Adapting to a Warmer World: Understanding What the Future Might Hold and U.S. Options for Responding

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Over the past few years, the focus on the climate change issue has finally shifted from the question "Is it changing?" to the important questions of "So what?" and "Can society manage the unavoidable changes?"

The recent release of a series of reports from the U.S. National Academies,[1] the U.S. Global Change Research Program,[2] the Intergovernmental Panel on Climate Change (IPCC),[3] the United Nations,[4] and the World Bank[5] underscore the recognition that humans are changing the climate rapidly and that the world must act collectively to damp the unsustainable trajectory of greenhouse gas emissions.

"Adaptation" is no longer a forbidden word. For too long, talking about adaptation or "coping with climate change" implied that no serious mitigation or emissions reductions were being contemplated. However, the accumulation of scientific evidence in the last few years makes it abundantly clear that climate changes are underway, impacts are already being felt, and humanity faces more in the future. Thus, the world needs to respond to ongoing changes now and prepare for those yet to come. Both mitigation and adaptation are needed. A sensible strategy to minimize the damages from anthropogenic climate change must work in parallel to mitigate the pace and ultimate magnitude of the changes that occur and to adapt to the changes that cannot be avoided.

A "mitigation only" strategy won't work because it is already too late to avoid substantial climate change. An "adaptation only" strategy won't work because most adaptation measures become more costly and less effective as the magnitude of the changes to which one is trying to adapt gets larger.

The study of adaptation is nascent compared to the many analyses of costs and technologies to reduce emissions. Congress presciently commissioned its first and only comprehensive report on adaptation to climate change in 1991 via the Congressional Office of Technology Assessment (OTA).[6] The report called for actions to reduce institutional and geographic fragmentation, improve communication of risk, and enhance contingency planning to prepare for extreme events, as well as a research program to fill vast gaps in the understanding of vulnerability and resilience. It suggested ways that existing legislation and regulations could incorporate concerns about climate change to increase the resilience of ecological and economic systems. Little such activity has occurred to date.

More recently, two National Summits on Adaptation were convened, in 2007 and 2009.[7] These conversations have served as input to an ongoing interagency climate change adaptation task force that is assessing what the federal government is doing to adapt to climate change and to develop recommendations for additional actions to support a national adaptation strategy.[8] Summit participants representing industry, academia, environmental groups, and policymakers from city, state, regional, national, and international levels met and discussed the problems climate change would pose. As well, they discussed options to enhance the ability of our social and ecological systems to withstand current and future changes. They highlighted, as OTA had two decades earlier, that it will require fundamental changes in planning, management, institutional arrangements, technologies, and research and development strategies.

Some key conclusions include:

1) ***"Past is not prologue:"*** Infrastructure and natural resource management and planning based on the last 100 years of climate will be wrong. The design features of infrastructure and tolerances of species will be exceeded as climate change proceeds. Society needs to prepare for the climate of the future, not the past.

2) ***Degrees of warming matter:*** Both the rate of climate change and the magnitude pose problems for ecological and social systems. Aggressive mitigation can lessen the impacts of climate change and increase the time to develop solutions.

3) ***"Average" change may not be most important:*** There will also be changes in extreme events such as droughts, floods, maximum temperatures, and hurricane intensities. These cause tremendous human pain and economic loss, and they are not handled well now.

4) ***A portfolio approach is needed:*** Both mitigation and adaptation measures need to be developed and implemented in concert. There are interrelationships between options that can reduce emissions and those that enhance adaptive capacity.

5) ***Adaptive management will be needed:*** "Best practices" to cope with climate change need to be shared now. But they may need to be refined and evaluated regularly since the detailed impacts superimposed on other environmental stresses are not yet fully understood. Different regions will have different needs.

6) ***Investment is not commensurate with the urgency of the problem:*** The research, development, demonstration, and deployment funding for both mitigation and adaptation research is inadequate.[9] More integrative science assessments should be conducted with a focus on understanding regional impacts and multiple stresses, resulting in a strategic prioritization of research needed by policymakers.

What changes are underway?

Human activities have changed the climate of the earth, with significant impacts on ecosystems and human society; and the pace of change is increasing. The global average surface temperature is now about 1.4°F above its level in 1750, with most of the increase having occurred in the 20th century and the most rapid rise occurring since 1970. It was just announced that 2010 has tied for warmest year of the instrumental record (Figure 1).

Temperature changes over the continents have been greater than the global average, and the changes over the continents at high latitudes have been greater still. The year-round average air temperature of the U.S. has already risen by more than 2°F over the past 50 years. Temperatures in Alaska have increased by approximately twice as much as in the rest of the nation, with significant impacts on sea ice, ecosystems, and coastal communities.[11] The pattern of the observed changes matches closely what climate science predicts from the buildup in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases (GHGs), taking into account other known influences on the temperature. The largest of all of the human and natural influences on climate over the past 250 years has been the increase in the atmospheric CO_2 concentration resulting from deforestation and fossil fuel burning. The CO_2 emissions in recent decades, which have been responsible for the largest part of this buildup, have come 75% to 85% from fossil fuels (largely in the industrialized countries) and 15% to 25% from deforestation and other land-cover change (largely from developing countries in the tropics).

More than half of the increase in temperature since pre-industrial times has occurred since 1970. The warmer temperatures are amplifying the water cycle of the planet, leading to great evaporation and greater precipitation worldwide; both droughts and intense rainfalls are increasing. There are fewer light rains and more heavy rains in every region of the U.S. The largest percentage increases in the heaviest downpours have taken place in the Northeast (67%) and Midwest (30%) (Figure 2).

Heat waves, ice melt, shifting ranges of plants and animals, sea level rise, droughts, floods and wildfires are increasing, as expected. The ocean is acidifying, making it hard for shell-forming creatures, key to the food chain, to live. Mountain glaciers are melting all over the world. The rate of sea-level rise has increased over this century and the phenomenal melting of the Greenland ice cap—a new record set in 2010[12]—and West Antarctica exceed model expectations, leading scientists to question whether meters, not feet, of sea-level rise are possible in this century. Weather-related disasters are climbing and by 2040 their costs could reach $1 trillion a year.[13] Changes have been documented on every continent. Some 20,000 data sets confirm that species are shifting towards the poles at six kilometers per decade, or altitudinally upwards at six meters per decade.[14] And more changes are in store. Perhaps 20 to 30% of the world's species could be facing extinction over this century. Crop yields in both temperate and tropical zones are expected to decline, but the poorest countries of the world will suffer the most. Tens of millions of environmental refugees could be homeless as rising seas claim their homelands and beachfront properties. While the World Health Organization attributes 150,000 deaths to climate change already, that number is projected to double by 2030.[15] There will likely be increases in waterborne diseases, in vector borne diseases, and heat stress. Worldwide, an additional two billion people could be without enough clean water.

Even if emissions were completely halted today, the total temperature increase from greenhouse gases already in the atmosphere would approximate another 1°F globally. To avoid the risk of crossing tipping points that could lead to intolerable impacts on humans, many experts are calling for a world agreement to prevent global average temperatures from exceeding 4-5°F above pre-industrial levels.[16] To put the matter in perspective, an increase of 10°F equals the difference between the height of the last Ice Age and the present warm period. Current predictions indicate global temperatures could average 6 to12°F above pre-industrial temperatures by 2100. Governments must begin the task of managing the changes that are already occurring and preparing for those yet to come.

What does climate change mean for the United States?

Congressional mandate[17] has helped characterize U.S. vulnerability to climate change by requiring periodic assessments of the likely impacts of climate change; two National Assessments[18] were completed in 2000 and 2008. More than 1,000 stakeholders participated in the workshops, analyses and review of each of these reports. From these documents, it is clear that the impacts of climate change are already manifest in the United States.

One of the press stories that really brought this fact home was the announcement that the U.S. plant hardiness zones have changed since 1990[19] (Figure 3). Michigan's growing zones today are more like Kentucky's of 1990. Twenty-eight states' trees and flowers won't live in them by the end of the century. Dogwoods are now flourishing in Nebraska. It raises the question of "What constitutes a native plant in a region?" The effort to plant and preserve native species has become much more complicated.

Maples are migrating north to Canada, affecting U.S. fall foliage and maple syrup production. The character of particular regions will change as the temperatures increase (Figure 4). Massachusetts is expected to feel more like South Carolina in the coming decades. Parts of Texas could endure more than four months of temperatures over 100°F.

Recent results suggest changes may not be gradual but that there may be physiological or ecological "tipping points." In the southwest of the United States, droughts that were not abnormal in intensity coupled with slightly warmer temperatures could lead to massive tree die-off.[20] The drought and intense heat stressed the trees; bark beetles delivered the final blow. For example, in Colorado alone, nearly two million acres of forests were killed by beetles. Similar situations occurred on 23 million acres in British Columbia and on 10 million acres of black spruce in Alaska.

Infrastructure built to withstand the historic 100-year floods are proving insufficient to handle changing hydrological regimes in many places, including California.[21] Water managers everywhere are declaring: "Stationarity is dead"![22] The attached **Box 1** describes particular concerns for the energy sector. As well, there may be tipping points in societal responses and institutions. The inability to evacuate Louisiana in the face of Hurricane Katrina was an example of failed preparedness and retreat strategies.

This changing world poses huge challenges for wise governance of natural resources at all scales, and climate change is not occurring in isolation. Increasingly, adaptation measures must be designed to be robust to the suite of environmental stresses of which climate change is one. There are interactions of climate change with air and water pollution, with invasive species, biodiversity loss, and habitat fragmentation. These connections must be recognized before strategies to cope with only one problem are designed. Species cannot keep pace with the climate map shifting over them if cities and roads are in the way. Perhaps migration corridors and greenways can be designed to facilitate movement, but fundamental research questions remain about corridor efficacy and optimal shape and size. Some coastal wetlands will certainly be inundated as sea level rises; and, therefore, the goal of preserving wetland habitat should incorporate that concern in the calculus as lands are prioritized.

In the Midwest, about 60% of wetlands and prairie potholes have already been lost. Given that enhanced evaporation and drying conditions will be expected more frequently as climate changes, perhaps preserving the deepest ones first, those that are likely to persist, would be a good strategy. In Florida, the Everglades are being replumbed at great expense to restore more natural water flows, yet a third of the Everglades will likely be inundated as sea level rises. Solutions should integrate the desire to improve ecosystem services, maintain water flow, and protect species in the face of climate change and other ancillary stresses. Options that are robust to the suite of concomitant environmental problems must be designed, or adaptation will be inefficient or worse, ineffective.

Another example of the intersection of multiple stresses is that the northeast region of the U.S. may not be able to achieve the ozone standards as temperatures increase and exacerbate smog formation.[23] Different strategies may be required to achieve health-based air quality standards in the future as climate changes.

Carbon dioxide enhances plant growth, if other necessary nutrients are not limiting, but it also enhances the allergenic compounds in the noxious weeds of poison ivy and ragweed.[24] There are "devils in the details" yet being discovered about the impacts of climate change and the interactions with other issues. For the most part, these details only heighten concerns rather than increase confidence. Climate change must be addressed together with other multiple stresses.[25]

The Way Forward

Adaptation is currently constrained by *lack of available technology/decision support tools, by institutional barriers and by limited information.*

In the first category, *technology/decision support tools,* it is clear that water intake pipes, combined sewer overflows, levee levels, transmission lines, reservoirs, and power plant design and management will all potentially need to be altered as climate changes. Additionally, rules for managing Great Lakes levels, reservoir levels, and dam dredging times will need revision; surveillance for disease outbreaks and extreme events such as floods, droughts, and heat waves will need to be heightened; and new tools to characterize 'break-points" in management and infrastructure must be increasingly developed and shared. The nation is currently developing a "Climate Services" capacity[26] which should incorporate information that can guide these decisions.

Current best practices for disaster preparedness, response to floods and hurricanes, heat stress management, and drought planning could easily be assembled and shared across regions to help define "Climate Resilient Communities." It may be possible to create 'buddy systems,' that is, to link cities, watersheds, and ecological zones with similar problems to jointly find solutions. A national clearing house for such "best practices" is needed, and existing networks could be networked. Building blocks could include the existing Agricultural Extension services, the Sea Grant Programs, and the Regional Integrated Science Assessments (RISAs) of the Department of Commerce.

The second category, *institutional barriers,* is also ripe for attention. Climate change will not only affect natural ecosystems and infrastructure. It will also stress existing social, institutional and legal arrangements. Disruption of settled expectations and arrangements will have real and significant costs, tangible and intangible. As stream water flows change due to a changing hydrological cycle, Total Maximum Daily Loads (TMDLs), a key component of the Clean Water Act that depends on flow, will need to be recalculated. Building codes (and landscaping provisions) will need to be updated not only for energy efficiency, but also to protect against disease vectors, reduce susceptibility to heat stress, and improve protection against extreme events. There are national and international jurisdictional issues of replumbing the Great Lakes to mitigate reduced lake levels, or to manage the Columbia River to adapt to declining snowpack, or to manage the Colorado River to deal with drought. Both "bottom up" community planning and "top down" response strategies will be needed to help regions deal with increases in brownout, heat stress, floods, and wildfires. Increasingly, national, state, and local operational agencies will need to incorporate climate risks and adaptation planning into their programs.

The mix of necessary changes to adapt zoning laws and building codes to climate change varies greatly around the U.S., depending on a region's vulnerability. The authority to undertake needed changes varies among levels of government. For example, land-use planning generally occurs at the local government level. Yet the need to identify needed changes at the appropriate scale and move forward to implement them is nationwide. The challenge is to assure, by mandate if necessary, that existing institutions, agencies, and networks identify the likely threats posed by climate change and move forward with an appropriate transparent and collaborative process to develop and implement effective adaptation plans and measures. Only the federal government can assure this occurs systematically and thoughtfully and with adequate provision of relevant information and needed resources.

In the third category, *limited information,* it is clear that there is still a need for basic and applied research—e.g., very little is known about managing the resources of an acidifying ocean. Similarly, regional scale analyses of impacts need to be conducted and refined. No one lives in the "global average temperature" and climate change impacts will play out in concert with existing regional conditions; thus, bringing back the regional assessments conducted in 1997-2000 by the federal government would be a good start and should be part of the new National Assessment that is just beginning.[27] Stakeholders must be included from the outset, to define the key questions to be answered and to identify feasible options for coping with climate change that address regionally-specific needs. Regional vulnerability mapping, and regional 'listening fora' will be key to determine which impacts are of greatest concern for different regions in order to develop effective response strategies. As well, a short- and long-term research agenda must be developed that will provide answers to decision makers in a timely fashion; the U.S. Global Change Research Program is currently designing its next 10-year strategic plan, also mandated by Congress.[28] Not all good research can be done at once, but an integrated federal research program geared to help planning and management decisions now, while also insuring needed new information will be available in future years, is needed.

None of this will happen without an increased emphasis on adaptation at all levels of government. As the 2010 Progress Report of the Interagency Climate Change Adaptation Task Force[29] concludes:

"The Government should consider how Federal policies may lead to unintended consequences that increase the Nation's vulnerability to climate risks, thus making adaptation more costly and difficult. For example, certain policies may lead to increased development in the very areas that climate risks would suggest people avoid.

The Federal Government also has an important stake in adaptation because climate change directly affects a wide range of Federal services, operations, programs, assets (e.g., infrastructure, land), and our national security. The Government must exercise a leadership role to address climate impacts on Federal infrastructure interests and on natural, cultural, and historic resources that it has statutory responsibilities to protect. The Federal Government should identify its most significant adaptation risks and opportunities and incorporate response strategies into its planning to ensure that Federal resources are invested wisely and that its services and operations remain effective in the context of a changing climate."

Adaptation options may involve innovative land-use planning to avoid invasive species or preserve biodiversity or facilitate migration or help wetlands persist. Options may require new technologies and management criteria to cope with changing water supply, demand, timing, and quality so that both humans and ecosystems have needed water. Early warning systems and monitoring and surveillance techniques will be key to preparing communities for impending disasters. Adaptation will involve emergency response plans for coping with droughts, floods, hurricanes, and heat stress. Increasingly, changes will be needed in existing institutional structures, incentives and disincentive systems, and insurance policies to encourage more sustainable practices.

In conclusion, national and international action on adaptation to climate change is overdue and desperately needed to protect people and resources in the coming decades.

Endnotes

Coping with Climate Change: National Summit Proceedings (R. Bierbaum, D. Brown, J. McAlpine [eds.]), University of Michigan/Island Press (2010), 256 p., ISBN: 9781597265560.

Global Climate Change Impacts in the United States (Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, [eds.]). Cambridge University Press (2009). 196 pp.

National Research Council (2010), *Advancing the Science of Climate Change, America's Climate Choices,* a 4-volume set: Panel on Advancing the Science of Climate Change; Panel on Limiting the Magnitude of Climate Change; Panel on Adapting to the Impacts of Climate Change; and Panel on Informing an Effective Response to Climate Change, National Research Council/National Academy of Sciences, (http://americasclimatechoices.org/).

The White House Council of Environmental Quality Interim Report (October 2010). *Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy.* (http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf).

Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations, National Research Council (2011). *Climate Stabilization Targets: "Emissions, Concentrations, and Impacts Over Decades to Millennia,"* (http://dels.nas.edu/Report/Climate-Stabilization-Targets-Emissions-Concentrations/12877).

The World Bank (2010). *World Development Report 2010: Development and Climate Change,* The International Bank for Reconstruction and Development/The World Bank, Washington, DC, 430 pp. (http://www.worldbank.org/wdr2010).

United Nations Scientific Expert Group on Climate Change (2010). *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable* (Rosina M. Bierbaum, John P. Holdren, Michael C. MacCracken, Richard H. Moss, and Peter H. Raven [eds.]). Report prepared for the United Nations Commission on Sustainable Development. Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, DC, 144 pp. (http://www.globalproblems-globalsolutions-files.org/unf_website/PDF/climate%20_change_avoid_unmanagable_manage_unavoidable.pdf

References

1 National Research Council (2010). *Advancing the Science of Climate Change: America's Climate Choices,* a 4-volume set: Panel on Advancing the Science of Climate Change; Panel on Limiting the Magnitude of Climate Change; Panel on Adapting to the Impacts of Climate Change; and Panel on Informing an Effective Response to Climate Change, National Research Council/National Academy of Sciences, http://americasclimatechoices.org/. Also, Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations, National Research Council (2011). *Climate Stabilization Targets: Emissions, Concentrations, and Impacts Over Decades to Millennia,* (http://dels.nas.edu/Report/Climate-Stabilization-Targets-Emissions-Concentrations/12877).

2 *Global Climate Change Impacts in the United States* (Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, [eds.]). Cambridge University Press (2009). 196 pp. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

3 Intergovernmental Panel on Climate Change (2007). *Climate Change 2007,* Cambridge, U.K., and New York: Cambridge University Press, http://www.ipcc.ch/.

4 United Nations Scientific Expert Group on Climate Change (2007). *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable* (Rosina M. Bierbaum, John P. Holdren, Michael C. MacCracken, Richard H. Moss, and Peter H. Raven [eds.]). Report prepared for the United Nations Commission on Sustainable Development. Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, DC, 144 pp. http://www.globalproblems-globalsolutions-files.org/unf_website/PDF/climate%20_change_avoid_unmanagable_manage_unavoidable.pdf .

5 The World Bank (2010). *World Development Report 2010: Development and Climate Change,* The International Bank for Reconstruction and Development/The World Bank, Washington, DC. 430 pp. http://www.worldbank.org/wdr2010.

6 I had the honor of directing this report. Three full Committees of the Congress requested a study on U.S. adaptation potential in 1991: The Senate Committee on Environment and Public Works; the Senate Committee on Commerce, Science and Transportation; and the House Committee on Science, Space and Technology. U.S. Congress, Office of Technology Assessment

(October 1993). *Preparing for an Uncertain Climate–Volume I, Volume II, OTA-O-567,* Washington, DC: U.S. Government Printing Office. http://www.gcrio.org/library/1993/otareport/index.htm and http://wwwe.Committ.gcrio.org/library/1993/otareport/ota2.htm.

7 *Coping with Climate Change:* National Summit Proceedings (R. Bierbaum, D. Brown, J. McAlpine [eds.]), University of Michigan/Island Press (2008), 256 p., ISBN: 9781597265560, and National Climate Adaptation Summit Committee (2010). *National Climate Adaptation Summit,* http://www.joss.ucar.edu/events/2010/ncas/ncas_report.pdf.

8 The interim report can be found at: The White House Council of Environmental Quality (October, 2010), *Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy,* http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf,. The Task Force is co-chaired by the Council on Environmental Quality (CEQ), the National Oceanic and Atmospheric Administration (NOAA), and the Office of Science and Technology Policy (OSTP).

9 The U.S. Global Change Research Program budget is currently $2.6 billion, but most of the money has been historically spent on the physical climate system and modeling. A recent National Research Council (NRC) report (*Restructuring Federal Climate Research to Meet the Challenges of Climate Change,* Committee on Strategic Advice on the U.S. Climate Change Science Program; National Research Council [2009]) concludes that understanding and predicting physical climate change is progressing well but that the national program is failing on several fronts. Observational capabilities are being lost, both from satellite instruments and from in situ measurements such as from stream gages. The NRC also notes that there has been little progress in assessing impacts on human well-being and vulnerabilities, in providing knowledge to support decision making and risk analyses, and in communicating results and engaging stakeholders in a two-way dialogue. The total spent for human dimensions funding, calculated at $30 million, was deemed "inadequate." Similarly, mitigation efforts need bolstering; A recent President's Council of Advisors on Science and Technology (PCAST) report calls for an immediate infusion of about $10 billion per year for clean energy technologies. (http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-energy-tech-report.pdf).

10 The 12 warmest years on record have all occurred since 1997. See the conclusions of four different analyses: the National Aeronautics and Space Administration (NASA) (http://www.giss.nasa.gov/research/news/20110112/); the National Oceanic and Atmospheric Administration (NOAA) (http://www.wmo.int/pages/mediacentre/news/index_en.html); the United Kingdom Met Office (http://www.metoffice.gov.uk/news/releases/archive/2011/2010-global-temperature); and the World Meteorological Organization (http://www.wmo.int/pages/mediacentre/news/index_en.html.

11 *Global Climate Change Impacts in the United States,* op. cit.

12 http://www.physorg.com/news/2011-01-greenland-ice-sheet-video.html.

13 The World Bank, op. cit.

14 Martin Parry et al., eds. (2007). *Climate Change 2007-Working Group II Report: Impacts, Adaptation and Vulnerability,* New York, NY: Intergovernmental Panel on Climate Change, http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-intro.pdf.

15 Jonathan A. Patz, et al., "Impact of Regional Climate Change on Human Health," *Science,* 17 November 2005, http://www.nature.com/nature/journal/v438/n7066/full/nature04188.html.

16 The World Bank, op. cit.; United Nations Scientific Expert Group on Climate Change, op. cit.; *Stern Review on the Economics of Climate Change,* Cambridge, U.K., and New York: Cambridge University Press (2006), http://www.hmtreasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

17 The *U.S. Global Change Act of 1990,* Title 15, Chapter 56A - Global Change Research, (16 November 1990) http://www.gcrio.org/gcact1990.html.

18 NAST (2008). *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change,* http://www.gcrio.org/NationalAssessment/index.htm. For a history and review of lessons learned from assessments, see Committee on Analysis of Global Change Assessments, National Research Council, *Analysis of Global Change Assessments: Lessons Learned.* Global Climate Change Impacts in the United States, Karl, Thomas R., Melillo, Jerry M., Peterson, Thomas C., (2009).

19 Hardiness zones are based on the coldest temperatures plants experience. See: Arbor Day Foundation,

Difference Between 1990 USDA Hardiness Zones and *2006 arborday.org Hardiness Zones Reflect Warmer Climate,* http://www.arborday.org/media/map_change.cfm.

20 See, for example, Phillip J. van Mantgem, et al. "Widespread Increase of Tree Mortality Rates in the Western United States," *Science* 23 January 2009: Vol. 323 no. 5913 pp. 521-524. http://www.sciencemag.org/content/323/5913/447.full and D. Breshears et al. "Regional Vegetation Die-Off in Response to Global-Change-Type Drought," PNAS Volume 102(42); October 18, 2005, http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1250231.

21 Anderson, Jamie et al. (2006). *Progress on Incorporating Climate Change into Management of California's Water Resources, Climatic Change DOI 10.1007/s10584-007-9353-1,* Springer Science. http://www.springerlink.com/content/tk10720k416377j5/fulltext.pdf.

22 Stationarity – the idea that natural systems fluctuate within an unchanging envelope of variability – is a foundational concept that permeates training and practice in water-resource engineering. See: P. C. D. Milly,et al. "Stationarity Is Dead: Whither Water Management?" *Science* Vol. 319 1 Feb. 2008, http://www.waterandclimate.org/UserFiles/File/WWW2009_milly_et_al.pdf.

23 New York Climate and Health Project (2004). *Assessing Potential Public Health and Air Quality Impacts of Changing Climate and Land Use in Metropolitan New York: A Study by the New York Climate & Health Project,* New York, NY: Earth Institute, Columbia University. http://www.earth.columbia.edu/events/2004/images/NYCHP_Briefing_Paper_June04.pdf.

24 Ziska, L.H., et al. "Rising Carbon Dioxide, Plant Biology Public Health: Potential Impacts on the Growth and Toxicity of Poison Ivy (Toxicodendron radicans)," *Weed Science,* 2007, http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=202298, and Singer, B.D., et al. "Increasing amb a 1 content in common ragweed (Ambrosia Artemisiifolia l.) pollen as a function of rising atmospheric CO_2 concentration," *Functional Plant Biology,* 2005, http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=169170.

25 See Committee on Earth-Atmosphere Interactions (2007). *Understanding Multiple Environmental Stresses: Report of a Workshop,* Washington, DC: National Academies Press.

26 See: http://globalchange.gov/whats-new/554-usgcrp-strategic-planning-underway and http://www.noaa.gov/climate.html.

27 See http://www.globalchange.gov/what-we-do/assessment/nca-overview.

28 Public Law 101-606, Section 104. (See: http://globalchange.gov/whats-new/554-usgcrp-strategic-planning-underway and http://www.gcrio.org/gcact1990.html).

29 The White House Council on Environmental Quality, op. cit.

Box 1: The Energy Sector: An example of Adaptation Concerns

The majority of U.S. emissions of carbon dioxide are a result of the combustion of fossil fuels and for that reason, the focus on this sector has historically been on reducing emissions. Much less work has been devoted to adaptation of energy systems to a changing climate[i]. The energy sector is not only a driver of climate change, but also subject to the effects of that change. Whether the U.S. can continue to supply reliable energy services to its citizens depends on how robust systems will be to the changing climate. The warming from climate change is expected to increase the demand for cooling (mostly electricity) by 5-20% per 1°C [1.8° F] and decrease overall demand for heating (mostly natural gas) by 3-15% per 1°C[ii]. Water availability concerns and increased frequency of severe storm events are the two most worrisome impacts of climate change on the energy sector.

Climate change will directly affect energy production and supply. Tropical storms and hurricanes will be more intense as climate changes, thus exposing energy production and delivery systems in off-shore, coastal areas and other low-land areas to more severe weather conditions. During Hurricanes Katrina and Rita, 109 of the 4,000 offshore oil and gas drilling platforms in the Gulf of Mexico were destroyed and 31 were damaged. Approximately 91% of oil production and 72% of gas production capacity was out of service, and energy companies were forced to shut down more than 25% of the refining capacity in the U.S. Sea level rise may also impact energy infrastructure. Increased temperatures may reduce the capacity of transmission lines due to increased sagging of the lines. The reduction in transmission capacity may compound the impacts of warming temperatures and the concomitant increased demand for electricity potentially increasing the incidence of brownouts. Climate change may affect the viability of some renewable energy technologies requiring a lot of water such as solar thermal, or biofuels.

In the regions most affected by heat and drought-like conditions, the effects on availability of water appear to be three-fold, with less water available to cool nuclear and thermal power plants, less water to float coal on barges to supply powerplants, and less water to flow through dams for hydroelectric power generation. This is particularly problematic during hot periods when demand for cooling from electricity is at its peak, but reduced water flows could exacerbate competition for over-allocated water resources

Climate change may also have indirect effects on energy supply and demand, including effects on: risk management; energy technology research and development and resource choices; energy prices; and energy security.

Incorporating climate change into ***planning*** efforts is important on a number of levels. First, utilities and energy companies should include climate change in their forecasts of energy demand and supply. Second, when planning infrastructure improvements, including repair, replacement, or installation of new equipment, changes should be made that make sense considering the likely impacts of climate change. Third, water managers, utilities and others in the energy sector should coordinate planning efforts to recognize the energy–water nexus and the impact of climate change on both sectors. And lastly, when planning for future events, learn from past failures such as the Midwest blackout and the California energy crisis.

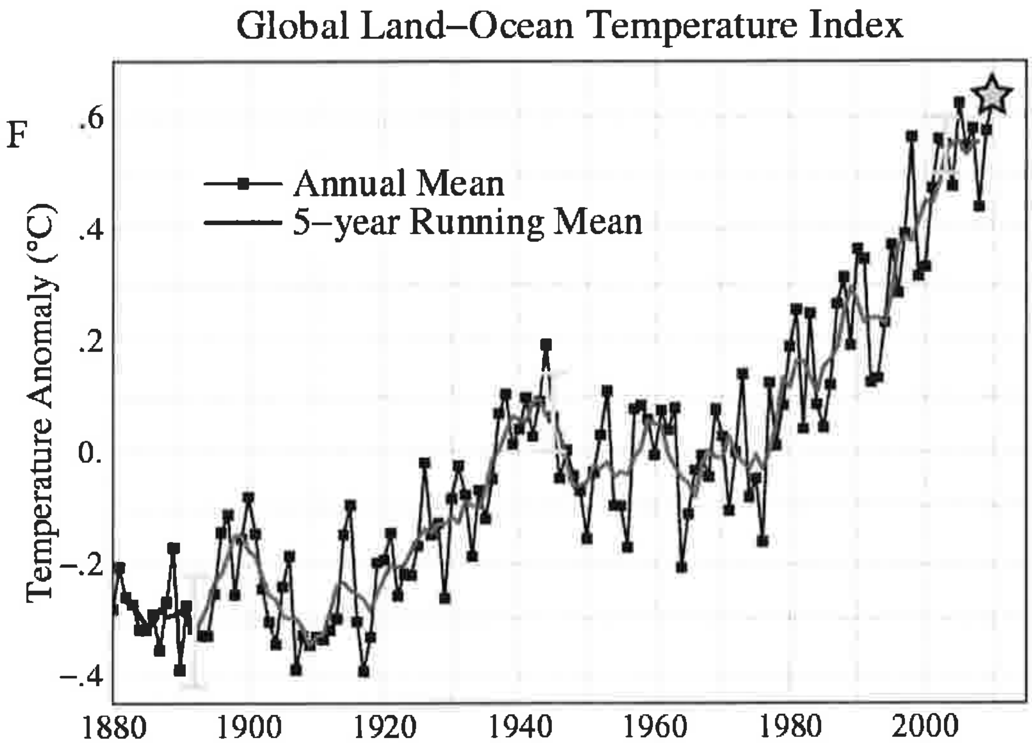
Efforts should be made to conduct or facilitate multi-state planning to accommodate large geographic scale extreme weather events. Diversification of energy supply may also be a viable adaptation option. Renewable energy technologies can modularize energy supply and possibly build in resilience to climate change.

Research on extreme weather events and large scale weather patterns is absolutely critical for utility and energy company planning and management and to assist government actors in understanding effective adaptation options. As well, improved surveillance and emergency response systems will need to be developed to protect people and to cope with extreme weather events.

Planned adaptation is preferred over reactive adaptation. The long-term investment horizons necessary for energy investment coupled with the lag in capital stock turnover means that taking proactive action is crucial.

i CCSP, 2007: *Effects of Climate Change on Energy Production and Use in the United States.* A Report by the U.S. Climate Change Science Program and the subcommittee on Global Change Research. [Thomas J. Wilbanks, et al., (eds.)]. Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA, 160 pp. (http://www.climatescience.gov/Library/sap/sap4-5/final-report/sap4-5-final-all.pdf)

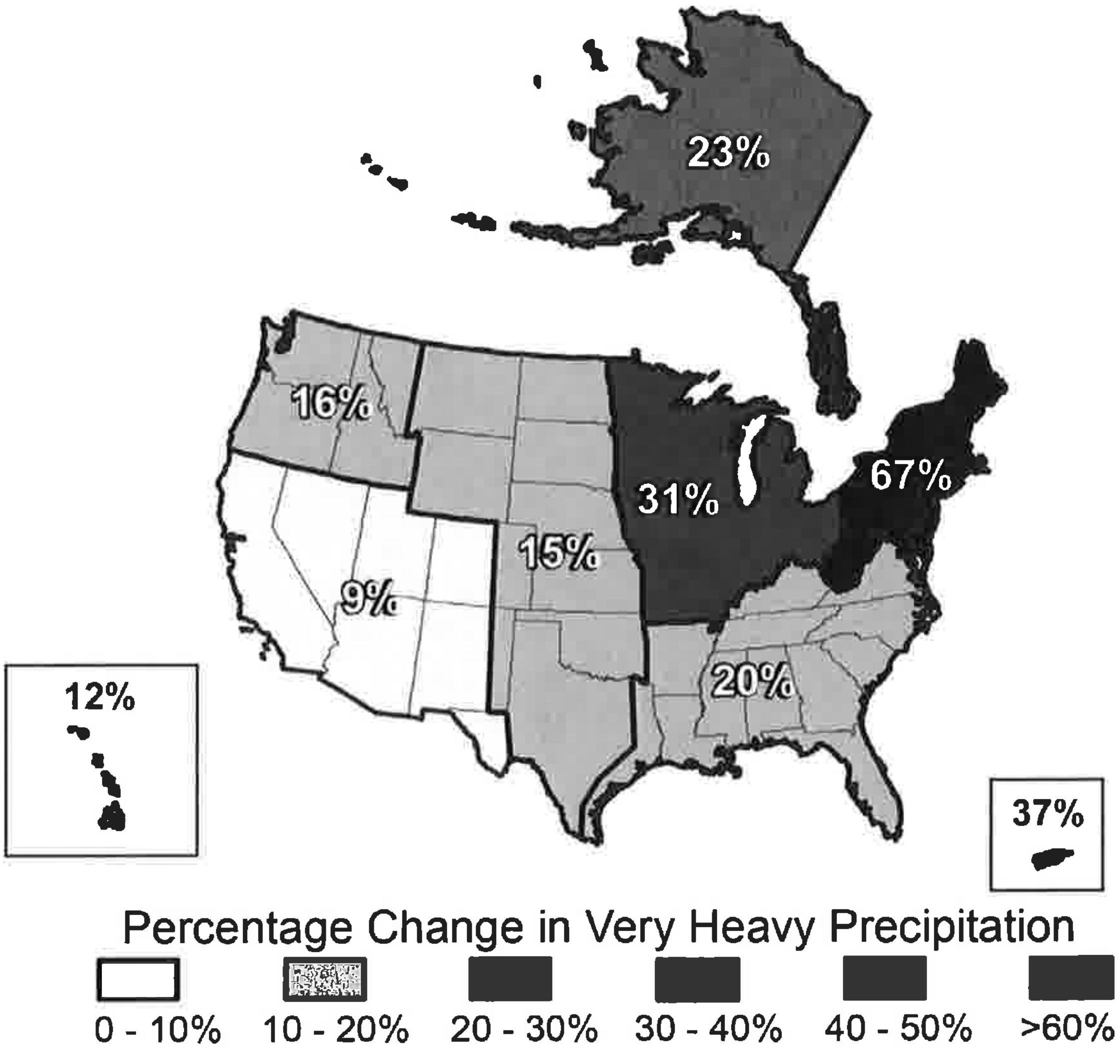
ii These generalized estimates of increased demand cannot yet account for: (1) the effect of changes in humidity, (2) changes and effects in peak loads, (3) human migration patterns and resultant effects on regional energy systems, (4) changes in behavior of energy use, or (5) the effect of increased energy demand for pumping/moving water.



☆ 1.4° Fahrenheit above pre-industrial temperatures

http://data.giss.nasa.gov/gistemp/graphs/ updated January 12, 2011

Figure 1



Updated from Groisman *et al.*[113]

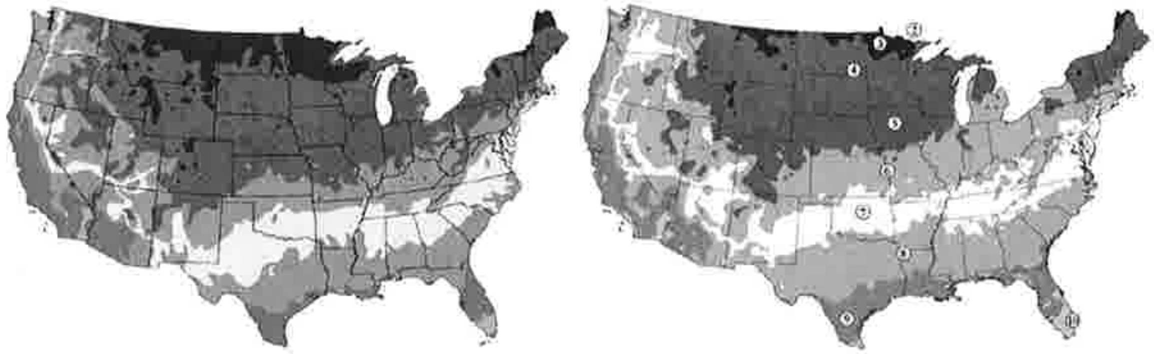
The map shows the percentage increases in very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report/national-climate-change

Figure 2

Changes in Planting Zones

1990 Map | **2006 Map**



After USDA Plant Hardiness Zone Map, USDA Miscellaneous Publication No. 1475, Issued January 1990

National Arbor Day Foundation Plant Hardiness Zone Map published in 2006.

Zone

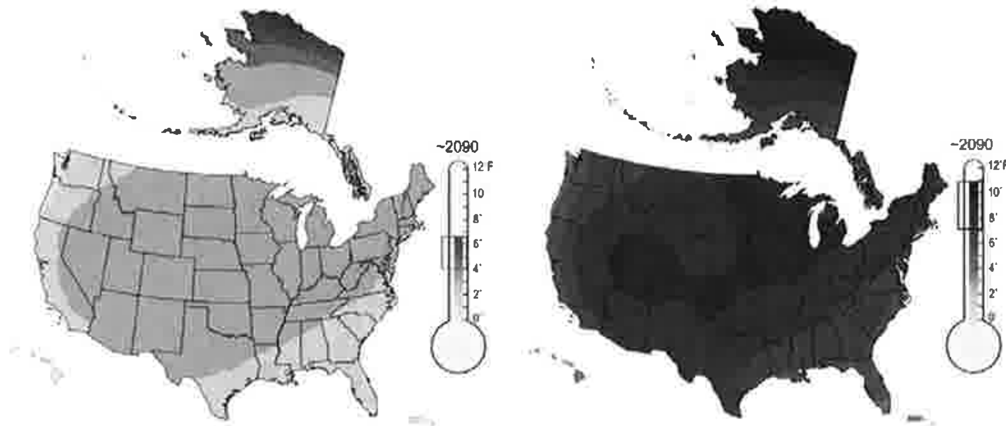
2 3 4 5 6 7 8 9 10

http://www.arborday.org/media/map_change.cfm

Figure 3

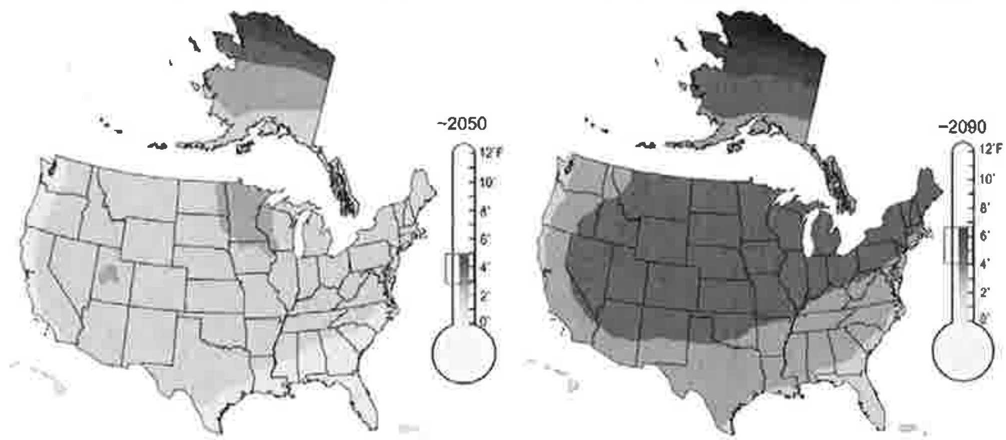
Higher Emissions Scenario[91] Projected Temperature Change (°F)
From 1961-1979 Baseline

Mid-Century (2040-2059 average) End-of-Century (2080-2099 average)



Lower Emissions Scenario[91] Projected Temperature Change (°F)
From 1961-1979 Baseline

Mid-Century (2040-2059 average) End-of-Century (2080-2099 average)



All Maps
CMIP3-C[109]

The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES).91 The "lower" scenario here is B1, while the "higher" is A2.[91] The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible.

http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report/national-climate-change

Figure 4