IN THE UNITED STATES DISTRCT COURT
FOR THE DISTRICT OF COLUMBIA

DECLARATION OF MICHAEL C. MacCRACKEN

I, MICHAEL C. MacCRACKEN, declare as follows:

1. Having devoted a career of 45 years to study of climate change, as enumerated in the following section on my personal background and experience, my declaration explains the basis for the scientific conclusion that the climate is being significantly affected by human activities, primarily the combustion of coal, petroleum, natural gas, and other fossil fuels. Three key findings can be drawn from observations and analyses of what has occurred in the relatively recent past: (1) there has been over a 40% increase in the atmospheric carbon dioxide (CO_2) concentration since the start of the Industrial Revolution that several lines of evidence make clear is a result of human-related activities; (2) surface and satellite data make clear that the increased concentrations of CO_2 and other radiatively active greenhouse gases have intensified the natural greenhouse effect that makes the Earth's climate so much more suitable for life than that of the Moon and other planets; and (3) three decades of detection-attribution studies have made clear that the temporal and spatial patterns of the increase in the global average surface temperature and changes in nearly a dozen other climate variables since the start of the 20th century (and particularly over the past several decades) can only be explained as a result of human activities, especially the emissions of CO_2 from combustion of coal and other fossil fuels.

As described more fully in this declaration, all of the widely reviewed national and international assessments of the state of scientific understanding[1], recognizing what has occurred and been learned about past responses of the Earth's climate to environmental changes of the type and magnitude being caused by human activities and using physically based numerical models of the Earth system, are definitive in three additional findings (thus numbering of the points is continued) regarding the future climate. In particular, these assessments find that: (4) continued emissions of CO_2 and other greenhouse gases will cause the global average temperature to increase to a level unprecedented in many, many millions of years, and that this will occur much more rapidly than is typical for changes of climate in the past; (5) serious, highly disruptive, and even irreversible regional, national and global environmental and societal consequences will be initiated and set in motion by continued emissions, with adjustment to many of them being very difficult, if possible at all; and (6) moving to near-zero and even negative net global emissions[2] will be required in order to "prevent dangerous anthropogenic interference with the climate system," as called for in Article 2 of the United Nations Framework Convention on Climate Change that was ratified by the U.S. Senate in 1992[3]. Especially given the emissions of CO_2 and other greenhouse gases in the

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[1] These scientific assessments most particularly include the five assessment reports of the Intergovernmental Panel on Climate Change (IPCC) issued since 1990, each of which has been agreed to unanimously by the member nations (at present, over 190 UN nations participate in the IPCC process) and the findings of which have been endorsed by virtually every national academy of sciences and many dozens of professional organizations. Additional information about IPCC is available at www.ipcc.ch/. Citations to both U.S. and Arctic assessments are provided later in this declaration.

[2] Net negative global emissions can be achieved if, for example, processes such as reforestation and soil carbon enhancement that remove CO_2 from the atmosphere are in excess of emissions occurring from fossil fuel combustion, deforestation, and soil degradation. Reaching overall net negative emissions would very likely require a cut in fossil fuel emissions of at least 90% and quite possibly more.

[3] The United Nations Framework Convention on Climate Change (UNFCCC) was signed by the United States on June 12, 1992 and ratified by the Senate on October 15, 1992. The text of the Convention is

past and the increasing environmental and societal impacts from these past emissions, the six specific findings indicated above, which have emerged from scientific research and analysis through decades of research, analysis and assessment, make clear that the scientific evidence is sound, that the pace of change and onset of impacts is intensifying and becoming more detrimental more rapidly than previously projected, and that continued mining and combustion of coal (as well as other high carbon fuels such as shale oil and tar sands) at the rate occurring in the U.S. must be rapidly and sharply cut if the increase in global average temperature is to be limited to the international goal of no more than ~2ºC (3.6ºF) over preindustrial conditions and other increasing impacts and risks of climate change are to be moderated.

PERSONAL BACKGROUND AND EXPERIENCE

2. I received my Bachelor of Science in Engineering with high honors in Aerospace and Mechanical Sciences from Princeton University in 1964 and was recognized by election to the Phi Beta Kappa honor society. I then received my Master of Science and Ph.D. degrees in Applied Science from the University of California Davis in 1966 and 1968, respectively. My dissertation involved the construction of one of the world's first numerical climate models and application of the model to quantitatively evaluate the plausibility of several hypotheses about the causes of glacial-interglacial cycling. My graduate studies were recognized by election to the Phi Kappa Phi honorary society.

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included as the annex to a report on the Earth Summit held in Rio de Janeiro in 1992 that is available at http://unfccc.int/resource/docs/a/18p2a01.pdf.

3. From 1968 to 2002, I was employed as a physicist at the University of California's Lawrence Livermore National Laboratory (LLNL), where, from 1968 to 1993, I led a number of scientific projects relating to analysis of natural and human influences on regional air pollution and on the global climate. These studies included consideration of observed trends and using numerical models to simulate the response of the climate to human-induced changes in atmospheric composition, including likely changes in climate from an increase in the concentration of CO_2 caused by human activities. From 1978 to 1993, in addition to my research activities, I also served in various advisory capacities for the climate change research program managed by the Department of Energy, and I participated actively in numerous other professional activities related to understanding and estimating climate change and its impacts on the environment. In addition, I served as Deputy Division Leader of LLNL's Atmospheric and Geophysical Sciences Division from its formation in 1974 to 1987 and as Division Leader from 1987 to 1993.

4. From 1993 to 2002, I accepted an assignment from my permanent position at LLNL to serve as senior scientist on global change at the interagency Office of the U. S. Global Change Research Program (USGCRP) in Washington, DC. In this capacity, I served as the first Executive Director of the Office from 1993-1997, leading a small staff and having responsibility for promoting coordination of the global change[4] research programs of ten federal agencies, including the Department of Agriculture, Department of Energy, Department of the Interior, National Science Foundation, Environmental

[4] The term "global change" encompasses research relating to seasonal to inter-annual climate variability, human-induced climate change, depletion of stratospheric ozone and atmospheric chemistry, changes in land cover such as deforestation and desertification, and associated impacts such as changes in water resources, ecosystems and land cover, etc.

Protection Agency, National Oceanographic and Atmospheric Administration, NASA, and others. In addition, in my role as senior scientist, I was responsible for maintaining currency with scientific advances in the field of global climate change for the USGCRP agencies and for updating and responding to requests and questions from leaders at the Office of Science and Technology Policy (OSTP) of the Executive Office of the President relating to scientific advances in the areas of climate and global change.

5. Following service as Executive Director of the Office of the USGCRP, I was appointed Executive Director of the National Assessment Coordination Office, and served in this role from 1997 through 2001. In this role, I led a small staff charged with facilitating preparation of the USGCRP's first National Assessment of the Potential Consequences of Climate Variability and Change (hereafter, National Assessment). As called for in the Global Change Research Act of 1990 (P.L. 101-606), the National Assessment was carried out at the direction of the Director of the Office of Science and Technology Policy in his role as Executive Secretary to the National Science and Technology Council, which is chaired by the President and the members of which are the cabinet secretaries. The National Assessment brought together the efforts of 20 university-based regional teams, five joint university-government scientific teams focused on particular sectors of the economy and natural resources, and a federal advisory committee composed of 12 leading scientists and experts. My responsibilities included participating in the design and integration of the assessment's regional, sectoral, and national components, ensuring the high quality of the scientific aspects of the assessment effort, and otherwise facilitating the efforts of the participating scientists, public stakeholders, and government officials and agencies. In addition to participating in

preparation of and reviewing many of the regional and sectoral activities and reports, I served as an additional lead author and generally contributed to the preparation of the national level reports entitled *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, which were published in 2000 and 2001[5] and particularly the chapters relating to climate change and to Native Peoples/Native Homelands.

6. In my role as Executive Director of the National Assessment Coordination Office, I also prepared Chapter 6 of the U.S. Government's *Climate Action Report 2002*[6], which was the government's official quadrennial communication under the United Nations Framework Convention on Climate Change (UNFCCC) that was negotiated by the Administration of President George H. W. Bush, and overwhelmingly affirmed by the U.S. Senate in 1992. Chapter 6 of the 2002 report, on impacts and adaptation, incorporated the findings of the National Assessment.

7. I have also served in various capacities in the preparation of the First, Second, Third, Fourth, and now Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC). In support of the UNFCCC, the IPCC is the international organization responsible for preparing authoritative assessments of the science of climate change (Working Group 1), impacts and adaptation (Working Group 2), and mitigation and policy options (Working Group 3). For IPCC's First Assessment Report, which was completed in 1990, I was a contributor to two chapters in the Working Group 1 report: Chapter 5 on "Equilibrium Climate Change—and its Implications for the Future" and

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[5] U.S. Global Change Research Program, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview Report* (2000) and *Foundation Report* (2001). Available from Cambridge University Press.
[6] U.S. Dept. of State, *U.S. Climate Action Report 2002* (U.S. Government Printing Office 2002).

Chapter 8 on "Detection of the Greenhouse Effect in the Observations." For the Second Assessment, which was completed in 1995, I was a contributor to Chapter 8 of the Working Group 1 assessment of the science of climate change, "Detection of Climate Change and Attribution of Causes," and a lead author of Chapter 25 of the Working Group 2 assessment of the impacts of climate change, "Mitigation: Cross-Sectoral and Other Issues." For the Third Assessment, which was completed in 2001, I was a contributing author to Chapter 12 of the Working Group 1 assessment, "Detection of Climate Change and Attribution of Causes." For the Fourth Assessment, which was completed in 2007, I served as review editor for Chapter 14 of the Working Group 2 assessment, which summarized past, ongoing, and expected future impacts of climate change on North America. For each of the assessments, I have also been a scientific reviewer of various chapters, and, as part of my responsibility with the Office of the U.S. Global Change Research Program (1993-2001), I served as scientific coordinator for the official reviews of the U.S. Government for both the Working Group 1 and 2 contributions to the Second and Third IPCC Assessment Reports. I also served as scientific advisor to the U.S. delegation at the international plenary meetings of Working Group 1 for the Second and Third Assessments, contributing to the preparation of the Summary for Policymakers of each assessment.

8. Since retiring from the University of California's Lawrence Livermore National Laboratory in September 2002 upon completing my assignment with the Office of the USGCRP, I have served, largely on a *pro bono* basis, as Chief Scientist for Climate Change Programs with the Climate Institute in Washington, DC [www.climate.org], which is the oldest non-governmental organization solely focused on understanding and

helping to address the climate change issue. My activities with the Climate Institute have focused particularly on improving and communicating understanding of: (a) the important contributions to climate change made by short-lived warming agents, particularly methane and black carbon, and the role that reducing emissions of these substance can have in limiting global climate change, and (b) the complications and potential for counterbalancing global warming by taking alternative actions, an effort often called "geoengineering" (my interests focus on potential regional rather than global implementation). I also served on the 13-member Assessment Integration Team of the 8-nation Arctic Climate Impacts Assessment (ACIA), which completed its assessment[7] in 2004, describing how climate change and enhanced ultraviolet radiation are now affecting and are likely in the future to affect the Arctic region (including Alaska), and how these changes are likely to impact the rest of the world. In addition, from 2004 to 2007 I was a member of the Scientific Expert Group (SEG) on Climate Change and Sustainable Development, organized by Sigma Xi, The Scientific Research Society and the UN Foundation, which prepared a report[8] for the UN Commission on Sustainable Development indicating the types of actions needed to simultaneously address the issues of climate change and sustainability, particularly the important need to limit emissions of CO_2 and methane to slow global warming and associated impacts.

9. In 2003 I was elected to a four-year term as President of the International Association of Meteorology and Atmospheric Sciences (IAMAS), which is an

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[7] Arctic Climate Impact Assessment (ACIA), *Impacts of a Warming Arctic: Arctic Climate Impact Assessment (Synthesis Report)*, Cambridge University Press, 2004; and *Impacts of a Warming Arctic: Arctic Climate Impact Assessment (Technical Report)*, Cambridge University Press, 2005.

[8] Scientific Expert Group on Climate Change (SEG), 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 by Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, DC, 144 pp.

international scientific organization whose sponsoring members are the national academies of science of over 60 leading nations. My association with IAMAS has continued to the present and I serve on the U.S. National Academy of Sciences' committee that facilitates participation of U.S. scientists with the international associations for the atmosphere, oceans, cryosphere, hydrology, and more. From 2003-2011, I also served as the international atmospheric sciences representative on the executive committee of the Scientific Committee on Oceanic Research, which oversees the scientific aspects of international ocean research programs.

10. Throughout the period since retiring from LLNL in 2002, I have continued to actively read and review scientific research being carried out on climate change and its consequent impacts, often being sought out to serve as an authoritative reviewer. For example, in 2009 I was a member of the blue-ribbon review for USGCRP's report "Global Climate Change Impacts in the United States"[9], a report that updated the 1997-2001 National Assessment of Climate Variability and Change that the Office I led had facilitated, and during 2012-13 I assisted World Bank staff in reviewing and revising two recent, and very important, reports: "Turn Down the Heat: Why a 4ºC Warmer World Must be Avoided"[10], which was released in November 2012, and "Turn Down The Heat: Climate Extremes, Regional Impacts, and the Case for Resilience"[11], which was released June 1, 2013; in addition, during 2014 I participated in the review of an additional major report due for release within the next

[9] Karl, T. R., J. M. 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]

[10] World Bank, 2012: *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*, prepared by the Potsdam Institute for Climate Impact Research and Climate Analytics, Washington DC, 119 pp.

[11] World Bank, 2013: *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience-Executive Summary*, prepared by the Potsdam Institute for Climate Impact Research and Climate Analytics, Washington DC, 34 pp.

few months. I also serve on the advisory boards of the Environmental and Energy Study Institute (http://eesi.org), the National Center for Science Education (http://ncse.com/), and several other organizations and groups relating mainly to public communication of the science of climate change.

11. Since retiring in 2002, I have also prepared expert declarations for a number of legal cases relating to climate change. My first declaration was prepared to support the granting of standing in what became Commonwealth of Massachusetts et al. versus EPA [Massachusetts v. EPA, 549 U.S. 497 (2007)] and was cited favorably by Justice Stevens in the majority opinion [Id. at 515-24]. When EPA's actions under Massachusetts et al. versus EPA were challenged in 2009, I carefully reviewed EPA's response, titled "Endangerment and Cause or Contribute Finding for Greenhouse Gases Under Section 202(a) of the Clean Air Act," 74 Fed. Reg. 66,496 (Dec. 15, 2009) and supporting materials[12] and submitted a declaration in support of the analysis of the science by EPA that had served as the explanation for their proposed action. I have also prepared declarations in separate lawsuits seeking to have the Department of Defense[13] and the Import-Export Bank/ Overseas Private Investment Corporation[14] prepare environmental impact statements under the National Environmental Protection Act (NEPA) to cover actions they were taking that would increase greenhouse gas emissions. In parallel with steps taken by the World Bank, President Obama has since

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[12] Specifically, EPA's Denial of the Petitions to Reconsider, 75 Fed. Reg. 49,556 (Aug. 13, 2010), and associated materials supporting these findings, including much of EPA's response to comments and response to petitions, documents, and the technical support document for the Endangerment Finding. The careful consideration EPA gave to the evidence it gathered is consistent with high scientific standards. *See* 74 Fed. Reg. at 66,510-12 (describing EPA's process) and materials available at http://www.epa.gov/climatechange/endangerment.html.

[13] Case 1:11-cv-0041-CMH-TRJ before the United States District Court for the Eastern District of Virginia, Alexandria Division, Sierra Club et al. v. v. U.S. Defense Logistics Agency Energy.

[14] Case 02-4106-JSW before the U.S. District Court for the Northern District of California, Friends of the Earth, Inc., et al. v. Watson.

that time instructed the Import-Export Bank and Overseas Private Investment Corporation, to the extent possible, to no longer finance coal-burning projects as called for in the lawsuit. With the increasing recognition that limiting climate change over coming decades will require ending the reliance on coal as a major source of energy, I submitted a declaration[15] (dated December 10, 2012, filed December 13, 2012; document 38-4) describing the consequences to climate and the environment from combusting the coal proposed to be extracted by mining of the Belle Ayre and Caballo leases in the Powder River Basin in Wyoming, where there is the potential to extract more than 300 million tons of coal during the lease period, and a declaration[16] (dated October 10, 2013, filed November 24, 2013) describing the consequences to the climate and the environment from combusting coal proposed to be extracted by mining the North Hilight, South Hilight, North Porcupine, and South Porcupine coal lease tracts in the Powder River Basin in Wyoming, where there is the potential to extract more than 2300 million tons of coal during the lease period. Of particular relevance, this most recent declaration analyzed and described the many shortcomings and outdated scientific findings contained in the NEPA analysis[17] used to justify the proposed leasing of coal tracts in the Powder River Basin.

12. As a result of efforts undertaken in my various positions and responsibilities, I am the co-author/co-editor of ten books/major reports, roughly 50

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[15] Case 1:11-cv-01481-RJL before the United States District Court for the District of Columbia, WildEarth Guardians, et al. v. U.S. Bureau of Land Management.
[16] Case 2:12-cv-00085-ABJ before the United States District Court for the District of Wyoming, WildEarth Guardians and Sierra Club v. U.S. Bureau of Land Management.
[17] Environmental Impact Statement, Section 4.0 Cumulative Environmental Consequences, Subsection 4.2.14.1 Greenhouse Gas Emissions, Global Warming and Climate Change (pages 4-130 to 4-135).

peer-reviewed journal articles and book chapters, and hundreds of other reports, articles, and notes relating to climate change.

13. Convinced strongly by the evidence of climate change, most of our home's electrical needs are met by a rooftop solar photovoltaic system and I take other actions to limit my personal carbon footprint.

OVERVIEW OF KEY POINTS

14. The findings and supporting information in this declaration are offered as my expert scientific opinion, based on my education, qualifications, experience, and knowledge of the relevant scientific literature and national, regional, and international assessment processes. Having participated in many of these activities as researcher, author and/or reviewer, my opinions draw extensively on the strong consensus regarding the science of climate change and its impacts as presented in the major national[18], regional[19], and international[20] assessment reports that assemble, evaluate and critically

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[18] National Assessment Synthesis Team (NAST), 2000: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview Report*, U. S. Global Change Research Program, Cambridge University Press, 154 pp.; National Assessment Synthesis Team (NAST), 2001: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Foundation Report*, U. S. Global Change Research Program, Cambridge University Press, 612 pp.; Karl, Thomas R., Jerry M. Melillo, and Thomas 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]

[19] Arctic Climate Impact Assessment (ACIA), 2004: *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, Cambridge University Press, 140 pp. [Available online at http://www.acia.uaf.edu/default.html]

[20] The Intergovernmental Panel on Climate Change (IPCC), which was formed in the late 1980s, has produced a series of major assessments of climate change in 1990, 1995, 2001, 2007, and 2013/2014. Their most recent assessments are available at http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml and include: Intergovernmental Panel on Climate Change (IPCC), 2007: *Climate Change 2007: The Physical Science Basis*, S. Solomon et al., eds., Cambridge University Press, 996 pp.; Intergovernmental Panel on Climate Change (IPCC), 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability*, M. Parry et al., eds., Cambridge University Press, 976 pp.; Intergovernmental Panel on Climate Change (IPCC), 2007: *Climate Change 2007: Mitigation of Climate Change*, B. Metz et al., eds., Cambridge University Press, 851 pp.; Intergovernmental Panel on Climate Change (IPCC), 2007: *Climate Change 2007: Synthesis Report*, R.

summarize the results of thousands of scientific papers going back 25 years and more. Each of the U.S. national and IPCC assessments has been thoroughly peer-reviewed and received formal approval by the U.S. Government as accurately representing the state of the science. These assessments collectively provide extensive information about past and projected impacts of climate change around the world and over the United States, including the 48 contiguous states, Alaska (and the Arctic generally), and Hawai'i and the many Pacific and Caribbean islands under the trusteeship or other jurisdiction of the United States. The five international assessments of the Intergovernmental Panel on Climate Change since 1990 (completed in 1990, 1995, 2001, 2007 and 2013/14) have, after extensive international review, been unanimously accepted by the ~190 nations of the world (including the U.S. Government) participating in the IPCC process, and none of the criticisms of these assessment reports over the past several years has been found to have any significant influence on their findings[21]. For example, the recent review of the IPCC assessment process by the InterAcademy Council, *Climate Change Assessments, Review of the Processes and Procedures of the IPCC* ("IAC Report"), concluded that "[t]he IPCC assessment process has been successful overall and served society well" [IAC Report at 52].

15. Based upon my review of the science in the context of the issues raised by the plaintiffs, this declaration focuses on three key points, each of which is elaborated on in one of the sections of the declaration that follows:

Pachauri, et al., eds., World Meteorological Organizations and United Nations Environment Programme, Geneva, Switzerland; and Intergovernmental Panel on Climate Change (IPCC), 2013: *Climate Change 2013; The Physical Science Basis*, T. Stocker et al., eds., Cambridge University Press, 1535 pp.

[21] For a response to many of the recent criticisms, both scientific and procedural, see EPA's Denial of the Petitions to Reconsider, 75 Fed. Reg. 49,556 (Aug. 13, 2010), and materials supporting this action, including much of EPA's response to comments and response to petitions, documents, and the technical support document for the Endangerment Finding; available at http://www.epa.gov/climatechange/endangerment.html.

(1) *The science linking human activities to changes in climate is solid and well-supported, particularly with respect to the important contribution of combustion of coal, petroleum, and natural gas* (see paragraphs 16-25).

(2) *The need for actions to sharply reduce emissions is urgent in order to reduce the likelihood of extremely disruptive consequences for the environment and society* (see paragraphs 26-32).

(3) *Release of the carbon contained in U.S. coal and shale reserves would directly contribute to disruptive climate change, while also undermining the U.S. commitment embraced in the UN Framework Convention on Climate Change to stabilize the climate in a manner that would "prevent dangerous anthropogenic interference with the climate system"* (see paragraphs 33-38).

POINT (1): The science linking human activities to changes in climate is solid and well-supported, particularly with respect to the important contribution of combustion of coal, petroleum, and natural gas.

16. Scientific research on the factors determining the climate and changes in the climate has developed over several centuries and has grown in intensity and extent, with advances in scientific understanding being internationally published, assessed and summarized. The fundamental science underpinning the finding that combustion of fossil fuels could have growing effects on the climate was first put forth in the late 19th century. After much careful study and gathering of new observations, the critical aspects of the science were sufficiently well established that they were reported to President Johnson and the Congress in a 1965 report prepared by the President's Science Advisory

Council[22]. By 1985, further research and assessments by the national and international scientific community, including reports by the National Academy of Sciences[23] and an initial comprehensive assessment by the U.S. Department of Energy[24], led to an international conference convened by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions (now the International Council of Science). Their report concluded that: "Many important economic and social decisions are being made today on long-term projects--major water resource management activities such as irrigation and hydro-power, drought relief, agricultural land use, structural designs and coastal engineering projects, and energy planning—all based on the assumption that past climatic data, without modification, are a reliable guide to the future. This is no longer a good assumption since the increasing concentrations of greenhouse gases are expected to cause a significant warming of the global climate in the next century"[25]. This finding and the consequent international interest in getting more definitive analyses and projects of climate change

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[22] President's Science Advisory Committee (PSAC), 1965: Appendix Y4: Atmospheric Carbon Dioxide, pp. 111-133 in *Restoring the Quality of our Environment*, Report of the Environmental Pollution Panel. The White House, Washington DC, November 1965.

[23] National Research Council (NRC), 1983: *Changing Climate*, Report of the Carbon Dioxide Assessment Committee, National Academy Press, Washington DC, 496 pp.

[24] Department of Energy, 1985: *Atmospheric Carbon Dioxide and the Global Carbon Cycle*, J. R. Trabalka, ed., DOE/ER-0239, U.S. Department of Energy, Washington, DC, 316 pp.; Department of Energy, 1985: *Detecting the Climatic Effects of Increasing Carbon Dioxide*, M. C. MacCracken and F. M. Luther, eds., DOE/ER-0235, U.S. Department of Energy, Washington, DC, 198 pp.; Department of Energy, 1985: *Projecting the Climatic Effects of Increasing Carbon Dioxide*, M. C. MacCracken and F. M. Luther, eds., DOE/ER-0237, U.S. Department of Energy, Washington, DC, 381 pp.; Department of Energy, 1985: *Direct Effects of Increasing Carbon Dioxide on Vegetation*, Boyd R. Strain and J. D. Cure, eds., DOE/ER-0238, U.S. Department of Energy, Washington, DC, 286 pp. Department of Energy, 1984: Glaciers, Ice Sheets, and Sea Level: Effect of a CO_2-Induced Climatic Change, Report of a workshop held in Seattle, Washington organized by the Polar Research Board, National Research Council, September 13-15, 1984, DOE/EV/60235-1, 348 pp.

[25] World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), and International Council of Science (formerly, International Council of Scientific Unions, ICSU), 1985: *Report of the International Conference on the Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts*, World Meteorological Organization Publication #661, Geneva.

led over the next few years to the formation, under WMO and UNEP auspices, of the Intergovernmental Panel on Climate Change (IPCC), members of which are the governments of the United Nations. The IPCC is now completing its Fifth Assessment Report. A key finding of its working group on the science of climate change is: "Continued emissions of greenhouse gases [i.e., CO_2 and similar gases that are known to exert a warming influence on the global climate] will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions."[26] The IPCC's key findings over its five assessment reports have not only been accepted *unanimously* by its national members (including the U.S.), but have also been endorsed by national academies of science (including the U.S. National Academy of Sciences) and professional scientific societies (including the American Meteorological Society, the American Geophysical Union, etc.). While research, of course, continues to further and further refine the detailed findings of how much change will occur, where and when the changes will occur, how extensive the consequences will be, how adaptation may be able to moderate emerging impacts, and the actions that are needed and the possibilities that exist for slowing, halting and even reversing climate change, there is no substantial questioning within the scientific community of the fundamental reasons for concern about the growing and increasingly disruptive influence of human activities on the climate.

17. That fossil fuel combustion would alter the atmospheric concentration of CO_2 was first hypothesized by Swedish scientist Svante Arrhenius and colleagues in 1896 and then first convincingly confirmed by observations taken at the Mauna Loa

[26] Page 19 in Intergovernmental Panel on Climate Change (IPCC), 2013: *Climate Change 2013; The Physical Science Basis*, T. Stocker et al., eds., Cambridge University Press, 1535 pp.

Observatory in Hawai'i by American scientist C. David Keeling starting in the late 1950s. Observations are now available from a global network of stations that document changes since the 1960s and from air bubbles trapped in ice cores drilled in the Greenland and Antarctic ice sheets that document the changes in the atmospheric CO_2 concentration going back roughly 800,000 years. This extensive record indicates that, prior to the influence of human activities, the CO_2 concentration had dropped to as low ~200 parts per million by volume (ppmv)[27] during the glacial periods and rose to ~300 ppmv during the warm, interglacial periods. Over the last 250 years (i.e., since the start of the Industrial Revolution), the data indicate that the CO_2 concentration has climbed from about 280 ppmv up to about 400 ppmv. Confirmation of the human origin of this increase is based on compilations of source and sink (i.e., removal) amounts and the changing isotopic makeup of the CO_2 molecules that are present in the atmosphere. These studies of the cycling of CO_2 through the various parts of the Earth system indicate that increased uptake of CO_2 by the upper ocean and terrestrial plants has had the effect of limiting the long-term increase in the atmospheric CO_2 concentration to about half of what would occur were all of the CO_2 emitted by fossil fuel composition to remain in the atmosphere. This finding that the airborne fraction of emitted CO_2 is about 50% (and for various reasons this value is expected to slowly increase over time) is the key reason that continuing emissions from combustion of coal would lead to a higher and higher atmospheric CO_2 concentration. There is no scientific dispute over the fundamental aspects of this point.

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[27] "parts per million by volume (ppmv)" refers to the number of CO_2 molecules per million molecules of air (which is mostly made up of nitrogen and oxygen molecules).

18. That some atmospheric gases can absorb infrared radiation (i.e., the heat radiated from a warm object) was first recognized by James Fourier and John Tyndall in the mid 19th century. Basically, any molecule having three or more atoms [so not nitrogen (N_2) or oxygen (O_2), but water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and many other natural and manmade gases] has a chemical structure and bonds that allow rotational and vibrational modes that can both absorb and re-emit infrared radiation while having little influence on solar radiation, which is much more energetic. As a result, incoming solar radiation that is not reflected back to space by clouds or the surface or that is absorbed in the atmosphere passes through and contributes to warming of the Earth's surface. As the surface warms, it will then radiate an amount of energy (as infrared, or heat, radiation) that is proportional to the fourth power of its temperature. Were this all that occurred, straightforward calculations make clear that the global average surface temperature would end up being well below freezing. That the surface temperature is roughly 33°C (60ºF) warmer than this is a result of the water vapor, CO_2, and other similar gases in the atmosphere that absorb most of the upward directed heat radiation from the surface and then re-radiate much of it back to the surface, where it causes further warming, further upward radiation of infrared radiation, further absorption by the water vapor, CO_2, and other similar atmospheric gases, and additional downward radiation to warm the surface, which then starts the cycle all over again. The physics of this warming is different than how an actual greenhouse tends to keep warm[28], but similar enough that this trapping of infrared radiation that further warms the surface has been dubbed the "greenhouse effect"—and its blanketing and warming influence is the well-

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[28] An actual greenhouse is kept warm mainly by its containment of atmospheric water vapor, which suppresses the cooling effect that results from evaporation. Nonetheless, this term is often used to describe the effect that water vapor, CO_2 and similar gases have in tending to warm the Earth's surface.

established physical explanation for the Earth's surface being as warm as it is. That the atmospheric concentrations of CO_2 and other greenhouse gases can increase the surface temperature is also confirmed by comparison of the observed atmospheric composition and the surface temperatures of Mars and Venus with those for the Earth, and by comparison of the ice-core records of the Earth's past surface temperature and atmospheric concentrations of CO_2 and CH_4. With all of this corroborating information, that increasing the concentrations of greenhouse gases in the atmosphere will exert a warming influence on the global climate is well-accepted in the scientific community.

19. For several decades, the consensus estimate from physical analysis and from the available evidence has been that a doubling of the CO_2 concentration would cause a global warming of ~3°C (i.e., ~5.4°F), plus or minus 50%, once all of the various components of the Earth system (meaning the atmosphere, oceans, glacial ice, biosphere, etc.) have adjusted to the change[29,30]. In general, the increase in temperature would be expected to be less than the global average in low latitudes (due in part to the higher heat capacity and evaporative cooling influence of the oceans) and higher than the global average for land areas (e.g., the U.S. and Arctic) in mid- and high latitudes (due in part to a lower surface heat capacity than over the oceans) and greater in winter than in summer (except where land areas tend to dry out and so evaporative cooling is prevented). With

[29] The first combined analysis of the observed evidence and consideration of the results of numerical climate models to estimate the climate sensitivity was carried out by a National Research Council panel chaired by MIT professor Jules Charney: Charney, J., 1979: *Carbon Dioxide and Climate: A Scientific Assessment*, Report of the Ad Hoc Study Group on Carbon Dioxide and Climate, National Research Council, National Academy Press, Washington DC.

[30] For context, it is estimated that the global average temperature was ~6°C (10.8°F) lower during the last glacial maximum (which peaked about 20,000 years ago) when roughly 1-2 km (~1.5 miles) of glacial ice covered the northern half of North America and Europe and sea level was lower by 120 meters (~400 feet). And similarly, the global average temperature was ~6°C (10.8°F) higher during the Cretaceous period (over 65,000,000 years ago) when dinosaurs roamed the Earth, palm trees grew in polar latitudes, and the Greenland and Antarctic ice sheets were not holding ice that, if melted, would raise global sea level by about 75 m (~250 feet).

human activities having already increased the atmospheric CO_2 concentration by over 40% over the last two centuries, analyses of the Earth's climatic history and of the physics governing the Earth's temperature make clear that further increases in the CO_2 concentration will lead to additional warming and associated climate change. While precise details are not fully worked out, that significant further warming and change will occur as a result of further emissions is solidly supported, as described in the series of already cited IPCC and U.S. national assessments.

20. With human-caused emissions of CO_2 and other greenhouse gases having been growing since the start of the Industrial Revolution, evidence of human-induced effects on climate is, as expected, becoming clearer and clearer. Scientists treat the search for and identification of the human influence in two steps: first, detect that an unusual change in climate has occurred, and then, second, considering all of the possible factors that could have been responsible and their characteristic pattern and timing, identify the cause of the change and attribute it to a specific factor (or proportionately to various factors). Doing this, analyses of observations of surface temperature, stratospheric temperature, sea ice, snow cover, sea level, distributions of flora and fauna, and more all indicate that changes are occurring relative to the pre-industrial baseline [e.g., the global average surface temperature is now ~0.8ºC (~1.4ºF) above its preindustrial value]. Consideration of the natural factors that could have caused the change (e.g., changes in solar radiation; changes in the frequency and intensity of volcanic eruptions; etc.) and of the human-induced factors (e.g., changes in the concentrations of greenhouse gases, including CO_2 from power plants; changes in the loading of sulfate aerosols resulting from sulfur dioxide emissions from power plants; changes in stratospheric ozone

concentrations resulting from CFC emissions; etc.) indicate that the only qualitatively and quantitatively consistent explanation for the accelerated warming during the late 20th century is the increasing concentration of greenhouse gases resulting from human activities. As the IPCC's Fifth Assessment Report (AR5) expressed the state of scientific understanding, "It is *extremely likely* [meaning scientific odds of better than 99 to 1; emphasis in the original] that human influence has been the dominant cause of the observed warming since the mid-20th century."[31] This is an extremely significant conclusion, especially recognizing that it is coming from the typically cautious scientific community and has been unanimously approved, word-for-word, by all of the ~190 participating nations! AR5 goes on to describe how human-related factors are also the only viable explanation for most of the changes in stratospheric temperature, sea ice, snow cover, sea level, and flora and fauna.

21. Critics suggest that the Earth's climate is always changing and so the changes could be mostly natural. Rather than be comforted by this assertion, what scientific research has shown is that changes in climate have primarily been a result of specific and identifiable factors that alter the global energy balance (e.g., changes in the Earth's orbit around the Sun; periods of volcanic eruptions; gradual movement of the continents; naturally induced changes in atmospheric composition, etc.). With human-induced influences (primarily due to the combustion of fossil fuels) now causing a warming influence larger than most natural influences have in the past, quantitative consistency leaves no other viable explanation than that significant changes in climate will be the result of the human-induced changes in the atmospheric concentrations of CO_2

[31] Page 17 in Intergovernmental Panel on Climate Change (IPCC), 2013: *Climate Change 2013; The Physical Science Basis*, T. Stocker et al., eds., Cambridge University Press, 1535 pp.

and other greenhouse gases. That these human-induced increases in warming influence are occurring much more rapidly and persistently than has resulted from natural-induced changes in the past is very worrisome because it will mean that there is much less time for ecological and societal systems to adjust; with much less time, it will be much more likely that highly adverse impacts will be the result. While scientific research continues to refine estimates of the amount and timing of the attribution to natural and human-induced influences, there is strong evidence that human-induced factors became of increasing importance over the 20th century and are now the dominant influence. In addition to this conclusion being drawn from the observations of changes in surface temperature, there is an array of confirmatory evidence across multiple indicators that makes very clear that human-induced influences are already affecting the climate—there is simply no other viable, quantitative and observationally supportable explanation.

22. Looking to the future, there are three basic contributors to changes in the climate:

a. The first contribution comes from whatever Nature might induce. Over the few thousand years preceding the Industrial Revolution, the global average temperature was relatively stable. Although the observational evidence is somewhat limited, the data suggest that the global average temperature did not vary by more than ~0.5ºC (~1ºF) around its baseline as a result of natural changes in incoming solar radiation, volcanic eruptions, and other natural influences. While it seems reasonable to assume that such variations will continue even as the increasing concentrations of CO_2 and other greenhouse gases from human activities induce warming and other changes in climate, the variations that have resulted in the recent past from changes in solar radiation, volcanic eruptions and other natural factors have generally been quite modest and are most likely going to result in modest ups and downs in global average temperature over seasonal to decadal time periods as compared to human induced warming, which is building up and will persist, at least to some degree, for centuries and longer.

b. The second contributor to future climate change is the ongoing adjustment of the global average temperature to past influences from human activities (i.e., from influences occurring during the 19^{th} and 20^{th} centuries). It is estimated, for example, that adjustment of the climate system to earlier emissions of CO_2 and other human influences will lead to a further global warming of ~0.5ºC (~1ºF) as compared to the present.

c. The third, and by far the largest, contributor to climate change over coming decades is going to be future emissions of greenhouse gases and other substances. All studies with numerical climate models that have been developed to emulate the behavior of Earth system indicate that the dominant determinant of future increases in global average temperature and the regional and seasonal patterns of climate change will be a result of the choices that we make now and in the future, particularly in how we choose to generate our energy and as a result cause changes in the atmospheric concentration of CO_2 and other greenhouse gases. At present, ~80-85% of global energy needs are being met by combustion of coal, petroleum, and natural gas. Scenarios for future emissions that are based on a continued dominance of such fossil fuels lead to estimates that the global average temperature will have been increased by ~4ºC (~7ºF) as compared to its preindustrial level by the end of the 21st century, far greater than any cooling that has resulted from a natural cooling influence (e.g., a major volcanic eruption) in the past. On the other hand, emissions scenarios based on aggressive pursuit of efficiency, conversion to non-fossil fuel sources of energy (so renewables, nuclear, etc.), and sharp reductions in emissions of non-CO_2 greenhouse gases suggest that the increase in global average temperature could be limited to ~2-3ºC (3.6-5.4ºF) above its preindustrial baseline if such actions start very soon.

Without doubt, the choices that are to be made with respect to future emissions will make a very large difference in the amount of climate change that occurs.

23. While the energy derived from combustion of coal and other fossil fuels provides many benefits to society, including electricity needed to store and prepare food, provide light and power for buildings and homes, supply fuels for transportation, and more, there are also significant environmental and societal impacts from the resulting emission of CO_2 and other warming agents. Drawing from the results of IPCC's 2007 assessment[32] and assessments of the impacts of climate change within the U.S.[33], the types of expected major impacts are quite diverse:

a. *Human health* will be affected in a wide range of ways. Because the absolute humidity will also increase, the heat (or discomfort) index will rise more than the

[32] Intergovernmental Panel on Climate Change (IPCC), 2007b: *Climate Change 2007: Impacts, Adaptation and Vulnerability*, M. Parry et al., eds., Cambridge University Press, 976 pp. More recent information will be available from Synthesis Report for IPCC's 2014 assessment, which was approved November 1, 2014 [see http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_SPM.pdf and http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_LONGERREPORT.pdf], but is not yet published. In general, the most recent IPCC assessment describes how the impacts are occurring more rapidly and severely than previously projected.

[33] *Global Climate Change Impacts in the United States*, 2009: Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 189 pp.; Melillo, J. M., T.C. Richmond, and G. W. Yohe, Eds., 2014: Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment, U.S. Global Change Research Program, 148 pp.

temperature, adding to threats from more intense, longer and more frequent heat waves. Disease vectors are already becoming more prevalent due to reduced suppression by cold, winter conditions, and this general trend of warming winters will continue (although occasionally broken by cold extremes). More severe storms and expansion of the areas where severe storms strike will increase the population at risk of injury and death.

b. *Agriculture and food production* in the U.S. and around the world will be disrupted by many aspects of the changing climate. Shifting season lengths, storm tracks[34] and temperatures will force shifts in the locations where crops can be productively grown, forcing agriculture into regions where soils may not be as suitable. Even though a higher CO_2 concentration enhances water-use efficiency, greater evaporation due to higher temperatures will lead to more rapid loss of soil moisture and more frequent occurrence of drought stress. Heat and water stress will also make animal-raising more difficult and expensive.

c. *Water resources* are a critical support element for food production, communities and their residents, industry, and hydroelectric power. Higher temperatures will raise the snowline and reduce the extent of glaciers in mountainous regions, sharply reducing water runoff during the longer and hotter warm season. Shifts in storm tracks are likely to move storms away from traditional water storage and

[34] The conditions over the Great Plains in the spring/summer of 2012 and 2013, for example, provided an indication of the type of changing conditions that will challenge ranchers and farmers. In 2012, the intense drought made it difficult, for example, for corn to mature, whereas in 2013, the unusually wet springtime conditions delayed and made planting difficult, allowing significantly fewer days for corn to reach maturity. Conditions representing the average of the departures from normal for the two years would have been much easier to deal with than the actual sequence of the two years. There are reasons to think that the rapid warming in the Arctic played a role in the two anomalies (e.g., see Francis, J. A. and S. J. Vavrus, 2012: Evidence Linking Arctic Amplification to Extreme Weather in Mid-Latitudes, *Geophysical Research Letters*, Vol. 39, L06801, doi:10.1029/2012GL051000).

flood control systems. As a result, increasingly intense storms are likely to lead to increased runoff and flooding where storms do occur, disrupting river channels and coastal communities. Expansion of the subtropics will tend to dry out the lower mid-latitudes, including especially the southern tier of the United States.

d. *Land cover and ecological services* are a critical link between society and the environment. As climatic zones shift poleward, existing forests and other ecosystems will be stressed, leading to more frequent likelihood of major wildfires, requiring tree and animal species to become established in new locations on an ongoing basis. As polar and mountainous regions warm, the conditions that determine the distribution of native species will change, with some species likely to be lost as their ranges are pushed northward into the Arctic Ocean or off the tops of mountains. As the climate continues to shift at well above historic rates, it is doubtful that forests and other vegetation will have time to adjust sufficiently to re-establish the full range of ecological services on which society has come to depend (i.e., water and air purification, soil stabilization, food and fiber production, recreation, biodiversity, etc.).

e. *Coastal regions and their marine resources* provide home and food for a large fraction of the global population. Sea level rise from the melting of glaciers and from thermal expansion of warming ocean waters will force the coastal edge inland, very likely inundating productive wetlands and pushing salt water into coastal estuaries and aquifers. Especially if the rate of sea level rise becomes large, building levees will become much less tenable as a protective measure for coastal communities and infrastructure. As storms draw increased energy and water vapor from warmer and warmer ocean and coastal waters, rainfall will increase in amount and intensity and higher winds, along with higher sea level, will carry damaging storm surges further inland, more severely damaging coastal communities and critical infrastructure. Simultaneously, increasing ocean acidification from the rising CO_2 concentration will make it more difficult for reproduction of marine life in wetlands, coastal marshes, and waterways.

f. The EPA Administrator's Endangerment Finding[35] also concluded that impacts in other regions of the world have the potential to affect the U.S. population. With the increasing mobility of the world's peoples, diseases in other regions can more readily spread, including back to the U.S. (in addition to affecting Americans who are overseas). With the tighter linkages of the international economy, reductions in food production and exports are more likely to be caused by extreme events in the U.S. and around the world, affecting the national and international economy. Worsening conditions, especially droughts and flooding, are also increasing the number of environmental refugees, increasing requests and pressures from those being affected to be allowed to enter the United States.

24. In response to the understanding of and risks resulting from climate change as understood at the time, the United States, along with most of the world's nations, negotiated the UN Framework Convention on Climate Change (UNFCCC) in 1992; the U.S. Senate ratified the Convention that same year. Article 2 lays out the Convention's objective:

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[35] EPA's Endangerment and Cause or Contribute Finding for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66,496 (Dec. 15, 2009).

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

Paragraph 23's overview of the types of disruptive impacts projected to result from on-going climate change, many of which are already emerging as a result of the human-induced changes in climate to date, makes clear that decisions leading to the continued emissions of CO_2 and other greenhouse gases require a consideration of the potential benefits and impacts/cost of the use of fossil fuels. At the international level, reports issued by the World Bank describe the impacts expected from the 4°C (~7°F) global warming projected by global climate models cited in the IPCC assessments to occur by 2100 as a result of the continued, unconstrained use of fossil fuels as likely to be devastating, including: "the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer [*sic*], wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many regions; increased frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef systems ... And most importantly, a 4°C world is so different from the current one that it comes with high uncertainty and new risks that threaten our ability to anticipate and plan for future adaptation needs."[36] In the United States, the U.S. Environmental Protection Agency summarized its analyses (drawing also from inputs across the U.S.

[36] Dr. Jim Yong Kim, President, World Bank Group, 2012, Foreword to *Turn Down the Heat: Why a 4ºC World Must be Avoided*, World Bank, Washington DC, 84 pp. Downloadable from http://www.worldbank.org/en/news/feature/2012/11/18/Climate-change-report-warns-dramatically-warmer-world-this-century

Government) in an Endangerment Finding[37], with the key finding being: "The Administrator finds that the current and projected concentrations of the six key well-mixed greenhouse gases — carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) — in the atmosphere threaten the public health and welfare of current and future generations." Based on such official findings, the present and projected impacts of climate change merit careful consideration in all decisions relating to continuing and future fossil fuel emissions.

25. Research on the global carbon cycle (i.e., the cycling of CO_2 and related compounds through the atmosphere, oceans, and terrestrial biosphere) makes clear that "stabilization" of the atmospheric concentration of CO_2, as called for in the UNFCCC, would require global CO_2 emissions to be cut by ~90% or more (even if all other nations cut their emissions to zero, total US emissions would need to be cut substantially). Given the nature of the impacts that are occurring and projected, stabilizing the CO_2 concentration at a lower level than its present value so as to tend to reduce impacts compared to the present would require CO_2 emissions to be totally eliminated, and perhaps even be made, in effect, negative (e.g., by promoting greater uptake by the oceans, forests, and grasslands than the emissions of fossil fuel-related CO_2 emissions). With observed impacts worsening as emissions continue, continuing on the present emissions path, much less expanding the level of emissions, which could result from continued mining of coal and extraction of petroleum and natural gas, would be expected to cause even more severe impacts than have already been described as unacceptable by

[37] U.S. Environmental Protection Agency, 2009, *Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act*. Downloadable from http://www.epa.gov/climatechange/endangerment/

leading national and international governmental organizations. Continuing to proceed with the licensing of additional land for extraction of coal in the face of the increasing seriousness of projected impacts would thus seem to go against the very clear findings of the national and international scientific community and national and international commitments to limit climate change.

POINT (2): The need for actions to sharply reduce emissions is urgent in order to reduce the likelihood of extremely disruptive consequences for the environment and society.

26. There have been only relatively limited actions to moderate the growth in emissions of CO_2 and other greenhouse gases since the issue was first raised to the level of the President and Congress in 1965 and the attention of international policymakers in 1985 (and many times since 1992 through the annual Conference of the Party negotiations under the UN Framework Convention on Climate Change). Meanwhile, the five international assessment reports of the Intergovernmental Panel on Climate Change and many supporting materials have documented the increasing intensity and breadth of the changes in climate and the seriousness and imminence of a widening range of impacts. Although the additional time has allowed even greater confirmation of the key scientific points (see paragraphs 16-25) and some clarification of details, the main result of the delays in taking action has been to further and further restrict the options and flexibility for responding, leaving less and less leeway for cutting back emissions enough to keep impacts from becoming unacceptably (i.e., dangerously) disruptive.

27. In addition to affecting the climate, the atmospheric CO_2 concentration also determines the dissolution of CO_2 into the ocean; the more CO_2 that is dissolved in the ocean, the lower the pH of the ocean (the pH is a measure of the acidity of a substance, with lower values indicating greater acidity). In terms of impacts, the lower the pH, the greater the ability of ocean waters to dissolve seashells and disrupt formation of coral reefs. The observed increase in the atmospheric CO_2 concentration has already lowered pH enough to raise the depth in the ocean where the carbonate in seashells starts to dissolve. This has been evident first in colder waters because, just as for soda pop, the lower the temperature, the more CO_2 it can hold, and so the lower the pH. Those raising oysters along the coast of the Pacific Northwest are already experiencing the impacts of lower pH, with increased rates of death of larva. Projections indicate that the continued rate of rise of the CO_2 concentration will cause a further decrease in pH by 2050 that is likely to seriously degrade coral reefs in the U.S. and throughout the world.[38]

28. The on-going increase in atmospheric temperature is likely not to occur smoothly. The historic record suggests that warming can occur in jumps, more like a staircase than a ramp. As this occurs, the occurrence of extreme weather and anomalous seasonal temperatures can change relatively rapidly. For example, analysis of observed changes in summertime average surface temperature, as described by Hansen et al.[39], suggests that the fraction of the Earth's land surface that, averaged over three decades,

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[38] Melillo, J. M., T. C. Richmond, and G. W. Yohe, Eds., 2014: Highlights of Climate Change Impacts in the United States; The Third National Climate Assessment. U.S. Global Change Research Program, 148 pp.; National Assessment Synthesis Team, 2000: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change: Overview Report*, U. S. Global Change Research Program, Cambridge University Press, Cambridge UK, 154 pp.

[39] Hansen, J., Mki. Sato, and R. Ruedy, 2012a: Perception of climate change. *Proceedings of the National Academy of Sciences*, **109**, 14726-14727, E2415-E2423, doi:10.1073/pnas.1205276109. Early draft posted as "Public perception of climate change and the new climate dice", arXiv.org:1204.1286. [Visualization available at http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=3975]

experiences extremely unusual summer heat has increased from ~0.1% to ~10% over about the last half century (so an increase by a factor of 100) [40]. While global warming is typically thought of as a slow and gradual process, many of the most severe impacts will arise as a result of the increasing frequency and intensity of extreme and disruptive weather.

29. Warming is not the only change in the climate caused by the increasing concentrations of CO_2 and other greenhouse gases. The warmer atmosphere tends to hold more water vapor, and thus creates the potential for more intense precipitation; indeed, observations from all continents indicate that an increasing fraction of precipitation is occurring in heavy rains that tend to lead to additional flooding. Warmer temperatures also tend to lead to greater evaporation, so that, in the absence of rain, soils dry more rapidly, and drought conditions can be reached more and more rapidly.

30. In high latitudes, the changes and impacts can be especially severe. Not only do snow and sea ice cover retreat, but frozen ground also thaws. Thawing of the permafrost, which contains large amounts of carbon that could be released to the atmosphere as CO_2 and/or CH_4 (depending on changes in surface hydrology), has the potential to further amplify global warming. In addition, the amplified high-latitude warming has already started to cause significant loss of ice from the Greenland and Antarctic ice sheets. As the rate of ice sheet melting continues to accelerate, it has the potential to increase the rate of sea level rise from its value of about 0.2 m (8 inches) per century during the 20th century to ~1.0±0.5 m (roughly 40± 20 inches) per century during

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[40] Observations indicate that the departures of summer average temperature from its three-decade average are distributed about the average roughly as a bell-shaped curve. With global warming, the bell-shaped curve is shifted to a warmer average. This has the effect of greatly increasing the likelihood of the likelihood that a particular summer average temperature anomaly will exceed what were earlier considered high temperature extremes.

the 21st century[41]. Such an increase would lead to increasing coastal damage and, over time, require abandonment of many particularly low lying, but highly populated, areas (e.g., southern Florida, the underlying geology of which is limestone that will be dissolved away as sea level rises). Such an increased rate of sea level rise is also especially worrisome because, once started, the melting of ice sheets and consequent sea level rise would very likely continue at an elevated rate for many centuries as the oceans and ice sheets continue to adjust to the warmer conditions. The amount of warming that would trigger such high rates of ice loss remains somewhat uncertain, but paleoclimatic records indicate that the sea level has been very responsive to changes in climate. As a rough indication of magnitude, the IPCC AR5 Working Group 1 report concluded that sea level was approximately 5 to 10 m (roughly 16-33 feet!) higher during the last interglacial period about 125,000 years ago when the global average temperature, due to slow, cyclic changes in the Earth's orbit around the Sun, was likely about one degree Celsius higher than at present. Based on this past indication of high sensitivity of the ice sheets to warming and on the accelerating loss of mass of the ice sheets now being observed, it seems likely that a threshold leading to even greater ice loss and to much higher sea level may be near, if not already passed. Even if these much higher sea levels are approached at a rate of only (!) 0.5 to 1.0 meter (about 1.5 to 3 feet) per century, the

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[41] Depending on emissions scenario, the new IPCC Assessment Report from WG 1 projects that the human-induced augmentation to sea level during the 21st century is likely to be 0.45 to 0.82 m [18 to 32 inches] higher for continuing high emissions scenarios as compared to 0.26 to 0.55 m [10 to 22 inches] higher for an emissions scenario driven lower by aggressive transition to renewable energy sources. These values would be on top of the roughly 0.17 to 0.21 m [7 to 8 inches] increase during the 20th century. While some sea level rise will occur due to the ongoing effects of past emissions, a very aggressive global emissions reduction scenario could reduce the maximum level somewhat further. See Intergovernmental Panel on Climate Change (IPCC), 2013: *Climate Change 2013; The Physical Science Basis: Summary for Policymakers*, T. Stocker et al., eds., Cambridge University Press, 1535 pp. Accessible at http://www.climatechange2013.org/.

inundation of low-lying lands will be very substantial, and the need for cities and coastal infrastructure to be protected by levees or possibly relocated would be substantial.

31. Recognizing the increasing emergence of important climate change impacts and the increasing likelihood that warming may soon exceed thresholds beyond which impacts would rapidly accelerate and not be stoppable, much less, reversible, international leaders agreed in 2009 to aim to limit the increase in global average temperature to 2ºC (3.6ºF) above its preindustrial baseline—a warming presently projected to occur in the mid-21st century and avoidable only if emissions reductions are started imminently. With important impacts already occurring at a global warming of ~0.8ºC (1.4ºF), scientific analyses suggest that a warming of 0.5ºC (0.9ºF) would have been a more appropriate cap to impose if serious impacts of climate change were to have been fully avoided. However, cutting emissions enough to limit warming to a cap of ~0.5ºC (0.9ºF) when fossil fuels provide over 80% of the world's energy would involve such sharp reductions in emissions that international leaders chose to set a goal of not exceeding an increase in global average temperature of 2ºC (3.6ºF) above the preindustrial baseline. With impacts emerging even more rapidly than projected in past scientific assessments (see Synthesis Report for IPCC's Fifth Assessment[42]), it is becoming more and more apparent that reaching or exceeding the 2ºC (3.6ºF) goal will likely lead to very disruptive impacts for many nations, as the series of World Bank reports is making explicitly clear[43].

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[42] Approved November 1, 2014. See http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_SPM.pdf and http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_LONGERREPORT.pdf

[43] World Bank, 2012: *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*, prepared by the Potsdam Institute for Climate Impact Research and Climate Analytics, Washington DC, 119 pp.; World Bank, 2013: *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience-*

32. The recent IPCC AR5 Working Group 1 report estimated that to have a 50% likelihood of the global average temperature not exceeding 2ºC (3.6ºF)[44], total allowable CO_2 emissions in the future would need to be limited to no more than ~1000 billion metric tons of CO_2[45,46]. Global emissions of fossil fuel CO_2 in 2013 are estimated to be ~36 billion metric tons of CO_2 per year[47], suggesting emissions at the current level could continue for no more than ~30 years and then would need to be near zero thereafter or, for a smoother economic and technological transition, emissions could phased down steadily to zero over 50 to 60 years[48]. The problem faced in international negotiations is that instead of going down, global emissions are still rising, which will necessitate an

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Executive Summary, prepared by the Potsdam Institute for Climate Impact Research and Climate Analytics, Washington DC, 34 pp.

[44] Even though a much higher likelihood of avoiding serious impact might be desired given the severity and potential irreversibility of emerging and projected impacts, the calculation for a 50% likelihood is used here in recognition of the important benefits being provided by use of fossil fuels.

[45] Scientific studies typically express global emissions in terms of billions of metric tons of carbon (GtC), whereas emissions are typically expressed in terms of millions of metric tons of CO_2 ($MMTCO_2$) in national inventories and in the international negotiations process. Expressing the value in terms of CO_2 rather than of C gives a number that is larger by a factor of 3.67 due to inclusion of the mass of the oxygen atoms in the calculation. So that the numbers are of more manageable size, this declaration expresses emissions in terms of billions of metric tons of CO_2 (i.e., $GtCO_2$), which simply involves dividing $MMTCO_2$ by a factor of 1000. Using $GtCO_2$ also makes it easy to divide emissions by the global population of about 7 billion to come out with per capita annual emissions. What is important, in any case, is to be careful and consistent in indicating the choice that is made.

[46] The value of 1000 billion metric tons of CO_2 ($GtCO_2$) as an estimate of maximum allowable emissions is derived as follows. The IPCC WG 1 AR5 Summary for Policymakers (p. 27) indicates that "[l]imiting the warming caused by anthropogenic CO_2 emissions alone with a probability of >33%, >50%, and >66% to less than 2ºC since the period 1861-1880, will require cumulative CO_2 emissions from all anthropogenic sources to stay between 0 and about 1570 GtC (5760 $GtCO_2$), 0 and about 1210 GtC (4440 $GtCO_2$), and 0 and about 1000 GtC (3670 $GtCO_2$) since that period, respectively. These upper amounts are reduced to about 900 GtC (3300 $GtCO_2$), 820 GtC (3010 $GtCO_2$) and 790 (2900 $GtCO_2$), respectively, when accounting for non-CO_2 forcings.... An amount of 515 [445 to 585] GtC (1890 [1630 to 2150] $GtCO_2$) was already emitted by 2011." For 50% likelihood, emission of 3010 $GtCO_2$ represents the upper allowable limit for total emissions since the mid 19th century. From this total, subtract the 1890 $GtCO_2$ mid-range estimate for emissions up through 2011 and this leaves about 1120 $GtCO_2$. With present annual emissions being about 35 $GtCO_2$ per year, this takes the total allowable remaining down to roughly 1000 $GtCO_2$ for 2015 and later years. Making different choices and considering uncertainties in the estimates would lead to values of allowable emissions that vary somewhat but not change the general conclusion that present reliance on fossil fuels for energy must be phased out over the next several decades.

[47] Source: The Global Carbon Project (GCP), see http://www.globalcarbonproject.org/index.htm; for visualization of total and per capita emissions by country, see http://www.globalcarbonatlas.org/?q=en/emissions

[48] Note that emissions are not presently continuing at current levels, but are increasing ~2.4% per year (see GCP, 2014).

even sharper rate of reduction in the future to achieve the internationally agreed-upon goal of having a 50% likelihood that the 2ºC (3.6ºF) cap is not exceeded (as indicated earlier, this temperature cap is well above the value that scientific results suggest would be likely to avoid quite serious impacts). It is this impending limit on emissions that is particularly important for nations to be evaluating in developing and implementing policies relating to future energy use and combustion of fossil fuels, particularly coal and unconventional petroleum (e.g., oil from shale) and the consequent release of CO_2.

POINT 3: Release of the carbon contained in U.S. coal and shale reserves would directly contribute to disruptive climate change, while also undermining the U.S. commitment embraced in the UN Framework Convention on Climate Change to stabilize the climate in a manner that would "prevent dangerous anthropogenic interference with the climate system."

33. The Energy Information Administration (EIA) indicates that the total U.S. demonstrated reserve base for coal totals ~481 billion short tons, of which about 54% is considered accessible by mining[49]. Using the EIA's conversion factor, combustion of a short ton of coal leads to emission of ~2.86 tons of CO_2[50]. Thus, as a limiting case, ultimate combustion of all of the U.S. coal resources would lead to emission of ~1375 billion short tons of CO_2, 54% of which totals ~743 billion short tons of CO_2. With the limit of *global* emissions of CO_2 being ~1000 billion metric tons (~1100 billion short tons of CO_2) to ensure a 50% likelihood that the increase in global average temperature

[49] See http://www.eia.gov/coal/reserves/. The phrase "short" ton refers to English tons, equivalent to 2000 pounds. Internationally, a metric ton is equivalent to 1000 kilograms, which is about 2200 pounds. For the purposes here, this 10% difference does not significantly affect the conclusions.
[50] See http://www.eia.gov/coal/production/quarterly/co2_article/co2.html

would not exceed 2ºC (3.6ºF) above the preindustrial baseline, total combustion of accessible U.S. coal (which at current rates would take of order 250 years--less if the rate of emissions grows) would take up roughly three-quarters of the allowable global total emissions. With annual U.S. CO_2 emissions from coal, oil, and natural gas representing less than 15% of annual global emissions and coal representing about half of U.S. emissions, all plausible emission scenarios for limiting global warming to 2ºC (3.6ºF) will require that most of the potentially accessible coal be left in the ground[51].

34. U.S. coal production totaled ~1000 million short tons of coal in 2012[52], equivalent to ~0.9 billion metric tons of coal per year. Combustion of this coal would lead to emission of ~2.6 billion metric tons of CO_2, which was ~7.3% of global CO_2 emissions that year. Were this share to continue into the future, U.S. coal's share of the ~1000 billion metric tons of CO_2 cap for keeping the increase in global average temperature below 2ºC (3.6ºF) would be ~73 billion metric tons,; this allotment would be used up in less than 30 years (73/2.6) at the current rate of coal production. Planning for any continued use of coal, consistent with the internationally agreed temperature cap (one worked out with leadership of President Obama in Copenhagen in 2009), will thus clearly require sharply phasing down combustion (and, thus, mining) of coal over only a very few decades, indeed even much, much more rapidly than would be achieved by the proposed emissions regulations on new and existing coal-fired electric power plants.

35. In that the U.S. population of roughly 314 million people is about 4.3% of the global population of about 7.25 billion, just the coal component of U.S. emissions is

[51] Note that exporting the coal for combustion overseas still leads to emission to the global atmosphere, leading to climate change impacts here in the U.S., such that a comprehensive analysis would still need to account for the indicated impacts.
[52] See http://www.eia.gov/coal/annual/

almost twice (i.e., 7.3/4.3) the total U.S. per capita share of global emissions. As indicated earlier, the U.S. share of global CO_2 emissions is presently ~15%, so roughly 3.5 times the U.S. per capita share. While international agreements are not currently based on per capita emissions, improvements in the standard-of-living in developing nations is raising their total and per capita energy use and, to the extent that this energy is derived from fossil fuels, decreasing the U.S. share of total emissions, and so, at least implicitly, the share of the 1000 billion metric tons of CO_2 allowable if the increase in global average temperature is to be kept below the agreed-upon cap of 2ºC (3.6ºF). Were per capita share to be the basis of an international agreement, or even were there to be a shift in that direction, and were coal's roughly 50% share of U.S. CO_2 emissions to continue, U.S. coal combustion would need to be cut off after of order 8 years![53] The need for immediate consideration of the U.S. Government policy on future use of coal and leasing of lands for mining of coal is thus very clear.

36. Were there good prospects for quick deployment of practical and cost-effective technologies for scrubbing, capturing and permanently sequestering the CO_2 being emitted from coal-fired power plants, such a technological innovation could extend the potential for use of coal as an acceptable source of energy. Even relatively optimistic views of the technology and the role that it can play suggest that it will take a few decades to play an important role[54]. Indeed, development of suitable technologies for removing perhaps two-thirds of the emitted CO_2 is still in the early demonstration stage, suggesting that there is little likelihood that suitable systems for sufficiently cutting CO_2

[53] The time is derived as follows: At present rates and U.S. share, coal production (and combustion) would need to be terminated in about 28 years (73/2.6 as indicated in paragraph 34). With U.S. emissions being about 3.5 times their per capita share, 28/3.5 gives 8 years.
[54] For example, see https://www.iea.org/Textbase/npsum/ccsSUM.pdf for the view of the International Energy Agency. Other views are less optimistic—for example, see http://fas.org/sgp/crs/misc/R42496.pdf

emissions will be in place at all coal-fired power plants over the next few decades. Given this situation, the path to achieving the U.S.-endorsed international proposed warming cap of about 2ºC (3.6ºF) above preindustrial will necessarily require the early phasing down of combustion of coal in the U.S. Also, note that mining the coal in the U.S. and then combusting it overseas (e.g., in coal-fired power plants in China) would not solve the problem because CO_2 is a long-lived global pollutant and no matter where it is emitted, it will contribute to global warming. Indeed, mining coal in the U.S. for combustion overseas would simply lead to greater climate change and consequent impacts on the U.S. without even the benefit of the energy that would be provided.

37. That climate change is an important issue for the U.S. has been recognized in EPA's Endangerment Finding[55], in the President's Climate Action Plan,[56] in the U.S. commitment through the UN Framework Convention on Climate Change process to limit global warming, and in many additional national statements, assessments and reports. To be consistent with these important positions, the implications for global climate change of all actions and policies leading to substantial emissions of CO_2 and other greenhouse gases need to be comprehensively considered. This is particularly the case for ongoing combustion of coal because the amount of CO_2 released per unit of useful energy is substantially greater for coal than for petroleum or natural gas (assuming little escape of methane during the extraction process).

38. An initial effort has been made by the U.S. Office of Management and Budget (OMB) to estimate the potential cost implications of emission of CO_2. OMB has

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[55] U.S. Environmental Protection Agency, 2009, *Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act*. Downloadable from http://www.epa.gov/climatechange/endangerment/

[56] The President's Climate Action Plan, Executive Office of the President, June 2013, 21 pp.

now been through two rounds of an effort to estimate what it is calling "the social cost of carbon" (SCC)[57]. This effort has sought to monetize the impacts of climate change most affecting the economy in the near term, including impacts occurring now and building into the future (although with a discount rate and method that is considered quite controversial[58]), and to apportion the costs to emissions of CO_2. Although the OMB report agrees there are many limitations to the approach it is using, including, for example, not accounting for the sharply increasing risks of extreme and nonlinear outcomes (i.e., not taking account of generally low probability/high consequence outcomes that are typically dealt with by purchasing insurance and otherwise reducing vulnerability to disastrous outcomes) and not accounting for the cultural and historic ties of societies to particular climatic conditions, OMB has nonetheless pushed forward. Their most recent update of the central value of the SCC was $43/ton of CO_2 for their reference year of 2020, which was a jump of ~60% from their 2010 estimate. Applying this to the annual total of coal-related CO_2 emissions suggests the annual climate-related impacts amount to roughly $125 billion dollars. In that a number of reputable academic studies suggesting the limitations in OMB's analysis makes its estimate a factor of several too low, the value derived from OMB's methodology needs to be considered a floor, useful perhaps for prioritizing among potential near-term regulatory steps and policies. However, in that the OMB estimate would not limit U.S emissions adequately to achieve the international reduction in emissions required to limit warming to 2ºC (3.6ºF), use of

[57] (a) Technical Support Document: *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*; Interagency Working Group on Social Cost of Carbon, United States Government, February 2010, 50 pp. (b) Technical Support Document: *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866*, Interagency Working Group on Social Cost of Carbon, United States Government, May 2013, 21 pp.
[58] Stern, Sir Nicholas, 2010: *Stern Review: The Economics of Climate Change: Executive Summary*. Available at http://webarchive.nationalarchives.gov.uk/20130129110402/http://www.hm-treasury.gov.uk/d/Executive_Summary.pdf

its value for the social cost of carbon is too low to us in development of an overall U.S. climate change policy.

SUMMARY

39. Scientific assessments carried out by the IPCC (of which the U.S. is an active and affirming member), by the U.S. Government, and by regional and other entities document with high confidence that human activities are the primary cause of climate change over recent decades and will be the cause of much more change over coming decades. The increasing atmospheric CO_2 concentration is a major contributor to the warming that has occurred and future warming will be largely determined by future emissions.

40. Considered as a whole, evidence from around the world and across the U.S. makes clear that the climate is changing in ways that are directly affecting the American public, as made clear both in EPA's Endangerment Finding and the U.S. National Assessment. Impacts include: shorter, less intense winters (which has significant negative impacts, although also some beneficial ones) and longer, hotter summers; sea level rise, often exacerbated by higher storm surges from tropical cyclones, that is already forcing construction of protective barriers in the face of increasing damage along coastlines; retreat of snow cover and melting of mountain snow and glaciers that are adversely affecting water resources; more intense storms and conditions more conducive to wildfires; ocean acidification; shifts in flora and fauna—and more. CO_2 emissions from continued mining and combustion of coal will amplify climate change at local,

regional, national and global scales, and the relatively rapid rate of change will make it very difficult for natural and human-created and managed systems to successfully adapt.

41. Based on my experience and review of the scientific literature, including having been on the blue ribbon review panel for the 2009 assessment of climate change impacts on the United States prepared by the U.S. Global Change Research Program, I consider the summary of climate change's many impacts contained in the EPA Endangerment Finding to be generally comprehensive and credible and agree with its recommendation about the need to limit emissions to moderate the amount and pace of climate change. Indeed, my only reservation is that, if anything, an even greater sense of urgency is appropriate based on the amplified changes in the Arctic that are already affecting Alaska and other high-latitude regions as well as likely causing the weather over the 48 contiguous United States to become more variable and extreme.

42. Continuing high levels of emissions from combustion of coal, which makes up a significant share of U.S. and global emissions, will increase the difficulty of international efforts to moderate and then stabilize the climate. The international community of nations, including the United States, has committed in the UNFCCC to "prevent dangerous anthropogenic interference with the climate system." Every emissions increment by combustion of coal in the U.S. pushes total global emissions toward the amount that is likely to cause a warming in excess of the internationally agreed cap of 2°C (3.6°F).

43. There are alternative policies (e.g., encouraging energy efficiency) and sources of energy (including particularly wind, solar, biomass, etc.) for the U.S. that could significantly reduce fossil fuel emissions and associated changes in the climate.

Failure to carry through a full evaluation of alternative approaches to generating energy from coal, which is the largest source of U.S. emissions, represents a serious failure in pursuing the best options for the environment and the people of the U.S. and the world.

I declare under penalty of perjury under the laws of the United States that the foregoing is true and correct to the best of my knowledge.

Dated: November 2, 2014

Michael C. MacCracken