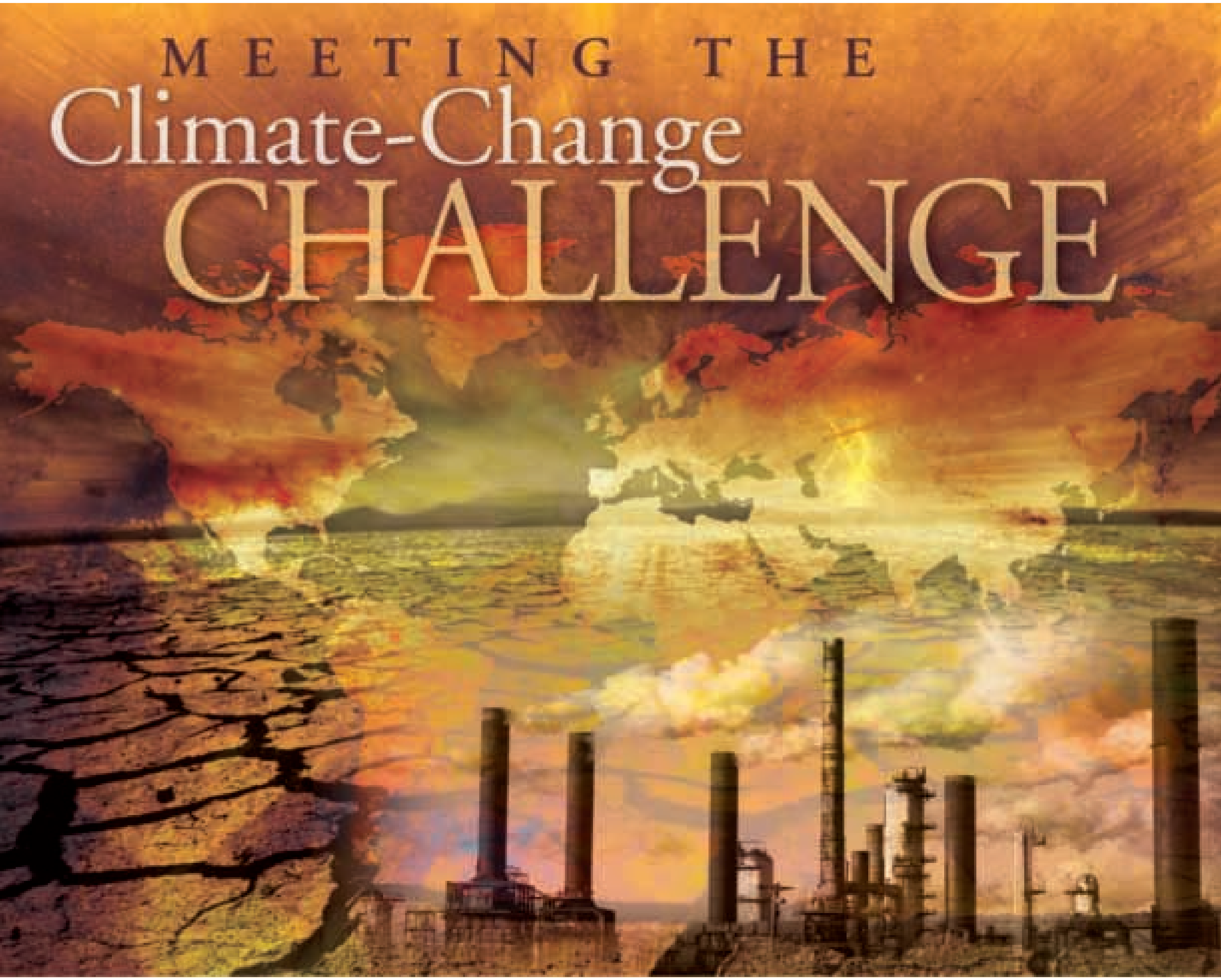
EIGHTH ANNUAL JOHN H. CHAFEE MEMORIAL LECTURE ON SCIENCE AND THE ENVIRONMENT

January 17, 2008



John P. Holdren

Professor, Harvard University, and
President and Director, The Woods Hole Research Center

National Council for Science and the Environment
Improving the scientific basis for environmental decisionmaking

National Council for Science and the Environment
Improving the scientific basis for environmental decisionmaking

The National Council for Science and the Environment (NCSE) improves the scientific basis of environmental decisionmaking through collaborative programs with diverse communities, institutions and individuals.

The Council works for a society where environmental decisions are based on an accurate understanding of the underlying science, its meaning and limitations, and the potential consequences of action or inaction. The Council does not take positions on environmental policy issues and is dedicated to maintaining and enhancing its reputation for objectivity, non-partisanship, and achievement.

The Council has programs in five strategic areas:

EDUCATION AND CAREER DEVELOPMENT

NCSE brings members of the academic community together to improve their environmental programs. Programs in this area include:

- The **University Affiliate Program** provides services to advance programs at 140 member schools ranging from large private and public research institutions to smaller liberal arts institutions.
- The **Council of Environmental Deans and Directors** brings academic leaders together to improve the quality and effectiveness of environmental programs on the nation's campuses.
- The **Council of Energy Research and Education Leaders** is a multidisciplinary membership organization made up of heads of academic energy research and education centers, institutes, and programs.
- The **EnvironMentors Program** prepares high school students in underserved communities for college programs and careers in science and environmental professions.
- The **Campus to Careers program** partners with government agencies, businesses, and foundations to advance young people in environmental careers through fellowships, internships, and other means.

NATIONAL CONFERENCE ON SCIENCE, POLICY AND THE ENVIRONMENT

The Council annually brings together more than 800 leaders from science, government, corporate, and civil societies to develop strategies to improve decisionmaking on a major environmental theme. Following the conference, the strategies are disseminated nationally and used to catalyze new initiatives with key communities.

PUBLIC EDUCATION—THE EARTH PORTAL (WWW.EARTHPORTAL.ORG)

Through the Environmental Information Coalition, the online Earth Portal was launched on April 27, 2007, including the Encyclopedia of the Earth (www.eoearth.org). Currently, nearly 800 scholars from 60 countries have contributed comprehensive and accessible resources for a global audience of decisionmakers and the general public.

SCIENCE SOLUTIONS FOR ENVIRONMENTAL CHALLENGES

The Council brings stakeholders together to develop and implement science-based solutions to specific environmental challenges. Programs in this area include:

- The **National Commission on Science for Sustainable Forestry** provides practical information and tools to serve the needs of forest managers and policymakers to improve sustainable forestry.
- The **Wildlife Habitat Policy Research Program** produces information and tools to accelerate the conservation of wildlife habitat in the United States through State Wildlife Habitat Plans.
- The **Outlook Forest Research Dialogue** enhances research coordination, collaboration, and partnership within the forestry community.

SCIENCE POLICY

NCSE builds understanding of, and support for, environmental science and its applications. The Council testifies before Congress, consults regularly with key decisionmakers in government, and works to promote funding for environmental programs at numerous federal agencies.

John H. Chafee Memorial Lecture on
Science and the Environment

John P. Holdren

Teresa & John Heinz Professor of Environmental Policy and
Professor of Earth and Planetary Sciences, Harvard University;
President and Director, The Woods Hole Research Center; Chair of the Board, AAAS

Sponsored by the
National Council for Science and the Environment (NCSE)

Presented at the
8th National Conference on Science, Policy and the Environment
Ronald Reagan Building and International Trade Center in Washington, DC

January 17, 2008

This volume is the eighth in a series of books documenting the annual
John H. Chafee Memorial Lecture on Science and the Environment.

ISBN 0-9710439-7-3

For citation purposes, please use:
Holdren, John, 2008, **Meeting the Climate Change Challenge**. Eighth Annual John H. Chafee Memorial Lecture on Science and the Environment. Washington, DC: National Council for Science and the Environment.

This volume is the eighth in a series of books documenting the annual John H. Chafee Memorial Lecture on Science and the Environment. The lecture was delivered at the 8th National Conference on Science, Policy and the Environment: Climate Change: Science and Solutions (David Blockstein, Conference Chair) on January 17, 2008, in Washington, DC.

National Council for Science and the Environment
1101 17th Street, NW, Suite 250
Washington, DC 20036
Phone: 202-530-5810
Fax: 202-628-4311
E-mail: NCSE@NCSEonline.org
Web: www.NCSEonline.org

Manufactured in the United States of America.

The National Council for Science and the Environment is grateful to the following sponsors for making possible the Eighth Annual John H. Chafee Memorial Lecture on Science and the Environment

Sponsors

USDA Forest Service

U.S. Geological Survey

Partners

Centers for Disease Control and Prevention

U.S. Environmental Protection Agency

National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration

Patrons

Duke Energy

Environ

National Institute of Environmental Health Sciences

National Institute of Standards and Technology

The Ocean Foundation

Toyota

Supporters

Center for Environmental Education

Disney's Animal Kingdom

Lighting Science

Mary Kay

Robert & Patricia Switzer Foundation

Media

Imaging Notes

Dedication

This book is dedicated to the memory of Senator John H. Chafee who, in his 23 years representing Rhode Island in the U.S. Senate, was a leader in promoting a bipartisan, science-based approach to environmental issues.

Top: Ross C. "Rocky" Anderson, Mayor, Salt Lake City (2000-2008); Lynn Scarlett, Deputy Secretary of the Interior; Ray Suarez, Senior Correspondent, "The NewsHour with Jim Lehrer," and Representative Jay Inslee (D-Washington) discuss political solutions to climate change at a Plenary Roundtable discussion on January 18, 2008, at NCSE's Eighth National Conference on Science, Policy and the Environment in Washington, DC. Left, conference attendees have lunch at the Ronald Reagan Building and International Trade Center. Below, participants gather for a plenary session (NCSE photos).

Table of Contents

Introduction

Lecture

Appendices

Ambassador Richard Benedick

President, National Council for Science and the Environment

Each year, ladies and gentlemen, a high point of our national conference, in addition to the presentation of the Lifetime Achievement Award, is the accompanying John H. Chafee Memorial Lecture, and also its handsome publication, which you will generally receive a little bit later in the year. There are copies of past lectures on the tables outside, handsomely produced, and I invite you to take them and enjoy reading them. It's a wonderful selection.

As senator from Rhode Island, Senator John Chafee was one of the pioneers to campaign on behalf of the environment. He was indefatigable, he was courageous, and he was eloquent in defending the environment against corporate greed, political ideologues, and an apathetic public. I personally experienced his commitment when ideologues within the Reagan Administration were trying to reverse the strong U.S. position for an effective ozone treaty, the Montreal Protocol, and incidentally, to relieve me of my position as chief U.S. negotiator in the process. Senator Chafee was solid as a rock in his support of me and of a strong protocol, and the rest, as they say, is history.

Ladies and gentlemen, the list of Chafee lecturers rivals the Nobel Prize I would say. In fact, the first were Nobel laureates, Sherry Rowland and Mario Molina, who provided a scientific underpinning for the Montreal Protocol and protection of the ozone layer. And after that came E.O. Wilson, Rita Colwell, Jared Diamond, William Ruckelshaus, Ralph Cicerone, and Larry Brilliant. They're all names that you all recognize.

And one of the most important fringe benefits for me as being president of this wonderful organization is introducing the annual John H. Chafee Memorial Lecture. In this case, it's an old friend and colleague, this year's laureate, John Holdren. He holds not one, but two professorships at my alma mater, Harvard University. He is Teresa and John Heinz Professor of Environmental Policy at the Kennedy School of Government, and he is also professor of Environmental Science and Public Policy in Harvard's Department of Earth and Planetary Sciences. It's particularly appropriate because Senator John Heinz was a very close colleague of Senator Chafee in those early days of providing leadership on environmental issues in the U.S. Senate.

Dr. Holdren is also the President and Director of the Woods Hole Research Center in Massachusetts, and is the immediate past President and current Chairman of the Board of the American Association for the Advancement of Science, AAAS. A more complete biography of our laureate is on page 32 of your program [see page 23 in this document].

Ladies and gentlemen, I'm happy to present this year's Chafee lecturer, Dr. John Holdren.

John P. Holdren

Teresa & John Heinz Professor of Environmental Policy and Professor of Earth and Planetary Sciences, Harvard University; President and Director, The Woods Hole Research Center; Chair of the Board, AAAS

Meeting the Climate-Change Challenge

JOHN H. CHAFEE MEMORIAL LECTURE ON SCIENCE AND THE ENVIRONMENT

It's a particular challenge that I face tonight to talk in an interesting way about meeting the climate change challenge before an audience that contains so many experts on the topic. I hope I can live up to it at least by offering a few perspectives and formulations that may be new to you.

I'm going to start by summarizing the main messages for those who lose interest, fall asleep, or heed the call of nature before I get done.

The first of these messages is that I think we in the scientific community have made a mistake by allowing the term "global warming" to capture the podium, the platform, the title of this problem. Global warming is a misnomer, because it implies something that is gradual, something that is uniform, something that is quite possibly benign. What we are experiencing with climate change is none of those things. It is certainly not uniform. It is rapid compared to the pace at which social systems and environmental systems can adjust. It is certainly not benign. We should be calling it "global climatic disruption" rather than "global warming."

Global warming is a misnomer, because it implies something that is gradual, something that is uniform, something that is quite possibly benign. What we are experiencing with climate change is none of those things.

The second key point is that the disruption and its impacts are now growing much more rapidly than almost anybody expected even a few years ago. The result of that, in my view, is that the world is already experiencing "dangerous anthropogenic interference in the climate system." Many of you will recognize that term in quotes as part of the text of the United Nations Framework Convention on Climate Change, which was signed by the senior President Bush in 1992 and subsequently ratified by the United States and 190 other nations. That Convention embodies the goal of avoiding dangerous anthropogenic interference in the climate system, and it is my contention that that goal is already out of reach. We are experiencing dangerous anthropogenic interference by any reasonable definition today. The question now is whether we can avoid catastrophic human interference in the climate system.

Our options in this domain are three. They are mitigation, adaptation, and suffering. Basically, if we do less mitigation and adaptation, we're going to do a lot more suffering.

In mitigation and adaptation, there's a lot of low-hanging fruit — measures that are inexpensive, measures that offer substantial co-benefits, measures that would be worth taking even if we were weren't worried about climate change — but it's not enough. We need a price on greenhouse gas emissions in order to motivate reaching higher into the tree, and we need research and development to bring more fruit into reach.

And the final key point is that the United States has to switch from being a laggard in addressing this problem to being a leader, and we need to switch sooner rather than later if the world as a whole is to act in time to avoid catastrophic interference in the climate system.

Let me back up some of this now with a bit of a tutorial, which will be old news to many of you, but I'll run through it quickly. First, one really needs to start with what climate change is and what climate change means. It's the pattern of weather, meaning the averages, the extremes, the timing, the spatial distribution not only of hot and cold, but of cloudy and clear, humid and dry, drizzles and downpours, snowfall, snowpack and snowmelt, blizzards, tornadoes, typhoons. And climate change means alterations in the patterns of all of those things. One absolutely key point that the scientific community has largely failed, I think, to get across adequately is that the global average surface temperature of the planet is simply an index of the state of the global climate as expressed in those patterns, and that small changes in that index represent big changes in the patterns. And that is what we are seeing.

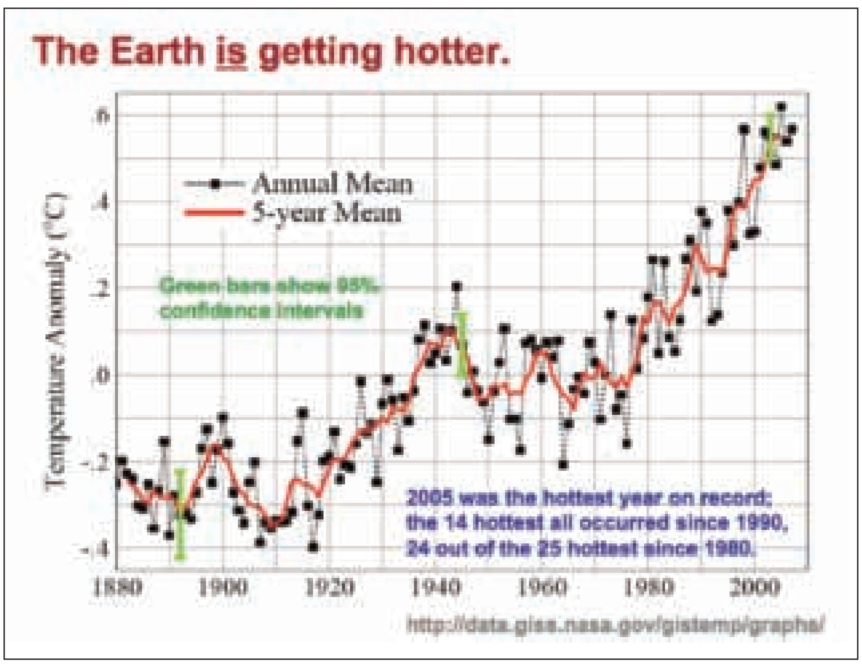


FIGURE 1

Climate governs the availability of water; the productivity of farms, forests, and fisheries; the prevalence of oppressive heat and humidity; the formation and dispersion of air pollutants; the geography of diseases; the damages that we have to expect from storms, floods, droughts, and wildfires; the property losses that we have to expect from sea-level rise; the expenditures that we have to make on engineered environments. How much of the environment do we have to air condition? What dams and dikes and barriers do we need to build, and so on? And climate governs the distribution and abundance of species, the ones we love along with the ones we hate.

The Earth *is* getting hotter. Figure 1 shows the latest update of the data for global average surface temperature released last Friday by the Goddard Institute for Space Studies, so it includes the data for the complete year 2007. It's now clear that 2007 is in a tie for the second hottest year with 1998. 2005 was the hottest. And you can see, as indicated in the instrumental record going back to 1880 — when there were first enough thermometer measurements to define meaningfully a global average surface temperature — the 14 hottest years in that record all occurred since 1990, and 24 out of the 25 hottest since 1980.

What's happening reverses a long cooling trend. Data from the National Research Council show, based on proxy reconstructions of global surface temperature, that the temperature was declining around 1600, leveled off, then started to rise after 1700, and more sharply after 1800 (see Figure 2).

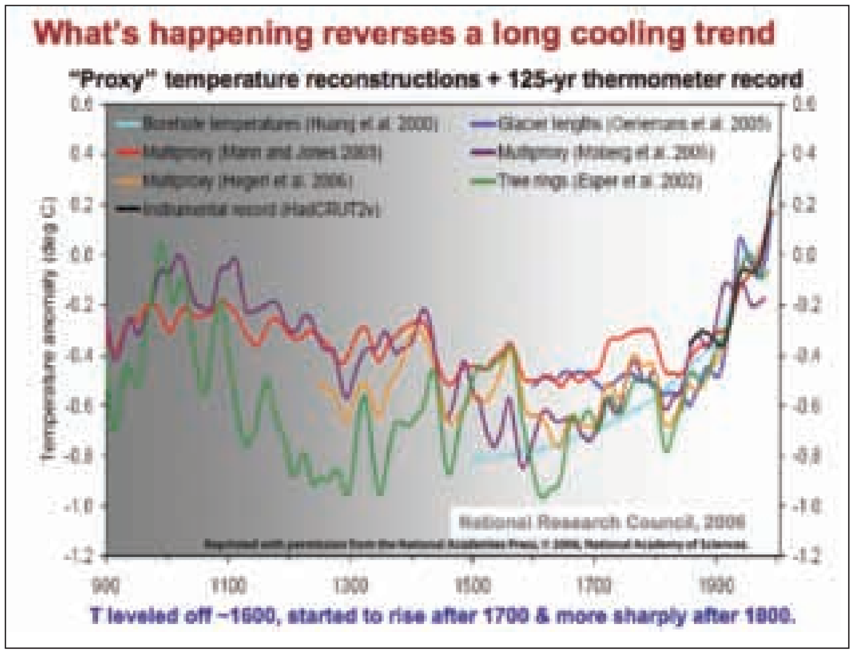


FIGURE 2

The key point is, we know why this has happened. When you put together the Intergovernmental Panel on Climate Change's (IPCC) best estimates of the forcings — literally meaning how hard we're pushing on the climate, positive in the heating direction, negative in the cooling direction — including increases in atmospheric carbon dioxide (by far the biggest factor); methane, nitrous oxide, and chlorofluorocarbons (combined, slightly less impact); contributions from ozone, absorptive particles, some partially counteracting effects from reflective and cloud-forming particles, and a little bit of influence from land-use change. And what you see, very interestingly given the skeptics who still claim the sun is doing this, is that the best estimate of the warming influence of greenhouse gases and absorbing particles from 1750 to 2005 is about 30 times the best estimate of the warming influence of the estimated change and input from the sun over this period.

Those key greenhouse gas increases were without question caused by human activities. As shown in Figure 3, the spike in those concentrations — carbon dioxide in the top graph,

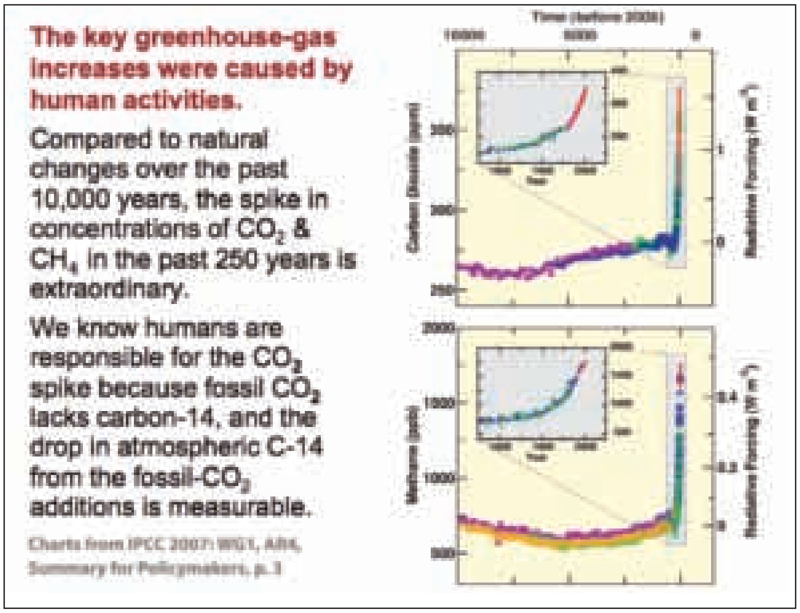


FIGURE 3

methane in the bottom graph — that came with the rise of industrial human activity is absolutely striking. And we know in fact that humans are responsible for the CO_2 spike, because the fossil CO_2 lacks carbon-14, and you can actually see the signal of the dilution of the atmospheric concentration of carbon-14 over time as fossil fuel burning grew.

I call Figure 4 the smoking gun of human influence. The top panel shows the best estimates of human and natural forcings from 1880 to 2005. The bottom panel compares the observed temperatures over this period with the temperature trajectories produced by a state-of-the-art climate model when it's given those forcings as input. You can see that the model reproduces with astonishing fidelity the last 125 years of observed temperatures.

The current heating, as I've already indicated, is not uniform geographically. Figure 5 shows the geographic variation of recent temperature increases, comparing the average temperatures for 2001-2005 with those in a reference period of 1951-1980. The overall increase over this time span was about half a degree Celsius (C), but what you see is that the increases mid-continent were high and those mid-continent at high latitudes higher still, to the point where the increase in the Arctic was in the range of three to four

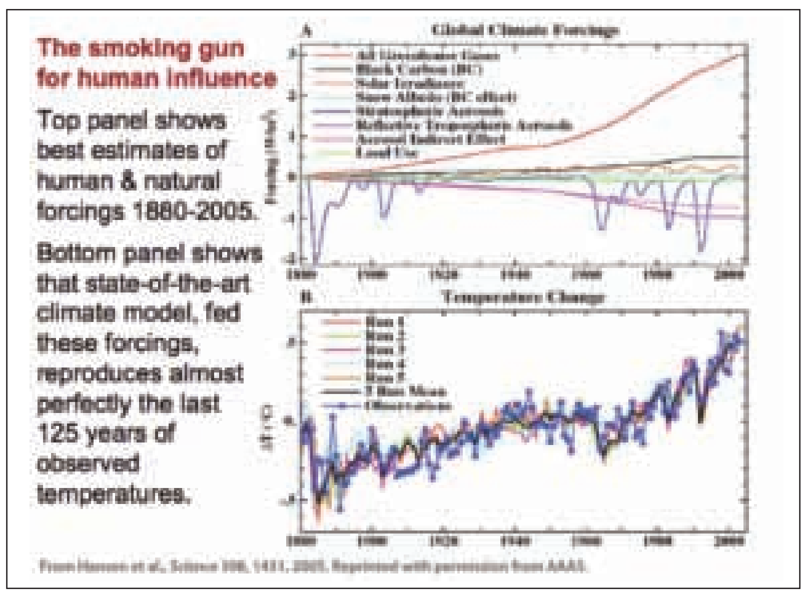


FIGURE 4

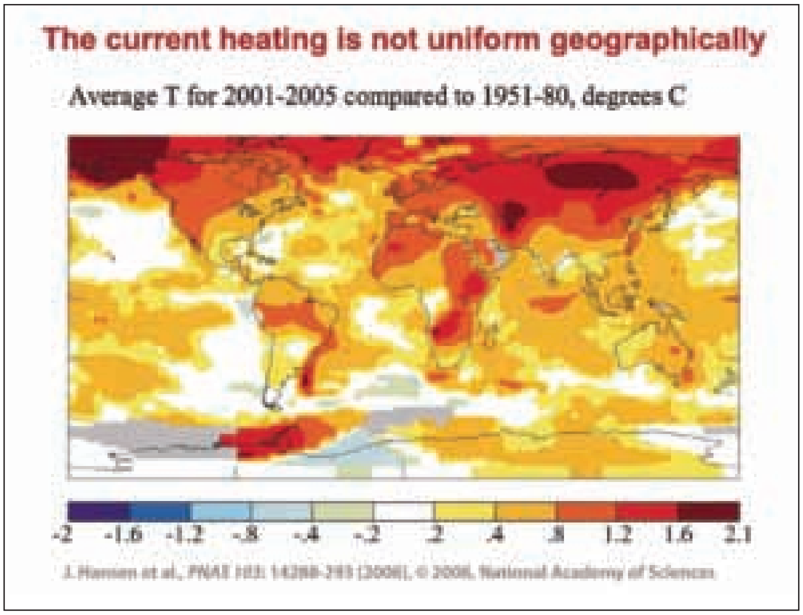


FIGURE 5

times the average increase over this period. That's one of the reasons the Arctic is the canary in the coal mine, the bellwether that's telling us where this is going.

As you would expect from non-uniform increases in temperature, circulation patterns are changing. For example, Chinese climate models indicate that data showing the weakening of the East Asia monsoon over 30 years is being driven by global climate change.

Evaporation and precipitation are increasing on average as you would expect in a warmer world, but not everywhere as you would expect in a non-uniform world. Some places are getting drier even as the world as a whole is getting wetter. In addition, more and more of the precipitation is falling in extreme events as is also predicted by basic climate science.

Permafrost is thawing, and Arctic summer sea ice is disappearing. When the average ground temperature in the Arctic gets to 0°C, the permafrost thaws, pipelines crack, foundations subside, roads collapse. Figure 6 shows summer Arctic sea ice in September 2005, which was a record low at the time, and in September 2007. The 2005 record was absolutely shattered two years later, astonishing just about everybody.

The extent of melting in Greenland in 2002 set a record (see Figure 7). That record, too, was shattered in

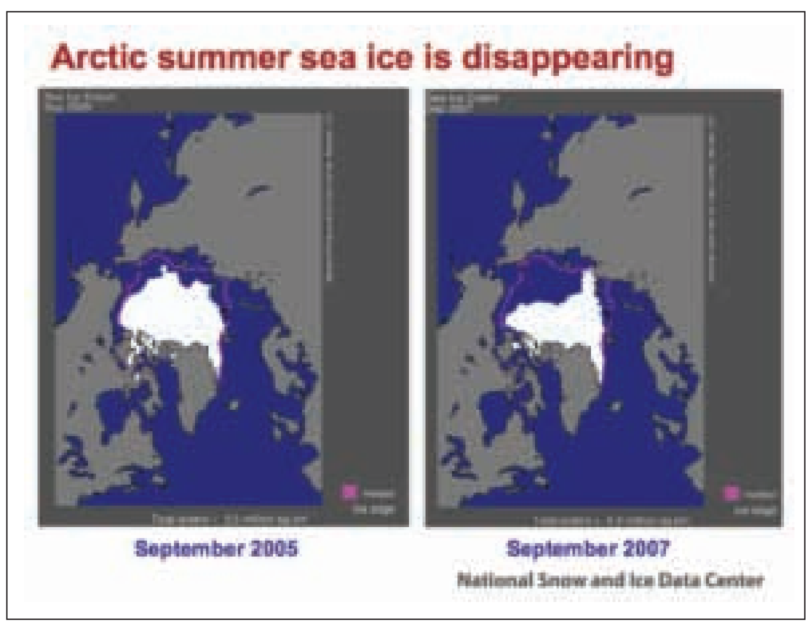


FIGURE 6

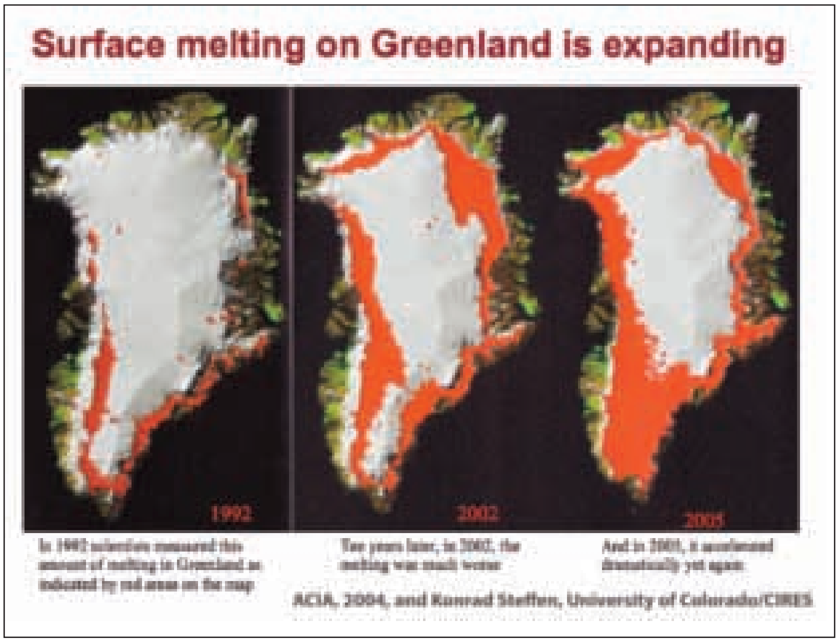


FIGURE 7

2005, and 2007 appears to have been worse still.

Sea level is rising, as you would expect from thermal expansion of heated seawater as well as increasing melting of glaciers. The rate in the last decade has been about twice the average for the 20th century (see Figure 8).

Those changes are already causing harm. Data show that major floods have consistently increased in all regions except Oceania from the 1950s up through the 1990s. Wildfires in the western United States have seen a fourfold increase in the last 30 years. Kerry Emanuel from MIT has found a correlation between the total power released by tropical cyclones and sea surface temperatures in the cyclone-forming regions of the world. This connection is still somewhat controversial, although even the rather conservative IPCC concluded there was a better than two-thirds chance that this trend will continue.

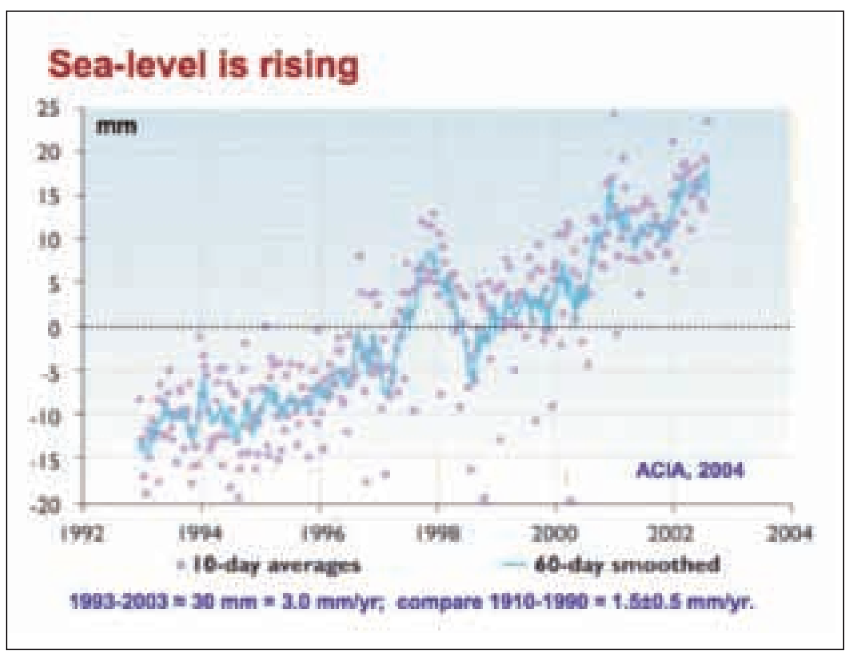


FIGURE 8

That weakening East Asia monsoon that I mentioned a few minutes ago has already meant less moisture flow from south to north over China, producing increased flooding in the south and increasing drought in the north. One reason Chinese leaders now recognize the need to participate in global solutions to climatic disruption is that they understand that climate change is already harming them.

The Amazon is drying and burning. The drying results from the combined effects of regional atmospheric circulation changes linked to global climate change and the local influence of deforestation itself. The result is that parts of the humid tropics, not just in the Amazon but also in Indonesia and Malaysia, that were previously too wet to burn are now periodically burning, and when they do they are launching additional carbon dioxide into the atmosphere. In a bad year, another billion tons of carbon can go into the atmosphere just from the burning in what I call the "formerly humid tropics."

The World Health Organization concluded in 2002 that in 2000 climate change was already causing more than 150,000 premature deaths per year – mainly from heat waves, floods, droughts, and expanded incidence of malaria.

The World Health Organization, not known for radical overestimation of health risks, concluded in 2002 that in 2000 climate change was already causing more than 150,000 premature deaths per year — mainly from heat waves, floods, droughts, and expanded incidence of malaria.

Bigger disruption is coming. In the 2007 IPCC scenarios shown in Figure 9, a mid-range trajectory takes us by 2050 to a global average surface temperature about 2°C above the 1900 level. The last time it was that warm on this planet was 130,000 years ago. At that time, sea level was four to six meters higher than it is today. On mid-range trajectories, we get to 3°C or so above the 1900 level by 2100. The last time the world was that warm was 30 million years ago. My Harvard colleague Dan Schrag likes to say that at that time there were crocodiles swimming off Greenland and palm trees in Wyoming. It was a

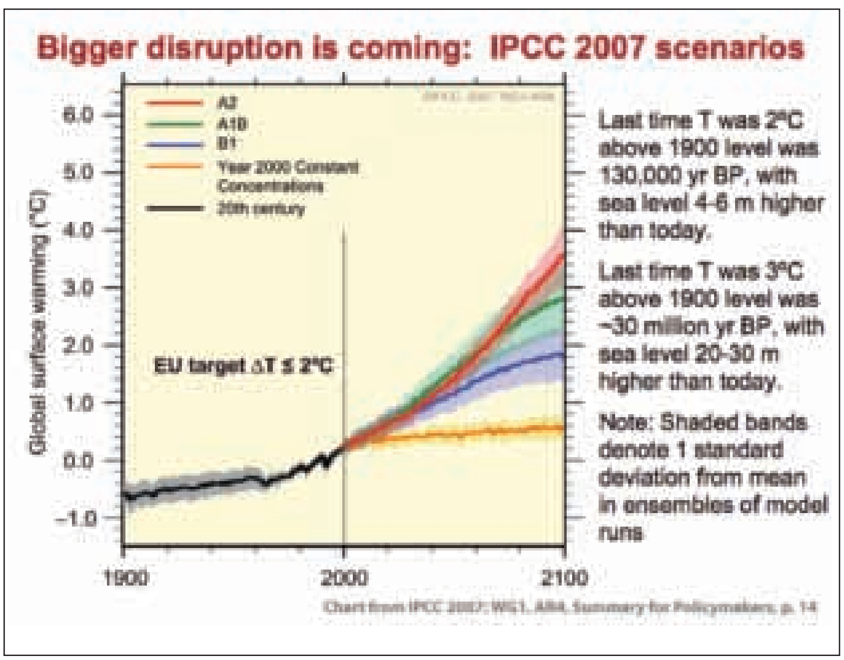


FIGURE 9

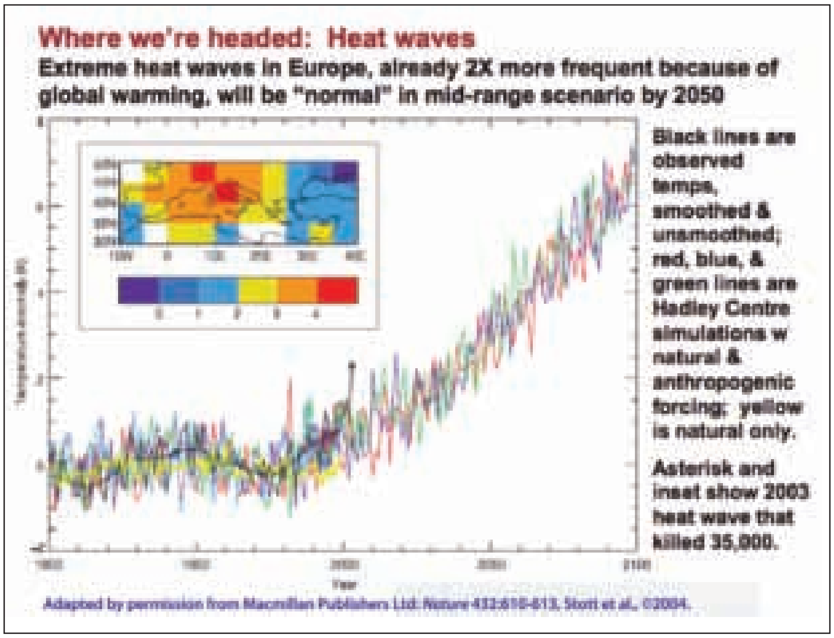


FIGURE 10

different world, with sea level 20 to 30 meters higher than today.

Heat waves in larger numbers and greater intensity are in store. Figure 10, a fascinating graphic, shows on the left the actual historical temperature record in the southern part of Western Europe to 2000 and simulations of the Hadley Center climate model going along with that. The spike a little after 2000 with the asterisk at the top is the 2003 summer heat wave that killed about 35,000 people in France, Italy, and Spain. The continuation of the heating trend under mid-range climate change scenarios would make that 2003 heat wave — which was about a one-in-a-100-year event at the time it occurred and a one-in-250-year event before humans started fiddling with climate — into a one-in-two-year event by 2050. In 2070, those deadly conditions of 2003 will be considered an unusually cool summer.

Higher temperatures also mean more air pollution of the conventional sort. And serious impacts on agriculture are in store. Studies of such staple crops as rice and corn indicate that yields start to fall at local temperature increases of 1-1.5°C in the tropics. In the temperate zone, they fall a little more slowly and a little later, but they fall nonetheless. And that's according to studies in which drought has not been taken into account. But data and projections show that droughts are getting more severe and will get far worse by the latter part of the century, making the prognosis for agriculture in a hotter world even worse.

The oceans of course are acidifying as well as warming. The Hadley Centre for Climate Prediction and Research has shown that ocean pH has dropped by about a tenth of a point in the last 150 years or so. The Hadley model projects a drop of another quarter of a point for the century we're now in. This will have severe consequences for corals and other organisms that make skeletons or shells out of calcium carbonate, never mind the additional stress being imposed by heating.

As for sea level, we know that melting the entire Greenland and Antarctic ice sheets would raise sea level by as much as 70 meters. The Greenland ice sheet has about seven meters of sea level in it. The West Antarctic ice sheet, which is the most vulnerable part of the Antarctic ice sheet, has about another five meters. The conventional wisdom has been that melting all this ice in a hotter world would take thousands of years. But we now know from the study of natural climate change in earlier eras that sea-level has sometimes gone up as quickly as two to five meters per century. Nobody can assure you with both hands above the table that this either will or will not happen in the next century or so, but it cannot be ruled out.

Figure 11 was produced by one of my graduate students using topographic maps. It shows what happens to the part of the world where I live under various levels of sea level rise — ending up, if all the Greenland and Antarctic ice melted, with the disappearance of Cape Cod, Boston, and vicinity.

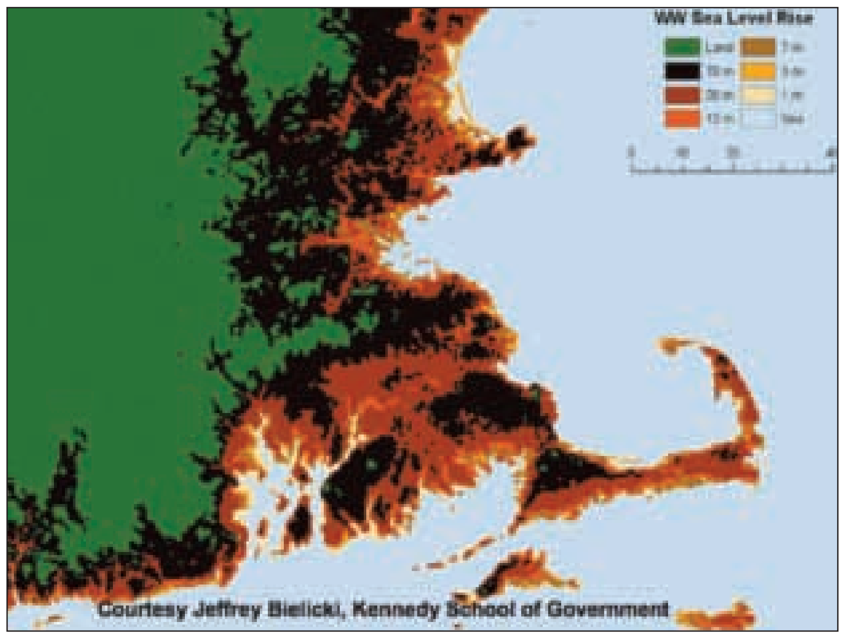


FIGURE 11

As I mentioned before, facing these dangers we have only three options. Mitigation means measures taken to reduce the pace and the magnitude of the changes in global climate we're causing. Adaptation means measures taken to reduce the adverse impacts on well-being that result from the changes that do occur. And suffering, of course, is the third option — suffering the adverse impacts that we fail to avoid by either mitigation or adaptation.

It's crucial to understand that we're already doing some of each. We're doing some mitigation, we're doing some adaptation, we're doing some suffering. What's up for grabs, depending on what steps we take, is the future mix of those three. And minimizing the amount of suffering in that mix can only be achieved by doing a lot of mitigation *and* a lot of adaptation. Mitigation alone won't work, because climate change is already occurring, and nothing we can do can stop it quickly.

But adaptation alone won't work, because adaptation gets costlier and less effective as the climatic changes to which one is trying to adapt get bigger. We need enough mitigation to avoid unmanageable climate change, and enough adaptation to manage the climate change that is unavoidable. "Avoiding the unmanageable and managing the unavoidable" was the subtitle of a study done for the U.N. by the Scientific Expert Group on Climate Change and Sustainable Development, co-chaired by Peter Raven and Rosina Bierbaum. There were a total of 18 authors from 11 countries, and the very apt subtitle came from John Schellnhuber, a German colleague who is now fortunately the Chief Climate Advisor to the Chancellor of Germany.

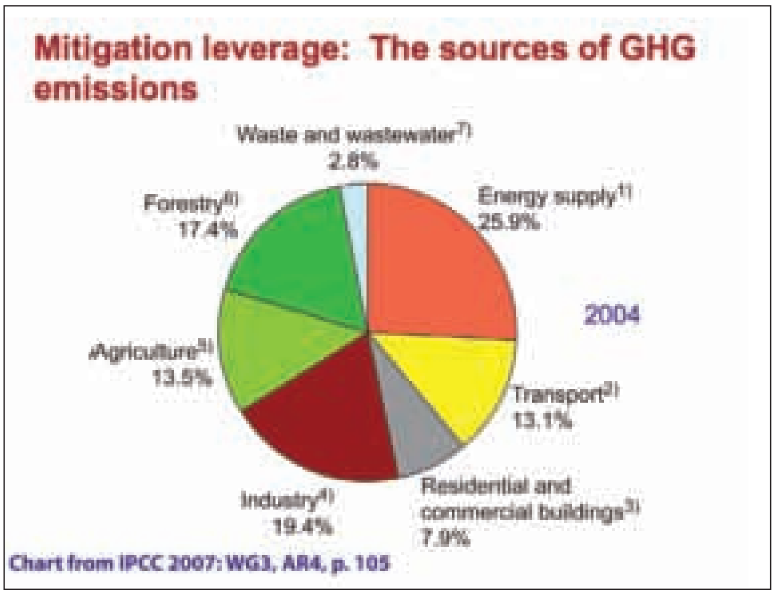


FIGURE 12

Let's look more closely at mitigation now, starting with where the greenhouse gases are coming from. Figure 12 is a depiction of the human sources of greenhouse gases worldwide in 2004, from the latest report of the Intergovernmental Panel on Climate Change.

The diversity of the sources means that we'll have to do a lot of things to get a grip on this problem. Mitigation possibilities obviously include: reducing the emissions of greenhouse gases and soot from the energy sector; reducing deforestation and increasing reforestation and afforestation; modifying agricultural practices; and, possibly, if we get desperate enough, scrubbing greenhouse gases from the atmosphere technologically. That looks to be considerably more expensive than scrubbing them from smokestacks and exhausts, of course, because once they're in the atmosphere they're much more dilute. Another possibility is "geo-engineering" — engineering the Earth's environment to counteract warming with artificial cooling — for example by injecting reflecting material either into the stratosphere or into orbit. There is no choice but to study this more closely, as a fallback in case other mitigation measures prove insufficient, but one has to worry about cost and about unintended side effects.

How much mitigation do we need and how soon? The U.N. Framework Convention on Climate Change says something about that, and having been ratified by the United States and 190 other countries it is the "law of the land" all over the world. (Alas, too many political leaders in the United States and elsewhere act as if they don't remember that it is a binding international agreement.) The convention calls for stabilizing the atmosphere at a level that prevents dangerous anthropogenic interference in the climate system. Unfortunately there was no agreement when this treaty was signed and ratified about what "dangerous" meant — about what constitutes dangerous anthropogenic interference and what level of greenhouse gas concentrations would produce it. There's still no official consensus, but I believe that by any reasonable definition of the word "dangerous" the current level of interference is already there.

Human-caused carbon dioxide emissions are about half of the problem, and their share is growing. About three-quarters of that carbon dioxide comes from burning oil, coal, and natural gas, and those energy sources are 80 percent of the energy supply of the world today.

The question now is, can we avoid climate catastrophe? In that connection we need to understand that the average global surface temperature — that sensitive index of the state of the climate that's gone up about 0.8°C since the beginning of the last century — would rise something like 0.5°C more (reaching 1.3° or 1.4°C above the 1900 level) even if the concentrations could be stabilized instantaneously where they are today. The reason for that is the thermal lag of the oceans. The oceans have a huge heat capacity, and it takes them a long time to catch up with changes you've imposed on the radiation balance of the atmosphere.

The chance of crossing a tipping point into truly catastrophic climatic change appears to grow rapidly, moreover, for increases in the average surface temperature of more than about 2°C above the 1900 level. This, combined with studies of the magnitude of the effort required to stabilize the climate, suggests that limiting the increase to less than 2°C is the most prudent target that might still be attainable. One can name more prudent targets, but most analysts think it unlikely that we can attain a target more demanding than this. And if we miss 2°C but manage to stop at 2.5°C, that at least would give better odds of avoiding catastrophe than 3°C, which a few years ago many people were saying might be an acceptable target. It doesn't look very good given what we know now.

Some key realities about mitigation tell us how big the challenge really is. First, the human-caused carbon dioxide emissions are the biggest piece of the problem. They're about half of it, and their share is growing. About three-quarters of that carbon dioxide comes from burning oil, coal, and natural gas, and those energy sources are 80 percent of the energy supply of the world today. The remaining quarter comes from deforestation and burning in the tropics. And while 60 percent of the fossil CO_2 came from industrialized countries in 2006, the developing countries are going to dominate within a few years. Thus mitigation has to happen everywhere.

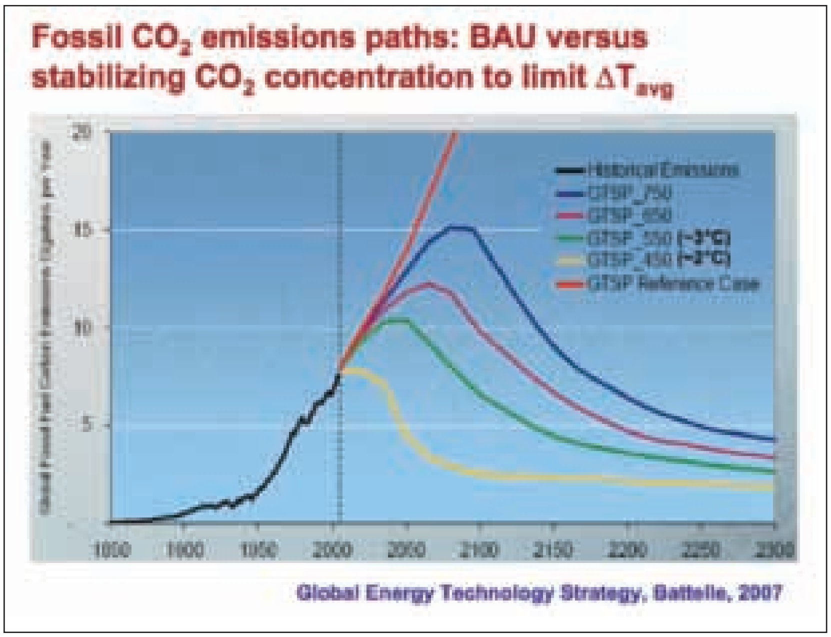


FIGURE 13

The global energy system unfortunately cannot be changed quickly. We've invested about $15 trillion in the energy-supply system we've got. That's the replacement cost of all the power plants, refineries, transmission lines, drilling rigs, and other energy-supply infrastructure in the world. That investment ordinarily turns over in about 40 years. If you want the energy system in 2050 to look a lot different than the way it looks today, you have to start changing it now. And deforestation — the other fourth of the CO_2 problem — is also not easy to change. The forces driving deforestation in the tropics are deeply embedded in the economics of food, fuel, timber, trade, and development. We can stop it, but it won't be easy.

Figure 13 shows historical CO_2 emissions paths and the continuation under "business as usual," compared to paths corresponding to stabilizing the atmospheric CO_2 concentration at some possible target levels. The yellow curve corresponds to stabilizing at an atmospheric concentration of 450 parts per million CO_2, which under reasonable assumptions about non-fossil CO_2, other greenhouse gases, and particles in the atmosphere would give a 50 percent chance of holding the increase in global average surface temperature to 2°C or less. The green curve similarly corresponds to a 50 percent chance of holding the increase to 3°C or less. It's evident that to get on that 2° curve, global emissions need to level off and start to decline virtually immediately.

Where could we find the leverage to do that? Well, the arithmetic is quite simple. Emissions of CO_2 from fossil fuel equal population, times GDP per person, times energy per unit of GDP, times CO_2 released to the atmosphere per unit of energy. And this equation then tells us what the options are. We could reduce the growth of energy use by reducing population growth, by reducing the growth of GDP per person, or by reducing the ratio of energy to GDP. There are a number of ways we could do the latter, such as increasing the efficiency of energy conversion to end-use forms; increasing the technical efficiency with which we use energy in buildings, vehicles, and manufacturing processes; or changing the mix of economic activities in the direction of less-energy-intensive activities. And finally we can reduce the CO_2-to-energy ratio by substituting natural gas for oil and coal (though we don't have enough natural gas to do very much of that for very long); by replacing fossil fuels with renewables; by replacing fossil fuels with nuclear energy; or by capturing and sequestering the carbon dioxide from the fossil fuel we use.

If you want the energy system in 2050 to look a lot different than the way it looks today, you have to start changing it now.

And that's basically it. Those are the options. And there's no panacea among them. All of the options have limitations and liabilities. Limiting population growth has social and political sensitivities; slowing GDP per person, economic liabilities. With wind energy, there are problems with intermittency and siting. Siting LNG terminals and nuclear power plants is difficult, too. Indeed, I fear that the well-known NIMBY phenomenon — "not in my back yard" — is being rapidly converted in this country into BANANA: "build absolutely nothing anywhere near anybody."

With biofuels, there are questions about net energy (how much energy you get out compared to how much you had to put in); with competition with other land uses; and with impacts on food production and ecosystems. With photovoltaics, there are problems with intermittency, cost, and toxic substances. With nuclear fission there are cost, waste, safety, and proliferation issues. Nuclear fusion doesn't work yet. (I started my career working on nuclear fusion, decided it was not going to work by the time I died, and started looking at approaches to meeting our energy needs that could help more quickly.)

CO_2 capture and sequestration has challenges related to cost, scale, and complexity. End-use efficiency — improving the efficiency of cars, refrigerators, trucks, manufacturing — is the cleanest, fastest, cheapest, safest, most reliable leverage on reducing greenhouse gas emissions that we have, but it still has limitations. It's in part an education problem, because to get efficiency right, billions of consumers ultimately have to do the right things, and that means they have to know what their options are. And there are a lot of other barriers to realizing the full potential of efficiency out there, and we have to figure out how to knock those barriers down.

What about hydrogen? Hydrogen is not an energy *source* (unless and until nuclear fusion technology succeeds). The liquid or gaseous hydrogen we'd use in fuel cells or hydrogen-powered engines must be produced from fossil fuels or made by splitting water, which takes more energy than the hydrogen contains. This makes hydrogen an energy *carrier*, like electricity — an energy form we make from our primary energy sources because of its attractive characteristics at the point of use.

Having a big problem and no panacea means that we're going to need a portfolio of approaches, not just one or two things to do but many. A portfolio doesn't necessarily mean choosing every option that's on the menu, though. Developing the better options to their full potential may allow foregoing some of the options that prove either very costly or very risky. But certainly we should be doing increased research and development on all of the options in order to try to improve their performance, to lower their costs, and to reduce their adverse side effects, so that the future menu from which we will choose what to deploy on a large scale will be better than today's menu.

Against that background there is some good news and some bad news in relation to climate-change mitigation. The good news is that the cheapest, fastest, cleanest, surest leverage against CO_2 emissions is to increase the efficiency of energy use, and the potential for doing a lot of this is large. Many of the approaches for increasing end-use efficiency meet the win-win criterion; moreover, there are co-benefits in saved energy, increased energy security, reduced conventional pollution, and so on that are more than worth their costs. We should be taking these steps even if we're *not* worried about climate change.

More good news: there are also some supply-side mitigation options that are "win-win" (such as cogeneration and wind and biofuels from wastes). Many adaptation options are likewise win-win. But the bad news is that the win-win approaches are not going to be enough. Adequate mitigation is going to require putting a substantial price on the emissions of greenhouse gases, either through an emissions tax or a tradable-emissions-permit system, to motivate the use of the more expensive remedies.

Figure 14 is a supply curve developed by McKinsey and Company for greenhouse gas abatement in 2030. It's a complicated diagram, but basically it shows that if we want to achieve emissions reductions large enough to stabilize atmospheric CO_2 at a level that might keep the temperature increase below 2°C, we need to buy a lot of the more expensive remedies. The less expensive ones by themselves just don't get us enough reductions.

A particularly conspicuous illustration of this is the carbon dioxide emitted by fossil-fuel-burning power plants. Capturing CO_2 from power plants is not going to be cheap, but we cannot stabilize atmospheric concentrations soon enough to have a substantial likelihood of avoiding catastrophic climate change unless we do this particular demanding and expensive thing. To underline this point, Figure 15 shows the result of a calculation first done by David Hawkins of NRDC and reproduced in a *Scientific American* article by Robert Socolow and Steve Pacala. The calculation shows that if the fossil-fuel-burning power plants projected to be built between now and 2030 are in fact built, and if they operate through their projected lifetime without capturing and sequestering CO_2, the lifetime CO_2 emissions from the new coal burning power plants alone will be about equal to the amount of CO_2 added to the atmosphere by all coal burning up until now in human history. We cannot accept that increment of carbon dioxide to the atmosphere and still avoid catastrophic climate change. We've got to capture the CO_2 even though it will be expensive to do so.

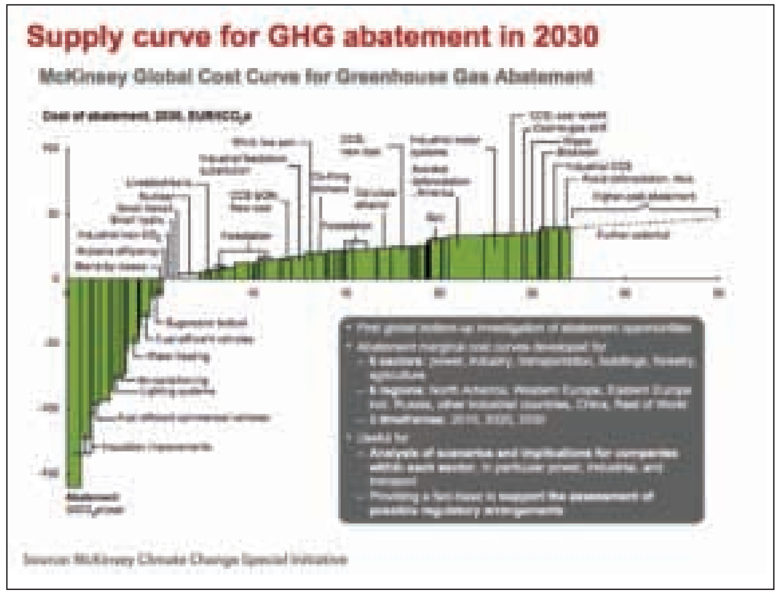


FIGURE 14

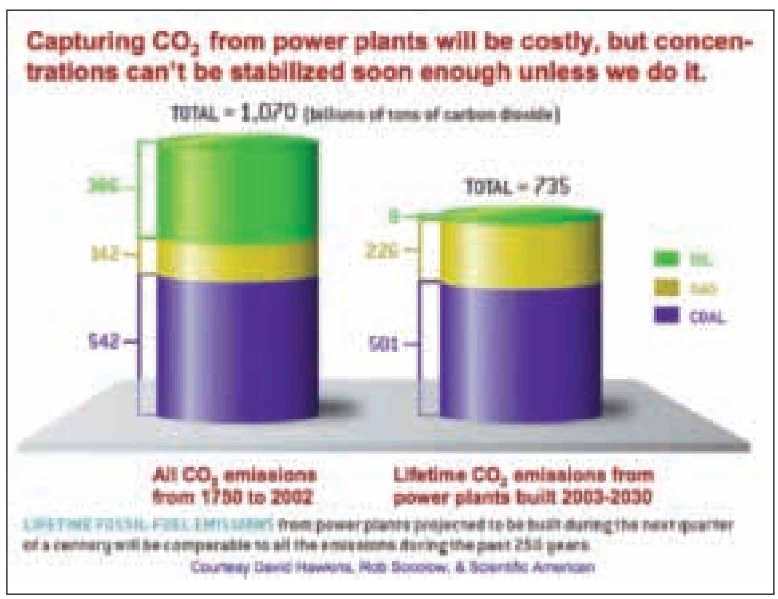


FIGURE 15

The challenge of doing what's needed at the necessary scale is enormous, as Socolow and Pacala and others have shown. Suppose we want to stabilize the CO_2 concentration in the atmosphere at 450 parts per million. That means global CO_2 emissions in 2050 have to be 8 or 9 billion tons of carbon per year below the "business-as-usual" projection. Here are some measures that would each suffice to avoid *one* billion tons of carbon in CO_2 in 2050:

- Cutting energy use in all of the world's buildings by 20 to 25 percent below business-as-usual.
- Having two billion cars that get 60 miles per gallon instead of 30.
- Capturing and sequestering CO_2 at 800 coal-burning power plants.
- Replacing 700 one-gigawatt coal-burning power plants with nuclear plants or with wind turbines (a million two-megawatt units required) or with solar power plants (2,000 one- gigawatt plants required).

The world today spends 2.5 percent of the world economic product on defense. The United States spends five percent on defense, two percent on environmental protection. The idea that we might spend one percent of GWP to avoid climate catastrophe is not such a radical idea.

And we need 8 or 9 of these billion-ton contributions!

There are some more realities about mitigation that need to be faced. First, in applying the more costly solutions, the industrialized nations are going to have to go first. We're going to have to pay more of the up-front costs, offering assistance in this to developing countries. That's a matter of historical responsibility. It's a matter of capacity. It's a matter of equity. And it's a matter of international law under the Framework Convention on Climate Change.

Second, developing countries are going to have to be compensated for reducing and avoiding deforestation. Without additional incentives not to cut down tropical forests, essentially all of them will disappear in this century. The impact of that on atmospheric CO_2 would put stabilizing at 450 parts per million or even 550 parts per million out of reach. (It would also have a staggering impact on global biodiversity.)

The third reality is that, without a formal and binding global agreement on the allocation of emissions after 2012, the needed degree of reductions will not be achieved. The job is just not going to get done by the actions of individual countries in the absence of a global agreement. I believe the best basis for such an agreement in the short term is probably reduction in emissions intensity — that is, countries agree to reduce the ratio of greenhouse gas emissions to gross domestic product at a particular rate. In the longer run, I believe the only politically acceptable basis for a global agreement will be equal per-capita emissions rights, which means people who are emitting above the allowable global average will have to pay people who are emitting below the allowable global average for their emissions permits.

The costs of mitigation in aggregate are a bit daunting but, in proper context, not unmanageable. Consider: current CO_2 emission rates from fossil fuels and deforestation are nine to ten billion tons of carbon per year. If we had to pay $100 per ton of carbon (which is in the mid-range of the cost of capturing CO_2 from coal burning power plants and sequestering it) to avoid half of these emissions, that would cost half a trillion dollars a year. That's less than one percent of gross world product (GWP). And it's not money down the drain. It doesn't disappear down a black hole. It's just a change, on the margin, in what kinds of goods and services are being bought.

The world today spends 2.5 percent of the world economic product on defense. The United States spends five percent on defense and two percent on environmental protection. The idea that we might spend one percent of GWP to avoid climate catastrophe is not such a radical idea. More sophisticated analyses of the economic impact of mitigation to stabilize atmospheric CO_2 at 450 to 550 ppm have led to estimates generally in the range of 1-2 percent GWP loss in 2100 and 0.5-1 percent loss in 2030. Given that a middle-of-the-road projected rate of economic growth in 2030 for the world is about 2.5 percent per year, a loss of 0.5-1 percent at that time would amount to 20 to 40 percent of one year's growth. People would need to wait until some time between mid-March and late May 2030 to be as rich as they otherwise would have been on January 1. I suggest that this is not too high a price for avoiding climate catastrophe.

On the adaptation side, there are also lots of possibilities — changing cropping patterns; developing heat-, drought-, and salt-resistant crop varieties; strengthening public-health and environmental-engineering defenses against tropical diseases. Another approach, not terribly popular for reasons that will be obvious to many people in this room, is building more water projects to try to alleviate floods and droughts. Another is avoiding further development on flood plains and near sea level. Many of these adaptation approaches, although not all of them, are win-win. They're things we ought to do anyway. Strengthening public health and environmental engineering defenses against tropical diseases is a good example.

So what should we get going on first? We need to accelerate the win-win mitigation and adaptation measures, the ones that are easiest to get done. We need to start seriously integrating adaptation with development strategy. We need to put a price on greenhouse-gas emissions in order to harness market forces to finding the cheapest reductions. We need to pursue a new global framework for mitigation and adaptation for the post-2012 period. We need to ramp up investments in energy-technology research, development, and demonstration by two- to five-fold. And we need to expand international cooperation on deploying advanced energy technologies, because this is a problem that needs to be addressed everywhere. We all live under one atmosphere; everybody's greenhouse-gas emissions change the climate everywhere; and so we have to solve this problem together. And above all, the United States has to lead.

Thank you very much.

Biography of John P. Holdren

John P. Holdren is Teresa and John Heinz Professor of Environmental Policy and Director of the Program on Science, Technology, and Public Policy at the Kennedy School of Government, Harvard University, as well as President and Director of the Woods Hole Research Center. He is also Professor of Environmental Science and Policy in Harvard's Department of Earth and Planetary Sciences and the immediate past President and current Chair of the Board of the American Association for the Advancement of Science (the largest general science society in the world). His work has focused on causes and consequences of global environmental change, sustainable development, energy technology and policy, nuclear arms control and nonproliferation, and science and technology policy.

Dr. Holdren is a member of the National Academy of Sciences, the National Academy of Engineering, the American Academy of Arts and Sciences, and the Council on Foreign Relations. Since 2002 he has been Co-Chair of the independent, bipartisan National Commission on Energy Policy, and from 2004 to the present he has served as a coordinating lead author of the Scientific Expert Group on Climate Change and Sustainable Development, reporting to the Commission on Sustainable Development and the Secretary-General of the United Nations. From 1993 through 2004 he served as Chair of the Committee on International Security and Arms Control of the National Academy of Sciences, and from 1994 to 2001 he was a member of President Clinton's Committee of Advisors on Science and Technology.

He has been the recipient of a MacArthur Foundation Prize Fellowship (1981-6), the Volvo International Environment Prize (1993), the Tyler Environment Prize (2000), and the John Heinz Prize in Public Policy (2001), among other awards. In 1995 he gave the acceptance speech for the Nobel Peace Prize on behalf of the Pugwash Conferences on Science and World Affairs (which he served as Chair of the Executive Committee from 1987 to 1997).

Biography of Senator John H. Chafee

Senator John H. Chafee (R-RI) was born in Providence, Rhode Island, in 1922. He earned degrees from Yale University and Harvard Law School. Upon the United States' entry into World War II, Chafee left Yale to enlist in the Marine Corps, and then served in the original invasion forces at Guadalcanal. In 1951 he was recalled to active duty and commanded a rifle company in Korea.

Chafee began his political career by serving for six years in the Rhode Island House of Representatives, during which time he was elected Minority Leader. He was then elected Governor by a 398-vote margin in 1962. He was re-elected in 1964 and 1966—both times by the largest margins in the state's history. In January 1969 he was appointed Secretary of the Navy and served in that post for three-and-a-half years. He was elected to the United States Senate in 1976.

As Chairman of the Environment and Public Works Committee, the Senator was a leading voice in crafting the Clean Air Act of 1990. He led successful efforts to enact oil spill prevention and response legislation and a bill to strengthen the Safe Drinking Water Act. Senator Chafee was a long-time advocate for wetlands conservation and open space preservation and was the recipient of every major environmental award.

As senior member of the Finance Committee, Senator Chafee worked successfully to expand health care coverage for women and children and to improve community services for people with disabilities. In 1990, Senator Chafee spearheaded the Republican Health Care Task Force. He went on to lead the bipartisan effort to craft a comprehensive health care reform proposal in 1994.

Senator Chafee also was a leader in efforts to reduce the federal budget deficit and co-chaired the centrist coalition that produced a bipartisan balanced budget plan in 1996. He was an active proponent of free trade and was a strong supporter of the North American Free Trade Agreement (NAFTA). He served as Chairman of the Republican Conference for six years.

The Senator received awards and endorsements from such organizations as the National Federation of Independent Business, the American Nurses Association, the League of Conservation Voters, the Sierra Club, Handgun Control Inc., Planned Parenthood, Citizens Against Government Waste, and the National PTA.

On October 24, 1999, Senator John H. Chafee died from congestive heart failure. He is sorely missed.

JOHN H. CHAFEE MEMORIAL LECTURES ON SCIENCE AND THE ENVIRONMENT

2000

Sherwood Rowland, Nobel Laureate, University of California, Irvine

Mario Molina, Nobel Laureate, Massachusetts Institute of Technology

2001

Edward O. Wilson, Pulitzer Prize recipient, Harvard University

2003

Rita R. Colwell, Director, National Science Foundation

2004

Jared M. Diamond, Pulitzer Prize recipient, University of California, Los Angeles

2005

William D. Ruckelshaus, First and Fifth Administrator,
U.S. Environmental Protection Agency

2006

Ralph J. Cicerone, President, National Academy of Sciences

2007

Larry Brilliant, Founder, Seva Foundation and Executive Director, Google.org

2008

John P. Holdren, Teresa & John Heinz Professor of Environmental Policy and
Professor of Earth and Planetary Sciences, Harvard University;
President and Director, The Woods Hole Research Center; Chair of the Board, AAAS

NCSE Board of Directors

A. Karim Ahmed
President, Global Children's Health and Environment Fund

Mohamed El Ashry
Senior Fellow, UN Foundation, and Chairman and CEO Emeritus, Global Environment Facility (GEF)

Richard E. Benedick
U.S. Ambassador (ret.), Battelle Pacific Northwest National Laboratory

Joyce Berry
Vice President for Advancement and Strategic Initiatives, Colorado State University

James L. Buizer
Executive Director of Strategic Institutional Advancement, Arizona State University

Rita Colwell
Distinguished University Professor, Center for Bioinformatics and Computational Biology, University of Maryland, and former Director, National Science Foundation

Sara J. Ethier
Regulatory Audit Manager, The Valspar Corporation

Joseph H. Highland
CEO Emeritus, ENVIRON

Stephen P. Hubbell
Distinguished Professor, Department of Ecology and Evolutionary Biology, University of California, Los Angeles

Randy Johnson
Chair, Board of Commissioners, Hennepin County, Minnesota, and Past President, National Association of Counties

Donald N. Langenberg
Chancellor Emeritus, University System of Maryland

Margaret Leinen
Chief Science Officer, Climos, Inc.

H. Jeffrey Leonard
President, Global Environment Fund

Astrid Merget
Executive Vice Chancellor and Provost, Louisiana State University

Anthony F. Michaels
Managing Partner, Proteus Environmental Technologies

Larry A. Nielsen
Provost and Executive Vice Chancellor, North Carolina State University

Dian Ogilvie
Senior Vice President, General Counsel and Chief Environmental Officer, Toyota Motor Sales, U.S.A.

Hazel O'Leary
President, Fisk University and former Secretary of Energy

Ron Pulliam
Regents Professor, Institute of Ecology, University of Georgia, and former Director, National Biological Service

Peter Saundry
Executive Director, National Council for Science and the Environment

Barbara Sheen Todd
Former Chair, Board of Commissioners, Pinnellas County, Florida, and Past President, National Association of Counties

Claire Van Ummersen
Vice President, Center for Effective Leadership, American Council on Education

Warren Washington
Senior Scientist, Head, Climate Change Research Section, National Center for Atmospheric Research (NCAR)

HONORARY MEMBERS OF THE BOARD

Dr. Dorothy I. Height
President Emeritus, National Council of Negro Women

Honorable Robert S. McNamara
Former President, The World Bank, former U.S. Secretary of Defense, and former CEO, Ford Motor Company

Honorable William K. Reilly
Former EPA Administrator, and President and CEO of Aqua International Partners

Honorable William Ruckelshaus
Former EPA Administrator, and Principal of Madrona Group

James Gustave Speth, Esq.
Dean, Yale School of Forestry and Environmental Studies

National Council for Science and the Environment

Improving the scientific basis for environmental decisionmaking

1101 17th Street, NW, Suite 250
Washington, DC 20036

Phone: 202-530-5810
Fax: 202-628-4311

E-mail: NCSE@NCSEonline.org
www.NCSEonline.org

ISBN 0-9710439-7-3

FSC
Mixed Sources
Product group from well-managed forests, controlled sources and recycled wood or fiber
www.fsc.org Cert no. SCS-COC-00635
© 1996 Forest Stewardship Council
25%