Sets a goal to reduce carbon pollution by at least 3 billion metric tons cumulatively by 2030 – more than half of the annual carbon pollution from the U.S. energy sector – through efficiency standards set over the course of the Administration for appliances and federal buildings;
- Commits to partnering with industry and stakeholders to develop fuel economy standards for heavy-duty vehicles to save families money at the pump and further reduce reliance on foreign oil and fuel consumption post-2018; and
- Leverages new opportunities to reduce pollution of highly-potent greenhouse gases known as hydrofluorocarbons; directs agencies to develop a comprehensive methane strategy; and commits to protect our forests and critical landscapes.

Prepares the United States for the Impacts of Climate Change. Even as we take new steps to cut carbon pollution, we must also prepare for the impacts of a changing climate that are already being felt across the country. Building on progress over the last four years, the plan:

- Directs agencies to support local climate-resilient investment by removing barriers or counterproductive policies and modernizing programs; and establishes a short-term task force of state, local, and tribal officials to advise on key actions the Federal government can take to help strengthen communities on the ground;
- Pilots innovative strategies in the Hurricane Sandy-affected region to strengthen communities against future extreme weather and other climate impacts; and building on a new, consistent flood risk reduction standard established for the Sandy-affected region, agencies will update flood-risk reduction standards for all federally funded projects;
- Launches an effort to create sustainable and resilient hospitals in the face of climate change through a public -private partnership with the healthcare industry;
- Maintains agricultural productivity by delivering tailored, science-based knowledge to farmers, ranchers, and landowners; and helps communities prepare for drought and wildfire by launching a National Drought Resilience Partnership and by expanding and prioritizing forest- and rangeland- restoration efforts to make areas less vulnerable to catastrophic fire; and
- Provides climate preparedness tools and information needed by state, local, and private-sector leaders through a centralized "toolkit" and a new Climate Data Initiative.

Lead International Efforts to Address Global Climate Change. Just as no country is immune from the impacts of climate change, no country can meet this challenge alone. That is why it is imperative for the United States to couple action at home with leadership internationally. America must help forge a truly global solution to this global challenge by galvanizing international action to significantly reduce emissions, prepare for climate impacts, and drive progress through the international negotiations. For example, the plan:

- Commits to expand major new and existing international initiatives, including bilateral initiatives with China, India, and other major emitting countries;
- Leads global sector public financing towards cleaner energy by calling for the end of U.S. government support for public financing of new coal-fired powers plants overseas, except for the most efficient coal technology available in the world's poorest countries, or facilities deploying carbon capture and sequestration technologies; and
- Strengthens global resilience to climate change by expanding government and local community planning and response capacities.

Download the Full PDF Report
View the Infographic