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CLIMATE CHANGE AND BALANCED ENERGY POLICY ACT

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

ON

SCIENCE AND TECHNOLOGY STUDIES ON CLIMATE CHANGE

AND

S. 597

TO PROVIDE FOR A COMPREHENSIVE AND BALANCED NATIONAL ENERGY POLICY

JUNE 28, 2001

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CLIMATE CHANGE AND BALANCED ENERGY POLICY ACT

THURSDAY, JUNE 28, 2001

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The committee met, pursuant to notice, at 9:37 a.m., in room SD–366, Dirksen Senate Office Building, Hon. Jeff Bingaman, chairman, presiding.

OPENING STATEMENT OF HON. JEFF BINGAMAN, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. Let me call the hearing to order and thank everybody for attending.

Today, we will take testimony from two panels of experts, first, on the recently released National Research Council report on the science of climate change, followed by a second panel on energy technology options for managing the risks posed by climate change.

I am sorry that the hearing this morning conflicts with a markup in the Appropriations Committee on the Interior bill. There are several members of our committee who have expressed regret at not being able to participate this morning and hear this presentation.

Clearly, there is a widespread consensus that warming of the earth's surface is occurring and that human activity is a significant contributor. We also know that any sustained effort to reduce greenhouse gas emissions would have a substantial effect on energy policy since roughly 98 percent of U.S. carbon emissions result from fossil fuel combustion. That is a combination of coal and oil and natural gas.

A well-crafted technology policy is critical to accelerating the development and adoption of new technologies for lowering the emissions of greenhouse gases. Energy technologies that have already been developed and those under development, which will be deployed over the next few decades, will largely determine the world energy system for most of the next century. Yet, as the Heinz Center study points out, the Nation's present science and technology system is highly decentralized with no compelling mission to reduce greenhouse gas emissions.

In my view, it is our responsibility as policymakers to provide the necessary focus to the various technology programs to ensure that we are moving toward sustainable outcomes. Smart policies can significantly reduce not only carbon dioxide emissions but other air

pollutants. Petroleum dependence as well can be reduced, and we can increase the efficiency of both energy production and use.

In addition, there are many opportunities for the United States to cooperate with other countries—industrial, transition, and developing countries alike—in developing and deploying energy efficient technologies. In order to take advantage of those opportunities, we need to change our own policies. Existing Federal programs for energy cooperation are not adequate neither from the standpoint of addressing the need nor ensuring that competitive opportunities are available to U.S. industry.

Many developing and transition economies are building homes and factories with out-of-date technologies which will be used for many decades. In doing so, developing nations are building in excessive costs, locking out environmental protection, and diminishing their own development potential.

However, progress can be both rapid and significant. China, through the energy sector reform and pursuit of energy efficiency opportunities, has made unprecedented progress in reducing energy intensity and carbon dioxide emissions. With technology and the right energy policies, developing countries can meet their energy needs and reduce greenhouse gas emissions while freeing up funds for investment in other critical development needs.

Section 111 of S. 597, which is a bill I introduced earlier this Congress with a number of cosponsors, establishes an interagency working group on clean energy technology transfer. This provision builds on Senator Byrd's initiative in the Energy and Water appropriations bill in the last Congress. I hope the witnesses on the second panel will offer their views as to whether this is the correct approach or how we should structure such an effort to be more effective.

I hope that we can hear suggestions from today's witnesses to help us move forward in our design of energy and technology policies consistent with the goal of reducing greenhouse gas emissions, both domestically and internationally.

Let me defer to Senator Murkowski for any opening statement he has before we begin with the witnesses.

Let me alert everyone that we have been advised by the Majority Leader that there are votes starting at about 9:45, two votes in a row, which will probably require us to interrupt the hearing.

But let us go ahead with Senator Murkowski's opening statement.

[The prepared statements of Senators Craig and Hagel follow:]

PREPARED STATEMENT OF HON. LARRY E. CRAIG, U.S. SENATOR FROM IDAHO

Thank you, Mr. Chairman, for inviting these eminent climate scientists to testify before the Committee. I always welcome the opportunity to hear scientists, such as those before us today, communicate their understanding of this fascinating and often confounding subject.

Mr. Chairman, let me also publicly state what a pleasure and a privilege it was for me to participate with you, Senator Jeff Sessions, Secretary Paul O'Neill, and Dr. Glenn Hubbard, the President's Chairman of the Council of Economic Advisors, in the four-hour Climate Science Forum sponsored by National Academies at its headquarters here in Washington, D.C. earlier this month.

My only disappointment is that we didn't have more of our Senate colleagues in attendance, particularly those who have many times publicly expressed serious concern about this issue. Congress cannot continue to learn about this issue from media reports contained in newspapers and popular magazines. The issue is too economi-

cally and environmentally important for Congress to continue to have only a casual interest in its scientific complexity.

As you know, Mr. Chairman, the National Academies made extraordinary efforts to get members of the Senate to attend its intensive Climate Science Forum, including sending a letter one month in advance of the forum to each member of the Senate, followed by a personal phone call to each Senate office. Perhaps, in the future, efforts to get the Senate's attention will be more fruitful.

Those facts notwithstanding, Mr. Chairman, your presence at that forum was a clear statement of your genuine interest in objectively tackling this very important and complex scientific issue. I commend you for your willingness to search for ways to strengthen our scientific understanding of this issue and commit to joining you in that important effort.

Your thoughtful and probing questions at the Forum stimulated a worthwhile dialogue that helped further advance my understanding of the issue. Clearly, many key uncertainties continue to plague our scientific community's progress toward a more confident understanding of what is happening to our global climate system.

However, with proper direction from the National Academies, I am confident that we can make meaningful and appropriate investments in scientific research and technology development that will yield breakthroughs in our ability to better predict and adapt to any future climate changes.

As you know, Mr. Chairman, I have invested much time and effort to understanding this issue. I have sought the counsel of many eminent scientists, three of whom are here today. Our national policy on this issue must evolve commensurately with the increasing confidence we achieve in our scientific understanding. Consensus on appropriate government action should be the cornerstone of that policy.

It is my hope that under your leadership, the Committee will continue to actively pursue the productive dialogue we have begun with our scientific community. It is my belief that our increased understanding of the science will lead to a consensus on what bipartisan legislative action is appropriate to address one of the most important economic and environmental issues of our time.

Thank you, Mr. Chairman.

PREPARED STATEMENT OF HON. CHUCK HAGEL, U.S. SENATOR FROM NEBRASKA

The National Academy of Sciences (NAS) report is a serious document on an important issue. As the report states, we do not know all of the factors contributing to climate change and the extent to which human activities or natural variables are playing a role. The report points out the vast uncertainties that remain and the need for major advances in our understanding and modeling of climate change. I agree with the need for greater research to enhance our knowledge of climate change. Reducing the uncertainties will help us make better decisions about the appropriate way to address this important issue.

This report is certainly not a prescription for the drastic measures required under the Kyoto Protocol. Far from it.

However, this report does provide us with enough evidence to move forward in a responsible, reasonable and achievable way to reduce greenhouse gas emissions. It provides us with a basis to move forward with an alternative to the Kyoto Protocol. That should be the goal of U.S. policymakers.

It is also important to note that the NAS report concludes that the Summaries for Policy Makers of the U.N. Intergovernmental Panel on Climate Change (IPCC) tend to understate the uncertainties and overstate the conclusiveness of scientific reports. This has been a criticism of the IPCC process and must be considered when evaluating their reports.

STATEMENT OF HON. FRANK H. MURKOWSKI, U.S. SENATOR FROM ALASKA

Senator MURKOWSKI. Thanks very much, Senator Bingaman. Good morning. We look forward to the testimony from our very qualified group.

I think it is important to hold this hearing. It is certainly a topical subject. Having witnesses of the caliber of those from the National Academy review climatic science I think is very timely.

I want to emphasize science because so much of our activities associated with this issue are based, to some extent, on emotion. I

would remind our scientists that we are novices, obviously, and we depend on your recommendations. We kind of expect you to, if you will, put behind your recommendations your own personal experience, your scholarly commitments over the years, in other words, to some extent your reputation, because those of us on this panel have one of two alternatives. That is to vote yes or no. Now, that may be an oversimplification, but if we cannot depend on you folks for accurate evaluation based on your expertise and knowledge, as opposed to what we might get out of a public hearing, why, I do not know who we can depend on.

In any event, I want to welcome you. I have often said the risk of climate change is a risk that we must recognize, address, manage, if you will, but to manage risks, I think you must first understand the risks that you face. That is where you gentlemen and others come in. Certainly the science suggests that we do face a risk of climate change from human activity.

All scientists seem to agree that some climate change will result from the direct effect of adding greenhouse gases to the atmosphere. I am told that the mid-range estimate from the IPCC is a global average warming of about 5.4 degrees Fahrenheit by the end of the 21st century.

But climate models used for those projections seem to differ on the role of the so-called feedbacks, particularly clouds, aerosols, and so forth. In fact, the NAS notes that the lack of understanding of these "feedbacks" appears to be a severe handicap to our ability to assess future climate changes.

The report also suggests that "without an understanding of the sources and degree of uncertainty, decision makers could fail to define the best ways to deal with serious issues of global warming." Obviously, we want to err, if we are going to err, on the side of safety and caution.

I have always been somewhat intrigued with the ice core record from Greenland which shows historically the temperature variations, volcanic activity, a great deal of history of climate change. I have often wondered why there was not more scientific research in that area of a continuing nature. It seemed to be a bit inconsistent. Perhaps I do not know all the facts. In any event, there is some historical data that supports dramatic change.

Now, some of my colleagues have suggested that this National Academy report on climate science is a call to action. I agree but I am wondering if the call is for improved climate monitoring and climate modeling, not necessarily a justification for caps on emissions. So, again, the decision should be made on science, not emotion.

In my opinion, caps are no different from the flawed Kyoto Protocol that would place unfair, expansive and expensive limits on the U.S. production. When you consider rationing the amount of energy the United States could use, even though energy is key to the prosperity of the American way of life, adequate, low cost energy is a part of our standard of living in this country.

The concern is over causing significantly higher energy costs: 53 percent higher it is estimated for gasoline under Kyoto; 86 percent increase in the cost of electricity. That is going to change the standard of living in this country.

Reducing the rate of economic growth by as much as 4 percent per year is going to affect a lot of jobs, hundreds of thousands of jobs. It could eliminate the surplus.

But in any event, it could threaten American global competitiveness. Our biggest economic rivals would be exempt from emissions limits, and that is one of the major problems with the Kyoto accord. It does not allow, if you will, for us to use our technology to reduce their emissions. It simply seems to allow them to catch up.

The U.N. Framework Convention on Climate Change, which the United States has ratified, calls for stabilization of greenhouse gas concentrations. But Kyoto will not stabilize concentrations. In fact, it will not make a measurable difference in the climate. Emissions from 130 developing nations will overwhelm any reductions made by the United States and 38 other countries.

So, a new approach to managing the risk of climate change is really needed. I think our President has provided that starting point. I applaud the President for his leadership in the face of so much criticism from our European allies and radical environmental groups. Sometimes the right thing to do is not the most popular thing to do.

The President's plan focuses on managing the risk of climate change using American technology and ingenuity and innovation, and America's can-do spirit; quantifying and understanding the risks of climate change through improved climate observations and models; developing tools we will need to reduce the future risk of climate change, advanced energy technologies.

We will discuss with our second panel of witnesses a variety of these short- and long-term energy technology options that will help us reduce, avoid, or sequester greenhouse gas emissions. And I look forward from hearing from them as well.

Personally I support cost effective actions to meet the long-term stabilization goal of the U.N. Framework Convention on Climate Change. It will require a fundamental change in the way that we produce the use energy—more energy with fewer emissions. It is not going to be as simple as regulating emissions. Certainly the question of reducing them out of existence is a major consideration. It is my hope that we can sit down at the table not long after this hearing and put forth a sensible bipartisan alternative to Kyoto.

I just want to make one more observation. It is my understanding that the White House will be sending up its recommendations in outlined legislative form relative to the President's Energy Task Force report. I would hope that we can take this up promptly in the Senate. As many of you know, Senator Lott had proposed to take up energy immediately after taxes and education, and the Democratic leadership has not addressed it, to my knowledge, on the calendar.

I feel that any delay in taking that up affects, to some extent, the security of this Nation. We are dependent on a plentiful supply of low cost energy, and anything to delay the development of an increased supply of energy and technology to reduce emissions, as well as increase efficiency, is going to affect the security of this Nation, the prosperity of this Nation, and certainly our standard of living.

And I would appeal, again as I will every day that we hold a hearing, that the majority move the Griles nomination. It has been pending 35 days now and clearly Griles was not a part of the agreement that was made and dictated by the Democratic side that they would hold back on all nominees until after there was an agreement on the makeup of the committees. In Griles' case, he was brought up prior to the change and should have been moved, and there is simply no excuse for that.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much.

As I think we all know, the administration asked the NRC to assist in identifying areas in the science of climate change where there are certainties and uncertainties, and that report was prepared. We have three of the leaders who worked on that report here to testify. Why do we not try to go ahead with testimony right now and see if we can go for about 10 minutes before we have to leave for this vote. We will start with Dr. Sherwood Rowland, who is head of this panel. If you will go right ahead with your testimony.

Let me say from the outset, we will include the complete testimony of all witnesses, as if read, in the record, but any comments you have or any summary you want to make, we would be anxious to hear.

STATEMENT OF F. SHERWOOD ROWLAND, Ph.D., DONALD BREN RESEARCH PROFESSOR OF CHEMISTRY AND EARTH SYSTEM SCIENCE, UNIVERSITY OF CALIFORNIA AT IRVINE, IRVINE, CA

Dr. ROWLAND. Good morning, Mr. Chairman and members of the committee. My name is F. Sherwood Rowland. I am the Donald Bren Research Professor of Chemistry and Earth System Science at the University of California at Irvine and served as a member of the Committee on the Science of Climate Change of the National Research Council. The chairman of that committee was Ralph Cicerone, the chancellor at the University of California at Irvine. In addition, I am a member of the National Academy of Sciences and have served as its Foreign Secretary since 1994.

This study originated from a White House request to help inform the administration's ongoing review of U.S. climate change policy. In particular, the written request asked for the National Academy's assistance in identifying the areas in the science of climate change where there are the greatest certainties and uncertainties and views on whether there are any substantive differences between the IPCC—that is, the Intergovernmental Panel on Climate change—reports and the IPCC summaries. In addition, based on discussions with the administration, specific questions were incorporated into the statement of task for the study. The White House asked for a response as soon as possible but no later than early June, less 1 month after submitting its formal request.

The National Academies is a private organization formed in 1863 under a charter from the U.S. Government with a mandate arising from that charter to respond to government requests when asked. The National Academies draw no direct institutional funding from the U.S. Government, although the actual costs of the majority of

its studies are reimbursed by the Government. In view of the critical nature of this issue, we agreed to undertake this study and to use our own funds to support it.

The report does not make policy recommendations regarding what to do in response to the potential of global warming. Thus, it does not estimate the potential economic and environmental costs, benefits, and uncertainties regarding various policy responses and future human behaviors.

Looking ahead for the next 100 years not only involves uncertainties in our understanding of the earth's climate system, but also estimates of changes which will result later in the century from choices not yet made. Inevitably such looks into the future have some near certainties. For instance, the global population will almost certainly grow from its present 6 billion to 8 billion or 9 billion by mid-century. But there are other areas with much greater uncertainty. Nevertheless, science does provide us with the best available guide to the future, and it is critical that our Nation and the world base important policies on the best judgments that science can provide concerning the future consequences of present actions.

Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are in fact rising. The changes observed over the last several decades are likely mostly the consequence of human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability.

The most significant greenhouse gas is carbon dioxide which is not only formed by the natural processes of the decay of biological matter, but is also released by the burning of wood, coal, oil, and natural gas.

Another greenhouse gas is methane, which from its natural emanation from waterlogged areas gained the name swamp gas, but is also released during agricultural activities such as rice growing and cattle raising.

The gas which contributes the most to the greenhouse effect is water vapor for which the concentration is controlled almost entirely by the global temperature and therefore subject to an indirect effect from mankind through other activities which affect global temperature.

Other greenhouse gases include nitrous oxide formed by bacterial reaction in soils, including attack on nitrogenous fertilizers; chlorofluorocarbons, synthetic chemicals now under global production bans because of their capability for depletion of stratospheric ozone; and tropospheric ozone, an important pollutant created in photochemical smog.

The total contribution of these greenhouse gases, especially of carbon dioxide, will continue to accumulate during the 21st century and consequently human-induced warming and associated sea level rises are expected to continue as well.

Secondary effects are suggested by computer model simulations and basic physical reasoning. These include increases in rainfall rates and increased susceptibility of semi-arid regions to drought.

The impacts of these changes will be critically dependent on the magnitude of the warming and the rate with which it occurs.

Surface temperature measurements, with near global coverage, have only been available since the latter half of the 19th century. During that period, the average global temperature has increased by about 1.1 degrees Fahrenheit or .6 degree Centigrade, with about half of that increase occurring during the last 2 decades. The warmest decade of that entire record occurred during the 1990's and the next warmest was that of the 1980's.

My colleagues, Dr. Wallace and Dr. Barron, will present other aspects of our report from the National Academy. Thank you.

[The prepared statement of Dr. Rowland follows:]

PREPARED STATEMENT OF F. SHERWOOD ROWLAND, PH.D., DONALD BREN RESEARCH PROFESSOR OF CHEMISTRY AND EARTH SYSTEM SCIENCE, UNIVERSITY OF CALIFORNIA AT IRVINE, IRVINE, CA

Good morning, Mr. Chairman and members of the Committee. My name is F. Sherwood Rowland. I am the Donald Bren Research Professor of Chemistry and Earth System Science at the University of California at Irvine and served as a member of the Committee on the Science of Climate Change of the National Research Council. In addition, I serve as the Foreign Secretary of the National Academy of Sciences.

This study originated from a White House request to help inform the Administration's ongoing review of U.S. climate change policy. In particular, the written request asked for the National Academies' "assistance in identifying the areas in the science of climate change where there are the greatest certainties and uncertainties," and "views on whether there are any substantive differences between the IPCC [Intergovernmental Panel on Climate Change] reports and the IPCC summaries." In addition, based on discussions with the Administration, the following specific questions were incorporated into the statement of task for the study:

- What is the range of natural variability in climate?
- Are concentrations of greenhouse gases and other emissions that contribute to climate change increasing at an accelerating rate, and are different greenhouse gases and other emissions increasing at different rates?
- How long does it take to reduce the buildup of greenhouse gases and other emissions that contribute to climate change?
- What other emissions are contributing factors to climate change (e.g., aerosols, CO, black carbon soot), and what is their relative contribution to climate change?
- Do different greenhouse gases and other emissions have different draw down periods?
- Are greenhouse gases causing climate change?
- Is climate change occurring? If so, how?
- Is human activity the cause of increased concentrations of greenhouse gases and other emissions that contribute to climate change?
- How much of the expected climate change is the consequence of climate feedback processes (e.g., water vapor, clouds, snow packs)?
- By how much will temperatures change over the next 100 years and where?
- What will be the consequences (e.g., extreme weather, health effects) of increases of various magnitudes?
- Has science determined whether there is a "safe" level of concentration of greenhouse gases?
- What are the substantive differences between the IPCC Reports and the Summaries?
- What are the specific areas of science that need to be studied further, in order of priority, to advance our understanding of climate change?

The White House asked for a response "as soon as possible" but no later than early June—less than one month after submitting its formal request.

The National Academies has a mandate arising from its 1863 charter to respond to government requests when asked. In view of the critical nature of this issue, we agreed to undertake this study and to use our own funds to support it.

A committee with broad expertise and diverse perspectives on the scientific issues of climate change was therefore appointed through the National Academies' Na-

tional Research Council. In early May, the committee held a conference call to discuss the specific questions and to prepare for its 2-day meeting (May 21-22, 2001) in Irvine, California. The committee reviewed the 14 questions and determined that they represent important issues in climate change science and could serve as a useful framework for addressing the two general questions from the White House.

For the task of comparing IPCC Reports and Summaries, the committee focused its review on the work of IPCC Working Group I, which dealt with many of the same detailed questions being asked above. The committee decided to address the questions in the context of a brief document that also could serve as a primer for policy makers on climate change science.

While traditional procedures for an independent NRC study, including review of the report by independent experts, were followed, it is important to note that tradeoffs were made in order to accommodate the rapid schedule. For example, the report does not provide extensive references to the scientific literature or marshal detailed evidence to support its "answers" to the questions. Rather, the report largely presents the consensus scientific views and judgments of committee members, based on the accumulated knowledge that these individuals have gained both through their own scholarly efforts and through formal and informal interactions with the world's climate change science community.

The result is a report that provides policy makers with a succinct and balanced overview of what science can currently say about the potential for future climate change, while outlining the uncertainties that remain in our scientific knowledge.

The report does not make policy recommendations regarding what to do about the potential of global warming. Thus, it does not estimate the potential economic and environmental costs, benefits, and uncertainties regarding various policy responses and future human behaviors. While beyond the charge presented to this committee, scientists and social scientists have the ability to provide assessments of this type as well. Both types of assessments can be helpful to policy makers, who frequently have to weigh tradeoffs and make decisions on important issues, despite the inevitable uncertainties in our scientific understanding concerning particular aspects. Science never has all the answers. But science does provide us with the best available guide to the future, and it is critical that our nation and the world base important policies on the best judgments that science can provide concerning the future consequences of present actions.

The rest of my comments provide a general summary of the material in the report. My colleagues, Dr. Wallace and Dr. Barron, will provide detailed responses to the questions in their testimony.

Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability. Human-induced warming and associated sea level rises are expected to continue through the 21st century. Secondary effects are suggested by computer model simulations and basic physical reasoning. These include increases in rainfall rates and increased susceptibility of semi-arid regions to drought. The impacts of these changes will be critically dependent on the magnitude of the warming and the rate with which it occurs.

The mid-range model estimate of human induced global warming by the Intergovernmental Panel on Climate Change (IPCC) is based on the premise that the growth rate of climate forcing agents such as carbon dioxide will accelerate. The predicted warming of 3°C (5.4°F) by the end of the 21st century is consistent with the assumptions about how clouds and atmospheric relative humidity will react to global warming. This estimate is also consistent with inferences about the sensitivity of climate drawn from comparing the sizes of past temperature swings between ice ages and intervening warmer periods with the corresponding changes in the climate forcing. This predicted temperature increase is sensitive to assumptions concerning future concentrations of greenhouse gases and aerosols. Hence, national policy decisions made now and in the longer-term future will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in this century. Because there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude of future warming should be regarded as tentative and subject to future adjustments (either upward or downward).

Reducing the wide range of uncertainty inherent in current model predictions of global climate change will require major advances in understanding and modeling of both (1) the factors that determine atmospheric concentrations of greenhouse gases and aerosols, and (2) the so-called "feedbacks" that determine the sensitivity

of the climate system to a prescribed increase in greenhouse gases. There also is a pressing need for a global observing system designed for monitoring climate.

The committee generally agrees with the assessment of human-caused climate change presented in the IPCC Working Group I (WGI) scientific report, but seeks here to articulate more clearly the level of confidence that can be ascribed to those assessments and the caveats that need to be attached to them. This articulation may be helpful to policy makers as they consider a variety of options for mitigation and/or adaptation.

The CHAIRMAN. Thank you very much.

They have started the last part of this vote. So, rather than to interrupt either of the next witnesses, I think I will just recess the hearing right now, and then as soon as we have made these two votes, we will be back here and we will continue with the testimony of the next two witnesses. We will stand in recess.

[Recess.]

The CHAIRMAN. Why do we not go ahead? I am sure some of the other members will be returning here as soon as the vote is over, but let me go ahead now with the other two witnesses on this panel. Dr. Wallace, why do you not go ahead with your statement, and then Dr. Barron.

STATEMENT OF JOHN M. WALLACE, Ph.D., PROFESSOR OF ATMOSPHERIC SCIENCES, UNIVERSITY OF WASHINGTON, SEATTLE, WA

Dr. WALLACE. Thank you. Good morning, Mr. Chairman and members of the committee. My name is John Wallace and I am a professor of atmospheric sciences at the University of Washington. I served as a member of the Committee on the Science of Climate Change of the National Research Council and I am member of the National Academy of Sciences.

I am going to address just three of the dozen or so questions that the administration posed to us, and in the interest of providing plenty of time for discussion, I am going to make my answers quite brief here.

The first of the three questions is: What is the range of natural variability of climate? This is a question that needs to be addressed looking at paleoclimate evidence, evidence from things such as the Greenland ice cores, which Senator Murkowski mentioned, for evidence of how climate has behaved over longer periods of time than we have observations. I should say that the ice cores are one of the most important pieces of the evidence. We believe that climate has varied by as much as 20 degrees Fahrenheit locally in connection with the transitions between the ice age and the warmer interglacial cycles in between the glacial periods. So, 20 degrees locally and perhaps as much as 10 degree Fahrenheit in global average temperature.

We believe that during the great thaw from the most recent ice age, that temperatures warmed quite rapidly for a few thousand year period and that we might have seen temperature increases of as much as 3 or 4 degrees per millennium during that time. It is notable that the 3 or 4 degrees per millennium would be just .3 or .4 of a degree per century, and that is smaller than the change that we have seen during the 20th century.

The ice core records provided some surprising evidence of some abrupt changes of up to a few degrees, perhaps as much as 5 de-

grees, locally during the recovery from the ice age period, though there has not been anything as striking as that in the last 5,000 to 8,000 years.

The proxy evidence also shows wide variations in rainfall from century to century over areas like the United States. The Dust Bowl of the 20th century showed us what conditions were like much more typically back during the period from the 10th to the 14th centuries. Very severe droughts like that were much more common at that time than they have been recently. So, we have been living a charmed life, so to speak.

Well, with that as a background, then to proceed to the two other questions. The first of them is, is the climate changing now, and if so, how? As Dr. Rowland mentioned, we do have measurements over the 20th century both at a wide array of surface stations on land and ship records also, millions and millions of observations of sea surface temperature and air temperature from ships, which indicated that over the earth's surface, temperatures warmed by about a degree Fahrenheit during the 20th century.

We also have recent evidence of a warming within the ocean, down to depths of 10,000 feet or so, during the second half of the 20th century. We have seen a retreat of mountain glaciers over many areas of the world during this time and a good deal of other evidence of a gradual warming. That is detailed in the report, and I will not take the time to go into it here.

It is worth noting, though, that the observed warming has not proceeded at a uniform rate. In fact, it was very rapid during the early part of the century, particularly the 1920's decade, and then temperatures leveled off for a while from the mid-1940's until the mid-1970's. I remember when I was in graduate school not hearing that there had been warming but that, if anything, there was a bit of cooling in the northern hemisphere at that time. That was back in the 1960's. But we have seen very rapid warming in the last 25 years or so.

Another thing which is puzzling is that the temperature changes aloft, the temperature of the troposphere, the lowest 5-mile thick layer of the atmosphere, have not kept pace with the changes at the earth's surface. During the 1970's, the balloon data that we have from that time indicated that the upper air temperatures were warming faster than the surface temperatures, and since 1980, the situation has been the other way around. So, a number of us in the community, as part of our research, are trying reconcile those differences.

So, that brings me to the final question, are greenhouse gases causing climate change? This is one where we were careful with our wording because it is a delicate balance to just express this in the right way. I am going to read you a couple of sentences from our report.

The IPCC's conclusion that most of the observed warming of the last 50 years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the current thinking of the scientific community on this issue. The stated degree of confidence in the IPCC assessment is higher today than it was 10 or even 5 years ago. I would certainly count myself among those who have swung in that direction. I would say 10 years ago I was kind

of at the 80 percent level in agreement with it, and now I would count myself at the 90 percent level.

But we go on to say, uncertainty remains because the level of natural variability inherent in the climate system, on time scales of decades to centuries, is still uncertain. We do not know how much of the variability during the past century was due to natural causes, and we acknowledge that the ability of the models to simulate that variability is limited at this point. And there are also uncertainties in our knowledge of past climate, for which we have to rely on proxy evidence.

But despite the certainties, we say that there is general agreement that the observed warming during the 20th century is real and particularly strong within the past 20 years.

So, I would leave off at that point.

[The prepared statement of Dr. Wallace follows:]

PREPARED STATEMENT OF JOHN M. WALLACE, PH.D., PROFESSOR OF ATMOSPHERIC SCIENCES, UNIVERSITY OF WASHINGTON, SEATTLE, WA

Good morning, Mr. Chairman and members of the Committee. My name is John Wallace. I am a professor of Atmospheric Sciences at the University of Washington. I served as a member of the Committee on the Science of Climate Change of the National Research Council, and am a member of the National Academy of Sciences.

My remarks summarize the committee's responses to eight of the questions.

What is the range of natural variability in climate?

The range of natural climate variability is known to be quite large (in excess of several degrees Celsius) on local and regional spatial scales over periods as short as a decade. Precipitation also can vary widely. For example, there is evidence to suggest that droughts as severe as the "dust bowl" of the 1930s were much more common in the central United States during the 10th to 14th centuries than they have been in the more recent record. Mean temperature variations at local sites have exceeded 10°C (18°F) in association with the repeated glacial advances and retreats that occurred over the course of the past million years. It is more difficult to estimate the natural variability of global mean temperature because of the sparse spatial coverage of existing data and difficulties in inferring temperatures from various proxy data. Nonetheless, evidence suggests that global warming rates as large as 2°C (3.6°F) per millennium may have occurred during retreat of the glaciers following the most recent ice age.

Are concentrations of greenhouse gases and other emissions that contribute to climate change increasing at an accelerating rate, and are different greenhouse gases and other emissions increasing at different rates? Is human activity the cause of increased concentrations of greenhouse gases and other emissions that contribute to climate change?

The emissions of some greenhouse gases are increasing, but others are decreasing. In some cases the decreases are a result of policy decisions, while in other cases the reasons for the decreases are not well understood.

Of the greenhouse gases that are directly influenced by human activity, the most important are carbon dioxide, methane, ozone, nitrous oxide, and chlorofluorocarbons (CFCs). Aerosols released by human activities are also capable of influencing climate. (Table 1 lists the estimated climate forcing due to the presence of each of these "climate forcing agents" in the atmosphere.)

Concentrations of carbon dioxide (CO_2) extracted from ice cores drilled in Greenland and Antarctica have typically ranged from near 190 parts per million by volume (ppmv) during the ice ages to near 280 ppmv during the warmer "interglacial" periods like the present one that began around 10,000 years ago. Concentrations did not rise much above 280 ppmv until the Industrial Revolution. By 1958, when systematic atmospheric measurements began, they had reached 315 ppmv, and they are currently ~370 ppmv and rising at a rate of 1.5 ppmv per year (slightly higher than the rate during the early years of the 43-year record). Human activities are responsible for the increase. The primary source, fossil fuel burning, has released roughly twice as much carbon dioxide as would be required to account for the observed increase. Tropical deforestation also has contributed to carbon dioxide re-

leases during the past few decades. The excess carbon dioxide has been taken up by the oceans and land biosphere.

Like carbon dioxide, methane (CH_4) is more abundant in Earth's atmosphere now than at any time during the 400,000 year long ice core record, which dates back over a number of glacial/interglacial cycles. Concentrations increased rather smoothly by about 1% per year from 1978, until about 1990. The rate of increase slowed and became more erratic during the 1990s. About two-thirds of the current emissions of methane are released by human activities such as rice growing, the raising of cattle, coal mining, use of land-fills, and natural gas handling, all of which have increased over the past 50 years.

A small fraction of the ozone (O_3) produced by natural processes in the stratosphere mixes into the lower atmosphere. This "tropospheric ozone" has been supplemented during the 20th century by additional ozone, created locally by the action of sunlight upon air polluted by exhausts from motor vehicles, emissions from fossil fuel burning power plants, and biomass burning.

Nitrous oxide (N_2O) is formed by many microbial reactions in soils and waters, including those acting on the increasing amounts of nitrogen-containing fertilizers. Some synthetic chemical processes that release nitrous oxide have also been identified. Its concentration has increased approximately 13% in the past 200 years.

Atmospheric concentrations of CFCs rose steadily following their first synthesis in 1928 and peaked in the early 1990s. Many other industrially useful fluorinated compounds (e.g., carbon tetrafluoride, CF_4, and sulfur hexafluoride, SF_6), have very long atmospheric lifetimes, which is of concern, even though their atmospheric concentrations have not yet produced large radiative forcings. Hydrofluorocarbons (HFCs), which are replacing CFCs, have a greenhouse effect, but it is much less pronounced because of their shorter atmospheric lifetimes. The sensitivity and generality of modern analytical systems make it quite unlikely that any currently significant greenhouse gases remain to be discovered.

What other emissions are contributing factors to climate change (e.g., aerosols, CO, black carbon soot), and what is their relative contribution to climate change?

Besides greenhouse gases, human activity also contributes to the atmospheric burden of aerosols, which include both sulfate particles and black carbon (soot). Both are unevenly distributed, owing to their short lifetimes in the atmosphere. Sulfate particles scatter solar radiation back to space, thereby offsetting the greenhouse effect to some degree. Recent "clean coal technologies" and use of low sulfur fuels have resulted in decreasing sulfate concentrations, especially in North America, reducing this offset. Black carbon aerosols are end-products of the incomplete combustion of fossil fuels and biomass burning (forest fires and land clearing). They impact radiation budgets both directly and indirectly; they are believed to contribute to global warming, although their relative importance is difficult to quantify at this point.

How long does it take to reduce the buildup of greenhouse gases and other emissions that contribute to climate change? Do different greenhouse gases and other emissions have different draw down periods?

Table 1.—REMOVAL TIMES AND CLIMATE FORCING VALUES FOR SPECIFIED ATMOSPHERIC GASES AND AEROSOLS

Forcing agent	Approximate removal times [a]	Climate forcing (W/m^2) up to the year 2000
Greenhouse gases:		
Carbon Dioxide	>100 years	1.3 to 1.5
Methane	10 years	0.5 to 0.7
Tropospheric Ozone	10-100days	0.25 to 0.75
Nitrous Oxide	100 years	0.1 to 0.2
Perflourocarbon	>1000 years	0.01
Fine Aerosols:		
Sulfate	10 days	–0.3 to –1.0
Black Carbon	10 days	0.1 to 0.8

[a] A removal time of 100 years means that much, but not all, of the substance would be gone in 100 years. Typically, the amount remaining at the end of 100 years is 37%; after 200 years 14%; after 300 years 5%; after 400 years 2%.

Is climate change occurring? If so, how?

Weather station records and ship-based observations indicate that global mean surface air temperature warmed between about 0.4 and 0.8°C (0.7 and 1.5°F) during the 20th century. Although the magnitude of warming varies locally, the warming trend is spatially widespread and is consistent with an array of other evidence detailed in this report. The ocean, which represents the largest reservoir of heat in the climate system, has warmed by about 0.05°C (0.09°F) averaged over the layer extending from the surface down to 10,000 feet, since the 1950s.

The observed warming has not proceeded at a uniform rate. Virtually all the 20th century warming in global surface air temperature occurred between the early 1900s and the 1940s and during the past few decades. The troposphere warmed much more during the 1970s than during the two subsequent decades, whereas Earth's surface warmed more during the past two decades than during the 1970s. The causes of these irregularities and the disparities in the timing are not completely understood. One striking change of the past 35 years is the cooling of the stratosphere at altitudes of ~13 miles, which has tended to be concentrated in the wintertime polar cap region.

Are greenhouse gases causing climate change?

The IPCC's conclusion that most of the observed warming of the last 50 years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the current thinking of the scientific community on this issue. The stated degree of confidence in the IPCC assessment is higher today than it was 10, or even 5 years ago, but uncertainty remains because of (1) the level of natural variability inherent in the climate system on time scales of decades to centuries, (2) the questionable ability of models to accurately simulate natural variability on those long time scales, and (3) the degree of confidence that can be placed on reconstructions of global mean temperature over the past millennium based on proxy evidence. Despite the uncertainties, there is general agreement that the observed warming is real and particularly strong within the past 20 years. Whether it is consistent with the change that would be expected in response to human activities is dependent upon what assumptions one makes about the time history of atmospheric concentrations of the various forcing agents, particularly aerosols.

The CHAIRMAN. Thank you very much for your testimony.

Dr. Barron, why do you not go right ahead?

STATEMENT OF ERIC J. BARRON, Ph.D., PROFESSOR AND DIRECTOR, EARTH AND MINERAL SCIENCES ENVIRONMENT INSTITUTE, THE PENNSYLVANIA STATE UNIVERSITY, COLLEGE PARK, PA

Dr. BARRON. Good morning, Mr. Chairman, members of the committee. My name is Eric Barron. I direct the Earth and Mineral Sciences Environment Institute and am distinguished professor of Geosciences at Penn State University. I served as a member of the Committee on the Science of Climate Change of the National Research Council, and I also am currently the chair of the NRC's Board on Atmospheric Sciences and Climate.

I am going to address the high points of the remaining questions of the report. The first one is, how much will temperatures change over the next 100 years and where?

Based on IPCC emissions scenarios, by the end of this century, we expect something on the order of a 2.5 to 10.4 degree Fahrenheit increase in temperatures relative to 1990. Now, that range, with a midpoint near 5 degrees Fahrenheit, reflects uncertainties in our ability to model and predict the future, and it also reflects differences and uncertainties in emissions scenarios.

That is a globally averaged temperature, so you can expect the fabric of that change to be somewhat different. So, for example, we expect higher latitude temperatures to warm more than lower latitude and continental temperatures to warm more than oceanic

temperatures. We also have an expectation that with warming you will have increased evaporation, and some regions will experience higher precipitation, and in experiencing higher precipitation, there is likely to be more event or heavy rainfall precipitation events. We will also have regions-most likely in the current semi-arid regions-like the Great Plains in which that increased evaporation is likely to result in an increased tendency for drying.

One other issue is how much of the expected climate change is associated with feedbacks and how much of it is a direct influence of carbon dioxide. This question focuses directly on the climate sensitivity of the models. Basically when we come down to an analysis of this, looking at the biggest feedbacks, the factor is about a 2.5 enhancement of the direct effects of CO_2. The two biggest feedbacks are associated with the fact that warming puts more water vapor into the atmosphere and water vapor serves as a greenhouse gas. And the second major feedback is called ice-albedo feedback. You are reducing the snow and ice cover, and therefore the earth is absorbing more solar energy. Those two factors give us this amplification of about 2.5.

There are, of course, still some levels of uncertainties associated with cloud cover and the distribution of moisture within the atmosphere.

A third question is, what will be the consequences of climate change of various magnitudes? Here we have both the U.S. national assessment of climate impacts and other recent NRC reports such as the one on climate and infectious disease. Basically what you can see is that there are several elements of the United States in particular which are fairly robust climate change. There are other elements of our society which are at greater risk.

Just to give you few examples, if we look at agriculture in aggregate for the Nation, because of CO_2 fertilization, and water efficiency, you expect that agriculture in aggregate for the Nation looks to be in pretty good shape. Now, this also takes into account the distributions in the locations of crops and differences between small farmers and larger farmers and their ability to adapt.

Looking at water and water resources, probably the two most significant issues that are important consequences, returns us again to the Great Plains and areas that are semi-arid today for which increased evaporation is likely to result in a greater tendency towards drying. We also see that in Western States that are particularly associated with snowpack for which their water supplies through the summer depend on melting of the snow that has accumulated in the winter, because the snow line is going up the sides of the mountains and you are melting that snow and ice more quickly during the spring, those regions may be more vulnerable.

Increased rainfall events. If event rainfall is occurring, it would also have an impact on pollution runoff and control.

With higher sea levels, even if severe storms like hurricanes do not change substantially, you would expect a higher sea level to create greater vulnerability for the same magnitude storm because it puts more coastal property at risk.

Health is an important issue. It is one for which there is substantial debate associated with it. For example, we know that the distribution of vectors like a mosquito that cause disease such as

malaria and dengue fever, will change in their distribution with climate change. But yet, we see substantial evidence that at least for the United States, because of our economic capability and because of a strong public health infrastructure, that we are capable of addressing these particular issues. The same thing is not necessarily true for the rest of the world.

In terms of ecosystems, there are perhaps more substantial impacts because of an inability of many ecosystems to adapt to several of these particular changes.

The next question was whether or not science has determined a safe level for the concentration of greenhouse gases. This is not an issue that is easy to address. It depends far too much on a value judgment for how significant the impacts and changes are over the surface of the earth, and it also requires that we have a very careful assessment of all of the different risks, advantages, and disadvantages. So, it is not something that is easy to determine.

We were asked what were substantive differences between IPCC reports and the summaries. In large measure, we see the technical summary and the full report to be a very fine assessment of the state of the science. It is also true that when you condense all of that material into a summary for policymakers, you expect to see some differences in that process of condensation and in trying to call out what you think are the most significant issues.

The last element of this set of questions is the further needs for science, in terms of addressing the uncertainties. You see about seven specific topics that range from greater efforts to understand the usage of fossil fuels to look at sources in sink terms for the greenhouse gases, to understand how these greenhouse gases and aerosols will evolve through time, what major changes in particular regions will occur, improving our ability to address the sensitivity of the system.

We also see that there is a need for an enhanced ability to cross and combine the disciplines and to focus science at an intersection with decision makers. Each of these things requires that we have a robust observing system, a strong effort dedicated to modeling and predicting climate change, and to ensure that climate research is supported and managed in a way that ensures innovation, effectiveness, and efficiency.

Thank you.

[The prepared statement of Dr. Barron follows:]

PREPARED STATEMENT OF ERIC J. BARRON, PH.D., PROFESSOR AND DIRECTOR, EMS ENVIRONMENT INSTITUTE, THE PENNSYLVANIA STATE UNIVERSITY, COLLEGE PARK, PA

Good morning, Mr. Chairman and members of the Committee. My name is Eric Barron. I am the Director of the Earth and Mineral Sciences Environment Institute and Distinguished Professor of Geosciences at Pennsylvania State University. I served as a member of the Committee on the Science of Climate Change of the National Research Council, and am currently the chair of the NRC's Board on Atmospheric Sciences and Climate.

My remarks will focus on the committee's responses to the remaining questions.

By how much will temperatures change over the next 100 years and where?

Climate change simulations for the period of 1990 to 2100 based on the IPCC emissions scenarios yield a globally-averaged surface temperature increase by the end of the century of 1.4 to 5.8°C (2.5 to 10.4°F) relative to 1990. The wide range of uncertainty in these estimates reflects both the different assumptions about fu-

ture concentrations of greenhouse gases and aerosols in the various scenarios considered by the IPCC and the differing climate sensitivities of the various climate models used in the simulations. The range of climate sensitivities implied by these predictions is generally consistent with previously reported values.

The predicted warming is larger over higher latitudes than over low latitudes, especially during winter and spring, and larger over land than over sea. Rainfall rates and the frequency of heavy precipitation events are predicted to increase, particularly over the higher latitudes. Higher evaporation rates would accelerate the drying of soils following rain events, resulting in lower relative humidities and higher daytime temperatures, especially during the warm season. The likelihood that this effect could prove important is greatest in semi-arid regions, such as the U.S. Great Plains. These predictions in the IPCC report are consistent with current understanding of the processes that control local climate.

In addition to the IPCC scenarios for future increases in greenhouse gas concentrations, the committee considered a scenario based on an energy policy designed to keep climate change moderate in the next 50 years. This scenario takes into account not only the growth of carbon emissions, but also the changing concentrations of other greenhouse gases and aerosols.

Sufficient time has elapsed now to enable comparisons between observed trends in the concentrations of carbon dioxide and other greenhouse gases with the trends predicted in previous IPCC reports. The increase of global fossil fuel carbon dioxide emissions in the past decade has averaged 0.6% per year, which is somewhat below the range of IPCC scenarios, and the same is true for atmospheric methane concentrations. It is not known whether these slowdowns in growth rate will persist.

How much of the expected climate change is the consequence of climate feedback processes (e.g., water vapor, clouds, snow packs)?

The contribution of feedbacks to the climate change depends upon "climate sensitivity," as described in the report. If a central estimate of climate sensitivity is used, about 40% of the predicted warming is due to the direct effects of greenhouse gases and aerosols. The other 60% is caused by feedbacks. Water vapor feedback (the additional greenhouse effect accruing from increasing concentrations of atmospheric water vapor as the atmosphere warms) is the most important feedback in the models. Unless the relative humidity in the tropical middle and upper troposphere drops, this effect is expected to increase the temperature response to increases in human induced greenhouse gas concentrations by a factor of 1.6. The ice-albedo feedback (the reduction in the fraction of incoming solar radiation reflected back to space as snow and ice cover recede) also is believed to be important. Together, these two feedbacks amplify the simulated climate response to the greenhouse gas forcing by a factor of 2.5. In addition, changes in cloud cover, in the relative amounts of high versus low clouds, and in the mean and vertical distribution of relative humidity could either enhance or reduce the amplitude of the warming. Much of the difference in predictions of global warming by various climate models is attributable to the fact that each model represents these processes in its own particular way. These uncertainties will remain until a more fundamental understanding of the processes that control atmospheric relative humidity and clouds is achieved.

What will be the consequences (e.g., extreme weather, health effects) of increases of various magnitude?

In the near term, agriculture and forestry are likely to benefit from carbon dioxide fertilization and an increased water efficiency of some plants at higher atmospheric CO_2 concentrations. The optimal climate for crops may change, requiring significant regional adaptations. Some models project an increased tendency toward drought over semi-arid regions, such as the U.S. Great Plains. Hydrologic impacts could be significant over the western United States, where much of the water supply is dependent on the amount of snow pack and the timing of the spring runoff. Increased rainfall rates could impact pollution run-off and flood control. With higher sea level, coastal regions could be subject to increased wind and flood damage even if tropical storms do not change in intensity. A significant warming also could have far reaching implications for ecosystems. The costs and risks involved are difficult to quantify at this point and are, in any case, beyond the scope of this brief report.

Health outcomes in response to climate change are the subject of intense debate. Climate is one of a number of factors influencing the incidence of infectious disease. Cold-related stress would decline in a warmer climate, while heat stress and smog induced respiratory illnesses in major urban areas would increase, if no adaptation occurred. Over much of the United States, adverse health outcomes would likely be mitigated by a strong public health system, relatively high levels of public awareness, and a high standard of living.

Global warming could well have serious adverse societal and ecological impacts by the end of this century, especially if globally-averaged temperature increases approach the upper end of the IPCC projections. Even in the more conservative scenarios, the models project temperatures and sea levels that continue to increase well beyond the end of this century, suggesting that assessments that examine only the next 100 years may well underestimate the magnitude of the eventual impacts.

Has science determined whether there is a "safe" level of concentration of greenhouse gases?

The question of whether there exists a "safe" level of concentration of greenhouse gases cannot be answered directly because it would require a value judgment of what constitutes an acceptable risk to human welfare and ecosystems in various parts of the world, as well as a more quantitative assessment of the risks and costs associated with the various impacts of global warming. In general, however, risk increases with increases in both the rate and the magnitude of climate change.

What are the substantive differences between the IPCC Reports and the Summaries?

The committee finds that the full IPCC Working Group I (WGI) report is an admirable summary of research activities in climate science, and the full report is adequately summarized in the *Technical Summary*. The full WGI report and its *Technical Summary* are not specifically directed at policy. The *Summary for Policymakers* reflects less emphasis on communicating the basis for uncertainty and a stronger emphasis on areas of major concern associated with human-induced climate change. This change in emphasis appears to be the result of a summary process in which scientists work with policy makers on the document. Written responses from U.S. coordinating and lead scientific authors to the committee indicate, however, that (a) no changes were made without the consent of the convening lead authors (this group represents a fraction of the lead and contributing authors) and (b) most changes that did occur lacked significant impact.

It is critical that the IPCC process remain truly representative of the scientific community. The committee's concerns focus primarily on whether the process is likely to become less representative in the future because of the growing voluntary time commitment required to participate as a lead or coordinating author and the potential that the scientific process will be viewed as being too heavily influenced by governments which have specific postures with regard to treaties, emission controls, and other policy instruments. The United States should promote actions that improve the IPCC process while also ensuring that its strengths are maintained.

What are the specific areas of science that need to be studied further, in order of priority, to advance our understanding of climate change?

Making progress in reducing the large uncertainties in projections of future climate will require addressing a number of fundamental scientific questions relating to the buildup of greenhouses gases in the atmosphere and the behavior of the climate system. Issues that need to be addressed include (a) the future usage of fossil fuels, (b) the future emissions of methane, (c) the fraction of the future fossil-fuel carbon that will remain in the atmosphere and provide radiative forcing versus exchange with the oceans or net exchange with the land biosphere, (d) the feedbacks in the climate system that determine both the magnitude of the change and the rate of energy uptake by the oceans, which together determine the magnitude and time history of the temperature increases for a given radiative forcing, (e) details of the regional and local climate change consequent to an overall level of global climate change, (f) the nature and causes of the natural variability of climate and its interactions with forced changes, and (g) the direct and indirect effects of the changing distributions of aerosols. Maintaining a vigorous, ongoing program of basic research, funded and managed independently of the climate assessment activity, will be crucial for narrowing these uncertainties.

In addition, the research enterprise dealing with environmental change and the interactions of human society with the environment must be enhanced. This includes support of (a) interdisciplinary research that couples physical, chemical, biological, and human systems, (b) an improved capability of integrating scientific knowledge, including its uncertainty, into effective decision support systems, and (c) an ability to conduct research at the regional or sectoral level that promotes analysis of the response of human and natural systems to multiple stresses.

An effective strategy for advancing the understanding of climate change also will require (1) a global observing system in support of long-term climate monitoring and prediction, (2) concentration on large-scale modeling through increased, dedicated supercomputing and human resources, and (3) efforts to ensure that climate research is supported and managed to ensure innovation, effectiveness, and efficiency.

The CHAIRMAN. Thank you very much.

Let me just ask a few questions, and Senator Hagel I am sure will have questions.

Let me sort of paraphrase the conclusions that I am drawing from what I hear from each of you here, and then just ask any of you, who want to, to comment on whether I have drawn the right conclusions.

The consensus in the scientific community is that surface temperatures are rising; that most of the increased temperature is traced to the accumulation of these greenhouse gases, which human activity plays a major part in creating; that the temperature increase that you anticipate in the balance of this century is somewhere between 2.5 degrees and 10.4 degrees Fahrenheit. And I do not think there was direct testimony on this, but I think it is in your written testimony that the period for reducing these build-ups of greenhouse gases is fairly extensive; that you can build them up in a decade or 2 or a few decades, but getting them out of the atmosphere and reversing the process takes substantially longer.

Any of you who would want to comment on any of those conclusions to tell me that I have misstated it or put the emphasis in the wrong place, I would be anxious to hear. Dr. Rowland?

Dr. ROWLAND. I think that basically your summary is correct. The only place that I would modify is that the greenhouse gases are not all alike, and they have different capabilities of staying in the atmosphere.

Carbon dioxide equilibrates with the surface waters of the ocean rapidly, and the removal of excess carbon dioxide depends upon surface waters mixing down into the deep ocean. That is the first major removal process, and that is of the order of a century. So, it is not going to be removed quickly.

The chlorofluorocarbons, which are now covered by the Montreal Protocol, and which are not going into the atmosphere in any appreciable quantity now, have lifetimes of the order of 100 years. I think I should say here that when we say 100 years, that means that 1 century from now, 37 percent of what was there will still be there; 63 percent will have gone away. In 200 years, 15 percent will still be there, and in 300 years, 5 percent. So, when we say a 100-year lifetime, there will still be quite a bit of holdover for another 2 or 3 centuries after that.

The molecule methane has a lifetime in the atmosphere of the order of 10 years. So, if the origins of methane were brought under control—and I am not suggesting anything about those are or how they might be brought under control—then the atmosphere could be expected to react on a decadal time scale.

And tropospheric ozone is part of smog, and it is produced every day in major cities all over the world and spreads from there. That excess ozone has a lifetime that is really in the category of weeks. So, tropospheric ozone is something where the response is very quick. But what response means is you have to solve the smog problem in each of those cities.

So, it is a complex mixture, but typically things like carbon dioxide are there on the century time scale.

The CHAIRMAN. Thank you very much.

Do either of the other witnesses have an amendment to that?

Dr. WALLACE. A brief comment. I agree with everything you said. I think just a footnote to add to your third observation that the factor of almost 4 range in the predicted temperature rise over the next century, 2.5 to 10.5 degrees Fahrenheit—just to note that range is wide not only because of our uncertainty about the way the atmosphere is going to respond to the greenhouse gases, but the uncertainties in how much greenhouse gases there are going to be a century from now. Actually if we were to agree on a single scenario to use as a basis for comparing what the models tell us, say, a doubling of carbon dioxide, then we would come out with a narrower range, something more like a factor of 2 rather than a factor of 4. I say that because this factor of 4 range makes it look like we almost do not know anything.

The CHAIRMAN. So, let me try to understand. If we take that entire range, a 2.5 degree increase in temperature assumes how much in the way of increased carbon dioxide emissions?

Dr. WALLACE. See, that 2.5 is a rather optimistic prediction of the future greenhouse gas concentrations, the lowest end scenario, which implies very strong efforts on the part of nations to control concentrations.

The CHAIRMAN. And does it imply that we have actually reduced the amount of greenhouse gas emissions that we are contributing to the atmosphere each year or that we are just slowing the growth?

Dr. WALLACE. A substantial slowing the growth in those low end scenarios. Then, on the other hand, the 10.5 degree estimate, the high one, Dr. Hansen has described it as a no policy scenario.

The CHAIRMAN. It is just business as usual without any change in our policy or the policies of other countries on this issue.

Dr. WALLACE. And that would be compounded by the scientific uncertainty. That would be an estimate from a model that is the most sensitive to whatever level of greenhouse gas increase occurred. So, there are two kinds of uncertainties being compounded here in these estimates: one in how much greenhouse gases there are going to be, and second, how sensitive the climate system will be to whatever the increase is.

The CHAIRMAN. Let me defer to Senator Hagel for any questions he has.

Senator HAGEL. Mr. Chairman, thank you.

Gentlemen, welcome. We are grateful that you would share with us your expertise. As you have all stated, the National Academy of Sciences report states a vast world of uncertainty. So, thank you.

The first question I would like to ask each of you, how much confidence would you as scientists put in our current computer model process to range out over 100 years and give some precision to what we can expect our great-great grandchildren to live with? A high degree of confidence, some degree? Do we need better modeling?

Dr. BARRON. You have to go variable by variable. So, if you took a global number, gave it within a range with a central number as being capturing the vast body of information, then I think you have to ascribe a fairly high level of confidence that you are going to be within that range, given that range of emissions scenarios.

If you look sort of down scale and shorter phenomenon, then the level of uncertainty changes. So, you could take the hydrologic cycle, water and water resources, an important issue. What we see is, for some of these models, parts of the country like the Northeastern United States, the models are quite different. That suggests how the winter storms track and how thunderstorms develop in a scenario for global warming is somewhat uncertain.

But then you can look at other aspects and realize that as long as the main structure of the circulation remains the same, the Great Plain States are not going to be altered dramatically, and you are not going to be able to get high rainfall in the Great Plains in the lee of the Rocky Mountains with a different climate. Yet, you are going to have higher evaporation rates because it is going to be warmer, and that is going to increase the tendency towards aridity. The same thing, if you have increased warming, you are very likely to move the snow line to a higher elevation and have less storage of snow for all those Western States.

So, what you see is that on a level of a global aggregate cited within a range, the community gives you a high level of confidence. Then you start to look at particular variables, and you discover that in some cases we cannot be so certain. In other cases, it is hard to imagine the changes to be very different.

Well, then we can come down and look at natural variability and the structure of particular storms, and because we are not actually simulating them, you end up with a higher level of uncertainty.

Or you look at the response to vegetation, and all of a sudden, you have to realize that you have human habitations that are there, pests that you have to incorporate, whether the weeds are going to be more fertilized by CO_2 than are plants that people would consider not to be weeds, and the level of uncertainty increases.

So, there is not a simple answer to the question. Some things we have a very good understanding of. Some of the specifics for specific regions and specific times, we do not have a high level of confidence in.

Senator HAGEL. Dr. Wallace, thank you.

Dr. WALLACE. Senator Hagel, I guess the best way I could try to respond to your question would be to focus on what is the second paragraph of the summary, which talks about an estimate of something on the order of 5 degrees Fahrenheit temperature rise for a doubling of carbon dioxide. That is an effort to try to be concrete, to focus on one scenario.

I think that that 5 degree estimate has a lot of backing for it. It is not based simply on just throwing it into the models and seeing what the models do, but one can do simple, "back of the envelope" calculations with the basic physics in those models that says that if you assume that water in the atmosphere is going to behave in that warmer world the way it does today, that we are going to have relative humidities and cloud amounts like we have today, then that is the number you are going to get, something like 5 degrees Fahrenheit.

You can make that number different if you want. You can assume that the atmosphere is going to get dryer, that clouds are

going to shrink. You can make it bigger by assuming the opposite kinds of changes.

To be frank, we do not know whether they might go one way or the other, but in the absence of a real clear understanding of how they are going to change, it would seem like the most conservative assumption would be that they are going to behave much like they do now. So, that is where that 5 degrees comes from.

It is also backed by the kind of sensitivity that we would need to explain the temperature changes that the ice core records tell us happened in connection with the ice ages and the ratio of those temperature changes to the changes in solar energy.

So, I guess I would attach that same 90 percent kind of confidence to that number but with full admission that it could turn out to be too high or too low. But it is the best we can give you right now.

Senator HAGEL. Thank you.

Dr. Rowland.

Dr. ROWLAND. I would like to emphasize, underlying all of these calculations—and I am going to make this as an hypothesis not as a statement—that we think we understand how climate works. What one has not included and does not know how to include is suppose there is a part of it that we really do not understand. That is, what is the surprise that might be involved in it?

We went through this in connection with the discussion of chlorofluorocarbons and stratospheric ozone depletion because the best understanding of the atmospheric science had not predicted that there would be a specialized loss of ozone over Antarctica. So, we went from a situation of saying we think that there will be some future loss—and, incidentally, now we are seeing some of that future loss—from the original mechanism. But there was, in addition to that, another process going on that changed the whole viewpoint of the scientific community, and eventually the regulatory community, because it was that which we did not understand which was suddenly showing up in a very strange place, but with very heavy ozone loss.

So, all of the questions about what we expect for the future are done on slow changes in our current understanding, but back in the back of your mind is the concern maybe there is some unexpected change, the kind of thing that when one hears the climate community talking about the difference between considering climate as a switch or a dial, that is a dial that slowly turns up the temperature or a switch that goes from one system to another. In that other one, if there were such a change, then maybe there would be major changes in a very short time period. And we do not know anything about how to predict that concern.

Senator HAGEL. Thank you.

Let me ask the three of you just a very quick question, a follow-up to this. I think you have all three made the point pretty well that there is a vast amount of uncertainty in this business for no other reason than all the different variables. My questions is, picking up on your point, Dr. Rowland, if you have one or two of these variables, which all of them are important—and I go back to what Dr. Lindzen, your colleague, has said recently about 25 years ago we were writing in Science magazine and other respected digests

about the future of global cooling, and there was a pretty significant amount of projection based on models and other things that maybe we were going into a cooling period 25 years ago. Now, of course, we are not talking about that.

But here is the question. If you see one or two or three of these variables change in some dramatic fashion, would that not affect the calculations?

Dr. ROWLAND. It certainly would.

The calculations of 25 years ago, before I even got into this business, had to do with the long-term expectation based on orbital geometry of the earth with respect to the sun. Those calculations are still there that say that the long-term future in the next few thousand years is that the climate ought to get colder, but it is sometime in the next few thousand years and does not envisage any rapid change such as that which we have seen over the last 2 decades.

Senator HAGEL. Dr. Wallace.

Dr. WALLACE. Just thinking back to 25 years ago, I was certainly with Dr. Lindzen at that time in being a real skeptic about the global cooling. In fact, I think most of the community had a rather amused view of that.

Senator HAGEL. But, nonetheless, it caught a lot of attention in very respected publications among respected scientists and meteorologists, of course, you and Dr. Lindzen notwithstanding.

Dr. WALLACE. The number of really solid refereed publications on that was pretty small. What I remember was more a lot of newspaper articles. In fact, I still have——

Senator HAGEL. We live by newspaper articles, Doctor.

[Laughter.]

Senator HAGEL. Dr. Barron.

Dr. BARRON. I think we actually benefit enormously by having a community that is very skeptical and is constantly attacking all of our results. Individuals like Dr. Lindzen have focused a lot of attention on things that we do not know. One of the consequences of that and 30 years of study is that we have looked at this from a viewpoint of a long time scale past climates, the record of the last 1,000 years. We have been challenged to replicate the last century by including both the sun and the aerosols and CO_2. And we have had an enormous national and international effort to look at the future.

I think the combination of that sort of intensity of this scrutiny—the fact of the matter is that the questions are beginning to change. It is much rarer for people to look at a document like this and attempt to challenge the science in there, which is careful about citing ranges and areas of substantial agreement. Instead, the issues are changing to how significant is this level of change. I think that level of scrutiny, because we are truly a community of skeptics, has taken us a long way from 25 years ago.

Senator HAGEL. Thank you.

Mr. Chairman, thank you.

The CHAIRMAN. Thank you very much.

Senator Cantwell.

Senator CANTWELL. Thank you, Mr. Chairman, and thank you for holding this historic hearing to cover these issues and for the

excellent testimony that we have gotten today. I commend you on your report and analysis and the fact that we can add to the growing body of evidence that this is a very serious issue that we must deal with and take action to mitigate.

I recently received a letter signed by almost 100 Washington State scientists asking that we continue our efforts and immediately take action on this. I strongly support the views that were articulated in the letter.

Dr. Wallace, great to have you here particularly as well.

I know that one of the key findings of the NRC study was that there was a lack of resources for climate modeling, and that has greatly hampered our ability to assess future climate changes and the potential impact. There has been some dependence on international models—I think basically the Canadian and British models.

Are there U.S. models that we can use? What do we need to do to make further progress on that?

Dr. WALLACE. I should start by saying that the National Academy has undertaken a study of precisely that issue, and I have for you a copy of that report that goes into your question in considerable detail.

I think there are really two kinds of impediments that we have been facing in the scientific community in trying to keep up with the Joneses, so to speak, with the computing. One has been the fact that for an extended period of time, on the order of 10 years—I do not know the timing exactly—there has been protectionist legislation that, in effect, has prevented the atmospheric sciences community from being able to buy what has been the state-of-the-art, sort of vector supercomputers that have, by and large, been Japanese made during this period. We have not had a U.S. industry of our own that has even tried to keep current.

A second problem that has contributed to this is that there has been strong leadership in our computing community pushing in the direction of what we call massively parallel computer architecture, in which we have a lot of small processors linked together doing a job by very sophisticated teamwork. This approach has been argued to be very promising for advanced scientific applications, but in fact it has not lived up to anything like its hoped-for potential in the climate modeling. The climate modeling does not seem to be amenable to that kind of computer architecture to the degree that people had hoped.

So, as a result, the present status of the United States, in terms of computer capability, is very, very low. In fact, it is my understanding that there are countries like Brazil that have much more throughput for the kinds of computer modeling simulations that scientists are doing today.

It is also my understanding that this ban on the importation of Japanese supercomputers has recently been lifted. But now it is a question of trying to take advantage of this new freedom and to get geared up with state-of-the- art computing and to get the community together as to how much of it will be massively parallel and how much of it will be the more traditional vector approach, which is like today's state-of-the-art computers.

Senator CANTWELL. So, you are saying that they have an advantage or that we have not put the resources behind it.

Dr. WALLACE. Yes.

Senator CANTWELL. There are obviously people in our back yard—yours and mine—who are in the supercomputing business and are quite renown. But you are saying that we have not, as a government, put the resources there to incentivize that?

Dr. WALLACE. The funds that we have been spending on computing—we have been disadvantaged because we have not been able to get the best computers for the money. And we have made a big investment in the massive parallel computing and trying to reprogram a lot of the computer models to be used on those machines. It has not panned out very well.

Dr. BARRON. It is worth pointing out what we are good at and what we are limited by the resources for. We have an extremely potent climate modeling community within the United States, and within that very strong research community, we have a tremendous effort at addressing areas of uncertainty in understanding how the atmosphere works and incorporating that. We have a tremendous focus on building new and better models.

But when you cross over to the side where you are attempting to look at issues like impacts or being able to couple large segments of the system in order to do a good job of long-term simulations, what you want is a higher resolution, a couple of models that you are running repeatedly from 1895 out to the end of the century. That requires enormous computer resources.

So, the U.S. community is focused on improving the models. We have been less focused on doing what are called these ensemble, high resolution, long-term simulations, and it is largely because we do not have these computational resources that allow it to be an easy task to complete. But we do have a very strong research community.

Senator CANTWELL. If I could, I do have another question. Mr. Rowland, did you want to comment on that?

Dr. ROWLAND. No. I will pass on that.

Senator CANTWELL. One of the questions, Dr. Wallace, that I did want to ask—or for any of the other panelists, but obviously being from the University of Washington, I direct it to you. And I will work with the chairman on this issue of modeling and on computer capacity. I am happy to look into it further and want to make sure that we get the best resources behind modeling, as it plays an effective role.

But a more local question, if you will. The global warming impacts or climate impacts on the Pacific Northwest. It is a very relevant question, given our reliance on hydro power and the significant amount of hydropower resources in our State. I literally was at a meeting this morning in which somebody brought up this point: do people understand what the impacts might be? We are talking about this as a global problem, but is anybody talking about the impacts that might happen on various regions of the country? So, I wondered if you might comment on that.

Dr. WALLACE. Well, we have a very active group at the University of Washington, a so-called climate impacts group chaired by Professor Ed Miles. At this point, it is one of about a half a dozen—

half a dozen to a dozen, depending on how you count them—really excellent regional groups around the country. It was groups like this which worked together to produce a national synthesis report that Dr. Barron was one of the people to put together.

I think this is very useful research and it is research where there is a big bang for the buck, for the relatively little expenditures. Right now it is my understanding that it is just a few million dollars total that are really available for grants from Federal agencies to support work like this. I think that this work really helps to build a constituency for climate forecasting, not only global warming, but the forecasting of El Nino and the year-to-year forecasting that would be very beneficial economically. It is building the ties between the scientists and the users that these groups really excel at doing.

Senator CANTWELL. Well, I see my time is expired, Mr. Chairman. So, I think I will get a copy of that report and look at the specific impacts that the Pacific Northwest may be subject to, given the research and analysis. Thank you.

The CHAIRMAN. Well, thank you very much.

Let me thank all three of you for your testimony and also for this report that the NRC prepared at the administration's request. I think it has been very helpful in highlighting the importance of dealing with this issue for the administration and for the Congress. I hope that we will follow your admonitions and move ahead this Congress to do some constructive things to deal with it. So, thank you all very much.

We have a second panel of witnesses, and I would ask them if they would come forward please. The second panel will talk about some of the technologies that hold out solutions to the climate change issue and give their perspective on the climate change issue and what technology solutions there are to this.

Dr. James Edmonds, who is the senior staff scientist with the Global Change Group, Pacific Northwest National Laboratory; Mr. Bill Chandler, who is director of the advanced international studies unit of the Pacific Northwest National Laboratory; Dr. Robert Friedman, who is vice president for research at the John Heinz Center for Science, Economics and the Environment; and Dr. Mark Levine, who is the director of environmental energies technology division at Lawrence Berkeley National Laboratory in Berkeley.

Why don't we just start on the left here and go right across and hear testimony from each of you? If you could summarize your major points and then we will be undoubtedly having some questions.

Dr. Edmonds.

STATEMENT OF DR. JAMES EDMONDS, SENIOR STAFF SCIENTIST, PACIFIC NORTHWEST NATIONAL LABORATORY, BATTELLE MEMORIAL INSTITUTE

Dr. EDMONDS. Thank you, Mr. Chairman and members of the committee for the opportunity to testify here this morning on energy and climate change. My presence here today is possible because the U.S. Department of Energy, EPRI, and numerous other organizations in both the public and private sectors have provided me and my research team at the Pacific Northwest National Lab-

oratory with long-term research support. That having been said, I come here today to speak as a researcher and the views I express are mine alone.

I have got three simple points to make.

First, it is concentrations of greenhouse gases that matter. For CO_2, cumulative emissions by all countries over all time determine the concentration.

The second point is technology is the key to controlling the cost of stabilizing the concentration of greenhouse gases.

And the third point is that managing the cost of stabilization at any level requires a portfolio of energy R&D investments across a wide spectrum of technology classes.

Now, let me just elaborate on those points.

My first point is that it is concentrations, not emissions. The United States is a party to the Framework Convention on Climate Change, which has as its objective the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. This is not the same as stabilizing emissions because emissions accumulate in the atmosphere. The concentration of carbon dioxide will, therefore, continue to rise indefinitely if the emissions are held at current levels or even at some reduced level. Stabilization of CO_2 concentrations means that the global energy system, not just the U.S. energy system, must undergo a fundamental transformation from one in which emissions continue to grow throughout the century into one in which global emissions peak and then begin a long-term decline.

Coupled with significant global population and economic growth, this transition represents a daunting task even if a concentration as high as 750 parts per million is eventually determined to meet the goal of the Framework Convention, though at this time the concentration that will prevent dangerous interference with the climate system is not yet known.

A credible commitment to limit cumulative emissions is also needed to move new energy technologies off the shelf and into widespread adoption in the marketplace.

My second point is that technology controls cost. The cost of stabilizing the concentration of greenhouse gases will depend on many factors, including the desired concentration, economic and population growth, and available portfolio of energy technologies. But not surprisingly, research shows that if the costs of stabilization are lower, the better and more cost effective the portfolio of available energy technologies is.

While technology is pivotal when it comes to controlling the cost of stabilizing the concentration of greenhouse gases, it is only one of four major elements that are needed in a comprehensive program to address climate change. The other three elements are resolution of scientific uncertainties, adaptation to climate change, and third, a credible global commitment that greenhouse gas concentrations will be limited.

My third point is that there is no silver bullet. The Global Energy Technology Strategy Program to address climate change is an international public/private sector collaboration advised by an eminent steering group, and its analysis, conducted during the first

phase of the program, supports the need for a diverse technology portfolio. It showed that no single technology controls the cost of stabilizing CO_2 concentration under all circumstances. The portfolio of energy technologies that is employed varies across regions and nations and over time.

And the technologies that contribute to controlling the cost of stabilizing the concentration of CO_2 include energy efficiency and renewable energy forms, non-carbon energy sources, such as nuclear power and fusion, improved applications of fossil fuels, and technologies such as terrestrial carbon capture by plants and soils, engineered carbon capture in geologic sequestration, fuel cells, commercial biomass and biotechnology, which holds the promise of enhancing a wide range of energy forms just mentioned.

Many of these technologies are undeveloped or play only a minor role in their present state of development. Research and development by both the public and the private sectors will be needed to provide the scientific foundations required to achieve improved economic and technical performance, establish reliable mechanisms for monitoring and verifying the disposition of carbon, and to develop and market competitive carbon management technologies.

Recent trends in public and private spending on energy research and development suggest that the role of technology in addressing climate change may not be fully understood or appreciated. Although public investment in energy R&D has increased very slightly in Japan, it has declined significantly in the United States and even more dramatically in Europe where reductions of 70 percent of more, since the 1980's, are the norm. Moreover, less than 3 percent of this investment is directed at technologies that, although not currently available commercially at an appreciable level, have the potential to lower the costs of stabilization significantly.

Mr. Chairman, thank you for this opportunity to testify. I will be happy to answer yours and the committee's questions.

[The prepared statement of Dr. Edmonds follows:]

PREPARED STATEMENT OF DR. JAMES EDMONDS, SENIOR STAFF SCIENTIST, PACIFIC NORTHWEST NATIONAL LABORATORY, BATTELLE MEMORIAL INSTITUTE

Thank you Mr. Chairman and members of the Committee for the opportunity to testify here this morning on energy and climate change. My presence here today is possible because the US Department of Energy, EPRI and numerous other organizations in both the public and private sectors have provided me and my team at the Pacific Northwest National Laboratory (PNNL) long-term research support. Without that support much of the knowledge base upon which I draw today would not exist. That having been said, I come here today to speak as a researcher and the views I express are mine alone. They do not necessarily reflect those of any organization. I have three simple points to make:

1. It's concentrations of greenhouse gases that matter. For CO_2, it is cumulative, emissions by all countries, over all time that determines the concentration not emission by any individual country, no matter how great, or any individual year;
2. Technology is the key to controlling the cost of stabilizing the concentration of greenhouse gases; and
3. No single technology controls the cost of stabilizing CO_2 concentrations under all circumstances. Managing the cost of stabilizing the concentration of greenhouse gases, at any level, requires a portfolio of energy R&D investments across a wide spectrum of technology classes from conservation to renewables to nuclear to fossil fuels, to biotechnology, to natural and engineered carbon capture and sequestration, and undertaken by both the public and private sectors.

It's Concentrations Not Emissions: My remarks are grounded in a small number of important observations. First, the United States is a party to the Framework Convention on Climate Change (FCCC). The FCCC has as its objective the "sta-

bilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." (Article 2) This is not the same as stabilizing emissions. Because emissions accumulate in the atmosphere, the concentration of carbon dioxide will continue to rise indefinitely even if emissions are held at current levels or even at some reduced level. Limiting the concentration of CO_2, the most important greenhouse gas, means that the global energy system must be fundamentally transformed by the end of the 21st century. Given the long life of energy infrastructure, preparations for that transformation must start today.

Second, research that I have conducted with Tom Wigley at the National Center for Atmospheric Research and Richard Richels at EPRI indicates that, to attain global CO_2 concentrations ranging from 350 parts per million volume (ppmv) to 750 ppmv, global emissions of CO_2 must peak in this century and then begin a long-term decline. The average concentration in 1999 was 368 ppmv and pre-industrial values were in the neighborhood of 275 ppmv. The timing and magnitude of the peak depends on the desired CO_2 concentration—though the concentration that will "prevent dangerous anthropogenic interference with the climate system" is not yet known—as well as on a variety of factors shaping future US and global technology and economy.

In 1997 global fossil fuel carbon emissions were approximately 6.6 billion tonnes of carbon per year with an additional approximately 1.5 billion tonnes of carbon per year from land-use change such as deforestation. (The values for land-use change emissions are known with much less accuracy than those of fossil fuel emissions.) Values taken from the paper Drs. Wigley, Richels and I published in *Nature* in 1996 for alternative CO_2 concentrations, peak emissions and associated timing are given in the table below:

CO_2 Concentration (ppmv)	350	450	550	650	750
Maximum Global CO_2 Emissions (billions of tonnes carbon per year)	8.5	9.5	11.2	12.9	14.0
Year in which Global Emissions Must Break from Present Trends	Today	2007	2013	2018	2023
Year of Maximum Global Emission	2005	2011	2033	2049	2062
Year 2100 Global Fossil Fuel Emissions (billions of tonnes carbon per year)	0	3.7	6.8	10.0	12.5

The time path of emissions will have a profound effect on the cost of achieving atmospheric stabilization. The emissions paths we developed were constructed to lower costs by avoiding the premature retirement of capital stocks, taking advantage of the potential for improvements in technology, reflecting the time-value of capital resources, and taking advantage of the workings of the natural carbon cycle regardless of which concentration was eventually determined to "prevent dangerous anthropogenic interference with the climate." It is also important to note that the transition must begin in the very near future. For example, for a global concentration of 550 ppmv, global CO_2 emissions must begin to break from present trends (i.e. deviations of more than 100 million tonnes of carbon from present trends) within the next 10 to 15 years. Given that it takes decades to go from "energy research" to the practical application of the research within some commercial "energy technology" and then perhaps another three to four decades before that technology is widely deployed throughout the global energy market, we will likely have to make this deflection from present trends with technologies that are already developed. To reduce global emissions even further will require a fundamental transformation in the way we use energy and that will only be possible if we have an energy technology revolution and that will only come about if we increase our investments in energy R&D.

The table above shows that the global energy system, not just the United States energy system, must undergo a transition from one in which emissions continue to grow throughout this century into one in which emissions peak and then decline. Coupled with significant global population and economic growth, this transition represents a daunting task even if a concentration as high as 750 ppmv is eventually determined to meet the goal of the Framework Convention. A credible commitment to limit cumulative emissions is also needed to move new energy technologies "off the shelf" and into wide spread adoption in the marketplace.

Stabilizing the concentration of greenhouse gases in the atmosphere will require a credible commitment to limit cumulative global emissions of CO_2. Such a limit is unlikely to be achieved without cost. The cost of stabilizing the concentration of greenhouse gases will depend on many factors including the desired concentration, economic and population growth, and the portfolio of energy technologies that might be made available. Not surprisingly costs are higher the lower the desired concentration of greenhouse gases. They are also higher for higher rates of economic and population growth. And, they are lower the better and more cost effective the portfolio of energy technologies that can be developed. This last point about the role of technology is very important, but not well appreciated.

It is not well recognized that most long-term future projections of global energy and greenhouse gas emissions and hence, most estimates of the cost of emission reductions, assume dramatic successes in the development and deployment of advanced energy technologies occur for free. For example, the Intergovernmental Panel on Climate Change developed a set of scenarios based on the assumption that no actions were implemented to mitigate greenhouse gas emissions. The central reference case that assumes "technological change as usual" is called IS92a. This central reference scenario assumes that by the year 2100 three-quarters of all electric power would be generated by non-carbon emitting energy technologies such as nuclear, solar, wind, and hydro, and that the growth of crops for energy (commercial biomass) would account for more energy than the entire world's oil and gas production in 1985. Yet with all these assumptions of technological success, the need to provide for the growth in population and living standards around the world drive fossil fuel emissions well beyond 1997 levels of 6.6 billion tonnes of carbon per year to approximately 20 billion tonnes of carbon per year. Subsequent analysis by the IPCC as well as independent researchers serves to buttress the conclusion that even with optimistic assumptions about the development of technologies that the concentration of in the atmosphere can be expected to continue rise throughout the century.

Technology Controls Cost: My second point follows directly from the preceding observations. Technology development is critical to controlling the cost of stabilizing CO_2 concentrations. Improved technology can both reduce the amount of energy needed to produce a unit of economic output and lower the carbon emissions per unit of energy used.

The Global Energy Technology Strategy Program to Address Climate Change is an international, public/private sector collaboration[1] advised by an eminent Steering Group.[2] Analysis conducted at the Pacific Northwest National Laboratory as well as in collaborating institutions during Phase I supports the need for a diversified technology portfolio.

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[1] Sponsors of the program were: Battelle Memorial Institute, BP, EPRI, ExxonMobil, Kansai Electric Power, National Institute for Environmental Studies (Japan), New Economic and Development Organization (Japan), North American Free Trade Agreement Commission for Environmental Cooperation, PEMEX (Mexico), Tokyo Electric Power, Toyota Motor Company, and the US Department of Energy. Collaborating research institutions were: The Autonomous National University of Mexico, Centre International de Recherche sur l'Environnment et le Developpement (France), China Energy Research Institute, Council on Agricultural Science and Technology, Council on Energy and Environment (Korea), Council on Foreign Relations, Indian Institute of Management, International Institute for Applied Systems Analysis (Austria), Japan Science and Technology Corporation, National Renewable Energy Laboratory, Potsdam Institute for Climate Impact Research (Germany), Stanford China Project, Stanford Energy Modeling Forum, and Tata Energy Research Institute (India).

[2] Richard Balzhiser, President Emeritus, EPRI; Richard Benedick, Former U.S. Ambassador to the Montreal Protocol; Ralph Cavanagh, Co-director, Energy Program, Natural Resources Defense Council; Charles Curtis, Executive Vice President, United Nations Foundation; Zhou Dadi, Director, China Energy Research Institute; E. Linn Draper, Chairman, President and CEO, American Electric Power; Daniel Dudek, Senior Economist, Environmental Defense Fund; John H. Gibbons, Former Director, Office of Science and Technology Policy, Executive Office of the President; José Goldemberg, Former Environment Minister, Brazil; Jim Katzer, Strategic Planning and Programs Manager, ExxonMobil; Yoichi Kaya, Director, Research Institute of Innovative Technology for the Earth, Government of Japan; Hoesung Lee, President, Korean Council on Energy and Environment; Robert McNamara, Former President, World Bank; John Mogford, Group Vice President, Health, Safety and Environment BP; Granger Morgan, Professor, Carnegie-Mellon University; Hazel O'Leary, Former Secretary, U.S. Department of Energy; Rajendra K. Pachauri, Director, Tata Energy Research Institute; Thomas Schelling, Distinguished University Professor of Economics, University of Maryland; Hans-Joachim Schellnhuber, Director, Potsdam Institute for Climate Impact Research; Pryadarshi R. Shukla, Professor, Indian Institute of Management; Gerald Stokes, Assistant Laboratory Director, Pacific Northwest National Laboratory; John Weyant, Director, Stanford Energy Modeling Forum; and Robert White, Former Director, National Academy of Engineering.

While technology is pivotal when it comes to controlling the cost of stabilizing the concentration of greenhouse gases, it is only one of four major elements that are needed in a comprehensive program to address climate change. The other three elements are:

1. Resolution of scientific uncertainties,
2. Adaptation to climate change, and
3. A credible, global commitment that greenhouse gas concentrations will be limited.

There's No "Silver Bullet": No single technology controls the cost of stabilizing CO_2 concentrations under all circumstances. The portfolio of energy technologies that is employed varies across space and time. Regional differences in such factors as resource endowments, institutions, demographics and economics, inevitably lead to different technology mixes in different nations, while changes in technology options inevitably lead to different technology mixes across time.

Technologies that are potentially important in stabilizing the concentration of CO_2 include energy efficiency and renewable energy forms, non-carbon energy sources such as nuclear power and fusion, improved applications of fossil fuels, and technologies such as terrestrial carbon capture by plants and soils, carbon capture and geologic sequestration, fuel cells and batteries, and commercial biomass and biotechnology which holds the promise of enhancing a wide range of the above energy forms. Many of these technologies are undeveloped or play only a minor role in their present state of development. Research and development by both the public and private sectors will be needed to provide the scientific foundations needed to achieve improved economic and technical performance, establish reliable mechanisms for monitoring and verifying the disposition of carbon, and to develop and market competitive carbon management technologies. For example, advances in the biological sciences hold the promise of dramatically improving the competitiveness of commercial biomass as an energy form.

Recent trends in public and private spending on energy research and development in the world and in the United States suggest that the role of technology in addressing climate change may not be fully understood nor appreciated. Although public investment in energy R&D has increased very slightly in Japan, it has declined significantly in the United States and even more dramatically in Europe, where reductions of 70 percent or more since the 1980s are the norm. Moreover, less than 3 percent of this investment is directed at technologies that, although not currently available commercially at an appreciable level, have the potential to lower the costs of stabilization significantly.

In summary, stabilizing the concentration of greenhouse gases at levels ranging up to 750 ppmv represents a necessary but daunting challenge to the world community. Energy related emissions of CO_2 must peak and begin a permanent decline during this century. The lower the desired concentration, the more urgent the need to begin the transition. Both a credible global commitment to limit cumulative emissions and a portfolio of technologies will be needed to minimize the cost of achieving that end including technologies that are not presently a significant part of the global energy system. Their development and deployment will require enhanced energy R&D by both the public and private sectors. Unfortunately, current trends in energy R&D are cause for concern.

Mr. Chairman, thank you for this opportunity to testify. I will be happy to answer your and the committee's questions.

The CHAIRMAN. Thank you very much.

Mr. Chandler, why don't you go right ahead, please.

STATEMENT OF WILLIAM CHANDLER, SENIOR STAFF SCIENTIST AND DIRECTOR, ADVANCED INTERNATIONAL STUDIES UNIT, PACIFIC NORTHWEST NATIONAL LABORATORY

Mr. CHANDLER. Thank you. I am Bill Chandler, Senior Staff Scientist at the Pacific Northwest National Laboratory and Director of the Advanced International Studies Unit. I very much appreciate the opportunity, at the invitation of you and the members of the committee, to be here today, though I confess whenever I am asked to speak about international energy issues, in the midst of our efforts to grapple with domestic energy problems, I think of something Mark Twain said over a century ago, which was that "nothing needs reforming quite so much as other people's bad habits."

We in the President's Committee of Advisors on Science and Technology looked not so much at the habits of international energy use but the technologies of energy use and how they affect strategic objectives for the United States, including the strong linkage with climate change.

We found very strong linkages with global economic growth and our ability to fuel our own economy because the consumption of gasoline, for example, in China affects the price of gasoline here.

It affects our ability to compete for markets to export advanced technologies and also U.S. values ranging from human rights to economic reforms in countries in which we develop energy resources.

PCAST assigned a sense of urgency to what we viewed as a closing window of opportunity to influence the deployment of advanced technologies around the world, a closing window of opportunity for three reasons.

First, rapid development in the developing countries and in the transition economies means that those countries are quickly locking in technologies which will be with us for decades to come or, as you put it, locking out mitigation opportunities.

Also, the timing for introducing new technologies is such that it takes perhaps a decade from the laboratory to the marketplace, and then you have the problem of market penetration.

Also, in the transition economies in the former Soviet Union and Eastern Europe, we have probably the largest and cheapest emissions reduction opportunities and yet the future remains up for grab in those countries because we still do not know whether Russia and Ukraine, for example, will make the full transition to market democracy. We have, we believe, an opportunity to influence the outcome of each of those opportunities. And we made four sets of recommendations, four initiatives we proposed, to influence the deployment of technology.

These include, first, foundations of energy innovation. By that we mean taking measures to build capacity in developing and transition economies, to promote energy sector reform, to get the prices right, to ensure that prices matter, to demonstrate technologies in order to help reduce the cost of those technologies, and to organize financing so that developing countries can afford more expensive technologies.

Second, we recommended a portfolio of energy efficiency measures, with emphasis on setting goals for reducing the energy use in the building sector. Perhaps developing countries could cut the energy intensity of their buildings in half compared to current practice over the next 2 decades.

In the transport sector, paying attention to two- and three-wheeled vehicles, which is the mode of transportation that many people in Asia, for example, utilize primarily for private transport and for buses.

In industry, helping to create road maps to factories of the 21st century so that the energy intensity of making steel, chemicals, paper, and other energy intensive materials can be cut in half. And in promoting cogeneration or combined heat and power so that up to a fifth of power in developing countries can be built using this more efficient approach.

We recommended a supply technology portfolio which emphasized things like biomass within the renewable sector, fossil energy decarbonization and carbon storage, and solving the problems of nuclear waste disposal and proliferation with nuclear technology.

Finally, to respond to something you suggested earlier, we did propose a management initiative which would elevate to the highest levels of government the coordination of U.S. efforts to innovate energy technologies around the world. Our approach was to recommend the creation of a working group within the National Science and Technology Council. While we feel that process matters, we do feel that leadership matters, and that is why a working group at that level is important and that is why setting goals at that level is important.

As a last point, I would like to say that we have found a number of success stories in this type of assistance, success stories that indicate just how cheap some of these measures can be. In my own program, I can tell you from experience that we have organized a billion dollars worth of investment in energy efficiency in the former Soviet Union and Eastern Europe over the last 5 years, and we have done so by taking, for each dollar of Federal investment, measures that leverage $25 to $50 of investment from multilateral development banks, private firms, and from the customers with which we are working ourselves. So, to respond to Senator Murkowski's concern, there are very high leverage, very cost effective measures that we can do. In order to resolve our own problems domestically, addressing them in the international marketplace we felt would be necessary.

Thank you.

[The prepared statement of Mr. Chandler follows:]

PREPARED STATEMENT OF WILLIAM CHANDLER, SENIOR STAFF SCIENTIST AND DIRECTOR, ADVANCED INTERNATIONAL STUDIES UNIT, PACIFIC NORTHWEST NATIONAL LABORATORY

THE U.S. STAKE IN INTERNATIONAL COOPERATION ON ENERGY INNOVATION

This testimony summarizes the conclusions of Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation, a 1999 report to the President by the President's Committee of Advisors on Science and Technology (PCAST). The authors of this report, the PCAST International Energy Panel, concluded that U.S. self interest would be served by increasing international energy cooperation, particularly with the transition and developing economies where most energy demand growth will occur this century. Our panel found that global energy use is tightly linked to U.S. economic, environmental, and national-security interests (see box, below). We concluded that energy technology innovation improves our security, helps the United States avoid inflation and recession, and expands our market share of multi-hundred-billion dollar per year global energy-technology market. Significantly, energy innovation can help mitigate greenhouse gas emissions in the fastest-growing energy demand markets.

INTERNATIONAL ENERGY CHALLENGES

Economic
- Growth and development
- Energy technology exports
- Oil Imports

Environmental
- Local air quality
- Regional acid rain
- Global warming

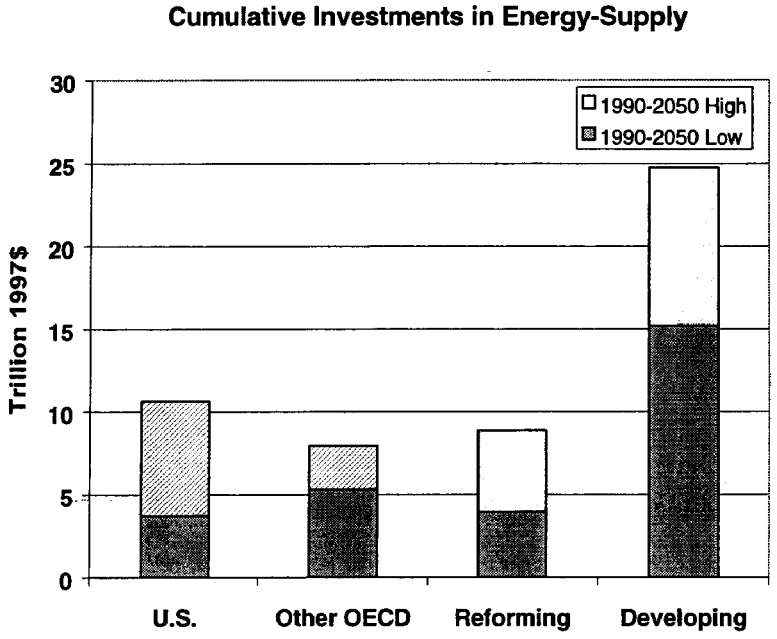
U.S. Leadership
- Energy Science
- Supply- and demand-side technology

International Security
- Insecure supplies of foreign oil
- Nuclear proliferation
- Political stability in developing countries

U.S. Values
- Human rights
- Civil society
- Equity, self-determination, stewardship.

U.S. President's Committee of Advisors on Science and Technology, *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation* (Washington, D.C.: The White House Office of Science and Technology Policy, June 1999). Available at http://www.ostp.gov/html/P2E.pdf.

The United States and the world face a historic window of opportunity. The largest investments in energy supply and conversion systems will occur in developing and reforming countries, and these will soon "lock in" technologies for decades to come (see figure). The long lead-time required to move new technologies through the innovation pipeline—let alone penetrate markets—means that efforts to deploy technology in the second quarter of this century need to be started today. PCAST proposed early but modest funding for international cooperation, with specific suggestions for budget increases amounting to $500 million per year by FY2005.



PCAST found that great leverage for greenhouse gas emissions reductions comes with supporting market-based policy reform and in organizing financing to implement energy technology transfer in developing and transition economies. Economic reform—getting prices right and making prices matter—can help reduce emissions

in countries as diverse as Brazil, India, China, India, Russia, and Ukraine by reducing distortions and subsidies that encourage energy waste. Efforts to organize investment financing for energy innovation can multiply the effectiveness of government funds.

Priority Initiatives

The PCAST International Energy Panel reviewed both successes and failures in international energy development and agreed to recommend four categories of initiatives for top priority, including capacity building for reform and innovation, deployment of energy-efficiency technologies, deployment of selected supply-side technologies, and management reform (see below).[1]

PCAST INITIATIVES FOR INTERNATIONAL ENERGY COOPERATION

Foundations of Energy Innovation
- Capacity Building
- Energy Sector Reform
- Finance

Energy Efficiency Portfolio
- Buildings
- Transport
- Industry
- Combined Heat and Power

Energy Supply Portfolio
- Renewables
- Fossil fuel
- Nuclear energy

Management Recommendations
- National Science and Technology Council working group
- External Advisory Board

Source: *Powerful Partnerships*, President's Committee of Advisors on Science and Technology, 1999. Available on-line at http://www.ostp.gov/html/P2E.pdf

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PCAST members were struck by the degree to which "reform matters," and by successful interventions by the U.S. government which have helped to support energy sector reform. The experience of Central Europe is instructive in this regard. Energy intensity serves as an index of reform, as an indicator of successful and unsuccessful policies. Central Europe has cut energy intensity by one third over the last decade, with major benefits for both the economy and environment of that region, and demonstrating that genuine reform works (see figure). Essentially, this means that the region has eliminated much of the energy waste that stemmed from the legacy of central planning. Poland, the Czech Republic, and Hungary achieved this success by implementing hard budget constraints, meaningful energy prices, institutional reform, and economic restructuring. Latin American nations, including Argentina, have also benefitted by embracing privatization and competition.[2] Nations failing to implement those measures elsewhere robbed citizens of economic and social well-being.

Foundations of Energy Innovation

Efforts to build the foundations of energy-sector innovation include measures to enhance management and technical capacity, reform of the energy-sector, and organizing financing for innovative investment. U.S. funds helped organize over $1 billion of energy-efficiency investment U.S. funds helped organize over $1 billion of energy-efficiency investment projects in this region over the past five years and has built non-governmental, not-for-profit organizations in Russia, Ukraine, Bulgaria, Poland, and the Czech Republic. These organizations have developed world-class expertise each with staffs of 15-50 people. Each center is now self-sustaining and fully independent. U.S. partners associated with the program have been honored with the "Global Climate Leadership Award" (International Energy Agency) and with the "International Energy Project of the Year Award" (Association of Energy Engineers) for this work. U.S. expenditures on these assistance programs through resulted in investment 25-50 times the initial grant. PCAST have reported on these and similar successes in Latin America, especially in Brazil.

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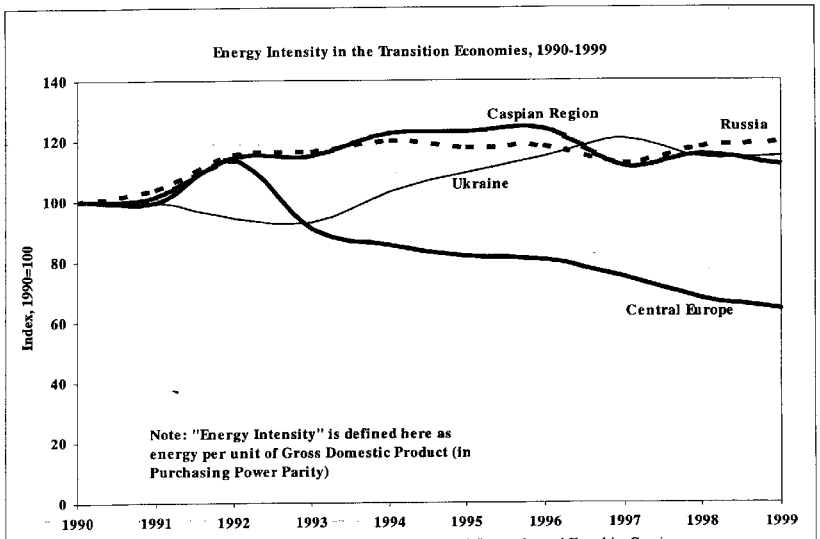
[1] U.S. President's Committee of Advisors on Science and Technology, *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation* (Washington, D.C.: The White House Office of Science and Technology Policy, June 1999). Available at http://www.ostp.gov/html/P2E.pdf. The author of this testimony participated as a panelist and author in this PCAST study.

[2] William Chandler, *Energy and Environment in the Transition Economies* (Boulder: Westview Press, 2000).



Note: Central Europe includes Bulgaria, Czech Republic, Hungary, Poland, Romania, and Slovakia; Caspian Region includes Azerbaijan, Kazakstan, Turkmenistan, and Uzbekistan.

Source: Author; *CO_2 Emissions From Fuel Combustion, 1999 Edition* (Paris: International Energy Agency, 1999), p. II.27; *World Economic Outlook 2000* (Washington: International Monetary Fund, 2000), p. 123; and BPAmoco, *Statistical Review of World Energy 2000*, www.BPAmoco.com.

China offers a remarkable success story in managing energy demand growth. China suffers severe environmental problems due to distorted markets, outdated technologies, and inefficient management. The World Bank estimates that approximately eight percent of the country's gross domestic product is lost each year due to pollution that damages human health, natural ecosystems, and physical infrastructure. Fortunately, China has made progress with energy efficiency having probably reduced current levels of greenhouse gas emissions by one-third or more.[3] China's post-reform economy has grown faster than energy use for more than two decades. China continues to rank energy efficiency as vital to the nation's energy interests. Domestic reforms within China have the potential further to cut carbon dioxide emissions significantly, as does cooperation with international partners.

The U.S. government has successfully collaborated with Chinese researchers for over a decade on China's energy and environmental problems working with some of China's leading energy and environmental specialists. In 1993, the Department of Energy and the Environmental Protection Agency (in collaboration with Pacific Northwest National Laboratory and Lawrence Berkeley National Laboratory) helped establish the Beijing Energy Efficiency Center (BECon) with support from the American and Chinese governments and the World Wide Fund for Nature. Chinese researchers have collaborated with U.S. experts to demonstrate that China could meet its future electric power needs at a lower overall cost if environmental factors where included in the planning process.[4] Ongoing Sino-U.S. collaboration on energy

[3] Over the past twenty years, China's energy consumption per unit of growth in gross domestic product measured in constant local currency has declined by over 4 percent annually, while energy consumption per unit of growth in the U.S. has fallen by slightly over 1 percent. Typical developing countries, on the other hand, exhibit an increase in energy consumption related to economic growth. See *Climate Action in China and the United States*, Battelle Memorial Institute and the Woodrow Wilson Center for International Scholars, Washington, DC, 1999. Official Chinese statistics on economic growth are viewed from abroad with increasing skepticism, however, and real growth may be significantly less than reported. A forthcoming report from Lawrence Berkeley National Laboratory provides a more realistic estimate of China's success in conserving energy based on revised economic growth estimates. See Sinton, J., and D. Fridley, "What Goes Up: Recent Trends in China's Energy Consumption," Forthcoming in *Energy Policy*.

[4] See, "Electric Power in Five Developing Countries: The Futures of China, Korea, India, Argentina, and Brazil," William Chandler, Battelle Memorial Institute, for the Pew Center on Climate, forthcoming 2001.

efficiency helps to catalyze additional measures to improve energy efficiency, reduce pollution, and boost exports of U.S. technology.[5]

Capacity-building efforts prepare the ground for rapid and sustainable energy-technology innovation. As indicated in the PCAST report executive summary, high-priority elements include:

- Increased support for existing regional centers of analysis and information dissemination on sustainable energy options (such as the PROCEL national electricity-conservation program in Brazil, energy efficiency centers in Eastern Europe and Russia,[6] and other centers in Africa, Asia, and Latin America) and establishment of new sustainable energy centers in regions with significant need that cannot be met by other means; and
- Development of in-country training for energy analysts and managers, to include workshops and internet-based courses and expert assistance, as well as a requirement that in-country technical and managerial training be a component of technology demonstration and deployment projects supported by the U.S. government.

Supporting and shaping energy-sector reform accelerates financial performance and helps retain incentives for energy-technology innovation. The U.S. government can mobilize private and public sector experts to provide technical and policy advice, particularly for price reform and imposition of "hard budget constraints". For example, one way the United States can help promote the use of low-carbon natural gas in China is by analyzing current obstacles and then promoting the needed legal framework for building and regulating natural gas supply pipelines and distribution systems (see below).[7]

WHAT U.S. COMPANIES SAY THEY NEED TO DO NATURAL GAS BUSINESS IN CHINA

1. Boost gas prices to international market levels.
2. Expand use of gas to industry and power sectors.
3. Allow access to choice areas for exploration.
4. Develop greater market transparency.
5. Improve data accessibility

Source: Logan, J. and W. Chandler, "Incentives Needed for Foreign Participation in China's Natural Gas Sector." *Oil and Gas Journal*, 10 August 1998. Volume 96, Number, 32. p. 50-56.

A large payoff comes especially by helping provide the conditions sufficient to attract international investors. Lack of credit, collateral, or funds to prepare business plans are the biggest barriers to energy efficiency and fuel switching in many economies. Financial programs can help overcome barriers to deployment of small-scale clean and efficient energy technologies in transition and developing economies. High-priority elements include increasing support for clean and efficient energy technologies from the multilateral banks or through U.S. mechanisms such as the Trade Development Agency and the Development Credit Authority. European nations are often much more pro-active in supporting multilateral banks in project planning work that would overcome barriers to obtaining financing and, as a result, often increase their market share of these developing markets.

"Financial engineering" is the best lever for emissions reduction because it transfers energy-efficient modern technologies through the marketplace. Specifically, the U.S. government can provide funding to identify customers for energy-saving equipment, develop business plans to move projects through the inception stage, and identify private and multi-lateral sources of finance to implement projects. An ap-

[5] A website on energy efficiency news in China reaches 5,000 readers each month from all over the world.

[6] The author led the creation of six institutions of local expertise, including energy-efficiency centers in Bulgaria, China, the Czech Republic, Poland, Russia, and Ukraine. See William U. Chandler, John W. Parker, Igor Bashmakov, Zdravko Genchev; Jaroslav Marousek, Slawomir Pasierb, Mykola Raptsun, and Zhou Dadi, "Energy Efficiency Centers in Six Countries: A Review," November 1999, PNNL-13073. See also www.pnl.gov/aisu.

[7] Jeff Logan *et al.*, "Expanding Natural Gas Utilization in China," Pacific Northwest National Laboratory and University of Petroleum, Beijing, (Washington and Beijing: U.S. Environmental Protection Agency and China's State Development Planning Commission), forthcoming July 2001; Logan, J. and D. Luo, 1999. "Natural Gas and China's Environment." Paper presented at the International Energy Agency-China Natural Gas Industry Conference, Beijing (available at http://www.pnl.gov/china/pubs.htm).

propriate goal is to leverage at least $25 of investment for each dollar spent by the U.S. government in project development.

Portfolio of Energy End-Use Technologies

PCAST's second category of initiatives addresses specific opportunities for international cooperation to promote innovation in energy-end-use technologies. These include efforts to reduce the energy intensity of heavy industry in key developing and transition countries. The PCAST panel estimated that energy use per unit of industrial output could be reduced by 40 percent over the next two decades. A successful example of this type of approach includes a dozen factories in Ukraine—a very difficult financial environment—which recently arranged millions of dollars of private investment in energy efficiency measures thanks largely to U.S. government support. Actual energy savings averaged 20 percent of total energy use per plant.[8]

The United States could encourage developing countries to cut energy use in major energy-intensive industrial processes by one-third or more compared to current performance. The largest energy-consuming sectors include iron and steel, cement, chemicals, pulp and paper, and non-ferrous metals. The Chinese steel industry, for example, uses 90 percent more energy to make a ton of steel than the Japanese steel sector. Similarly, India uses twice as much energy to make a ton of pulp and paper than the OECD average. Russian cement makers use 30 percent more energy to manufacture a ton of cement than French manufacturers. American technologies could be applied to cut energy use in each of these cases. However, these technologies have not penetrated these markets due to price distortions, lack of trained personnel to develop and implement projects, and lack of business skills and credit to arrange financing to make projects reality.

High-priority efforts toward that goal could include cooperation with the private sector and foreign counterparts to develop "technology roadmaps" and pre-competitive research and development for energy-intensive basic-materials industries such as iron and steel, chemicals, pulp and paper, and cement. Pilot demonstration programs and joint project development can sometimes facilitate technology transfer between U.S. firms and their partners.

PCAST's set of end-use recommendations included cooperation on vehicles research, development, and demonstration of cleaner, more energy-efficient buses and two- and three-wheeled vehicles (the main source of individual transport in many Asian nations) and accelerating deployment of advanced vehicles in developing and transition countries. High-priority efforts might include integration and expansion of cooperative research and development, especially for hybrid, fuel-cell, and alternative-fuel propulsion systems. U.S. encouragement of the multilateral development banks to help finance energy-efficient vehicle-manufacturing capacity, infrastructure, and consumer-credit systems could speed large-scale deployment of these advanced vehicles.

INTERNATIONAL ROLE OF ENERGY-EFFICIENCY TECHNOLOGY

- Efficiency aids development and cuts emissions.
- Transition (and some developing) economies rank least-efficient in the world.
- Investment and reforms promote efficiency and fuel switching.

PCAST recommended buildings sector demand-side energy cooperation. The U.S. government could help transition and developing countries cut energy use in new appliances, homes, and commercial buildings in developing countries by 25 percent compared to current practice. Developing countries continue to build homes with energy-intensive materials that have low thermal-insulation values. Buildings-energy use can be cut by one-third or more with advanced design techniques available in the United States.

High-priority efforts could include technical and policy assistance for efficiency standards and ratings and labeling of building equipment and appliances. PCAST supported the idea of U.S. sponsorship of labeling and promotion programs similar to the "Energy Star"; design competitions to push the envelope of building energy performance; and technical assistance for development, analysis, and implementation of building energy codes and standards, including use of monitoring, compliance, enforcement programs, and software.

[8] Pacific Northwest National Laboratory senior research scientist Meredydd Evans won the "International Energy Project of the Year" award from the Association of Energy Engineers for work organizing energy-efficiency investment for the Gostomel Glass Plant in Ukraine.

PCAST end-use experts recommended efforts to promote combined-heat-and-power, or cogeneration, technologies for new power supply. Countries with rapidly growing power demand such as China, India, and much of Latin America could obtain one-fifth of their new power supply from cogeneration or distributed power systems using microturbines, renewable energy, and other new power generation systems.

Enron Corporation's frustrating experience in building and operating a power plant in Dabhol, India, is well known. That experience, and others like it around the world, have shown that regulatory reform in developing nations is badly needed.[9] Assistance by U.S. experts to "level the playing field" for modern generating technologies, especially cogeneration, can help create functioning markets and facilitate penetration of advanced technologies in countries like India. PCAST determined that successful deployment of cogeneration will required five things: information and education programs; collaborative assessments of power and heat loads at potential cogeneration sites; addressing potential regulatory and market barriers; funding for demonstrations; and help in securing financing.

Funding for market surveys of potential cogeneration sites would help to determine power and heat loads and output ratios in order to identify favorable conditions. Such an effort would also need to identify and suggest solutions to regulatory barriers such as difficulties selling power to the grid. Technical and policy assistance could help develop and implement policies that are equitable for cogeneration. This activity, like the industrial initiative above, could also leverage funding for innovative demonstrations of combined heat and power and to help secure financing from international private and public sources.

Portfolio of Supply-Side Projects

PCAST noted that specific opportunities exist for international cooperation for innovation on energy-supply technologies to help spread use of technologies for renewable energy, fossil-fuel decarbonization, carbon dioxide sequestration, and nuclear fission and fusion. Priority was placed on accelerating the development and deployment of biomass, wind, photovoltaic, solar thermal, and other renewable energy technologies. Also needed are collaborative research on restoring degraded lands, and developing fossil-energy hybrids to provide complete energy services for agricultural, residential, and village-scale commercial and industrial applications in rural areas.

Among the supply-side options considered, PCAST emphasized the need for collaboration to develop industrial-scale biomass energy conversion technologies, as well as collaborative research on the restoration of degraded lands and their use for growing crops optimized to yield multiple products. PCAST found that collaboration is needed to accelerate the deployment of grid-connected intermittent renewable electric technologies with fossil energy. The panel further suggested then need for collaboration on assessments of renewable energy resources on a region-by-region basis.

PCAST found need to add an explicit international activity to promote research focused on advanced technologies for improving the cost, safety, waste management, and proliferation resistance of nuclear fission energy systems, and to expand and strengthen exchanges on geologic disposal of spent fuel and high-level wastes. Our panel recommended pursuit of a new international agreement on fusion research and development that commits parties to a broad range of collaborations on all aspects of fusion energy development to enhance U.S. participation in existing fusion experiments abroad and inviting increased foreign participation in new and continuing smaller fusion experiments in the United States.

Management Initiative

PCAST recommended that the President should establish an interagency working group on strategic energy cooperation in the National Science and Technology Council to develop and promote a strategic vision of the role of the government's contributions to international energy. This working group would be responsible for continuing assessment of the government's full portfolio and would assist the agencies to strengthen their internal and external mechanisms for monitoring and reviewing projects, for terminating unsuccessful ones, and for handing off successful ones to the private sector at the appropriate time.

PCAST stressed the role of the private sector. Government programs should be structured to catalyze and complement the private sector, not replace it. International programs should help lower barriers and supplement private incentives

[9] Khozem Merchant in Bombay and David Gardner, "Enron Threatens to Withdraw from Indian Power Project," *Financial Times*, 9 April 2001.

and capacity to address U.S. interests in energy innovation. But assistance should be limited in the rate and duration of the government's investment, with specific criteria for terminating projects that fall short and for transferring successful ones to the private sector.

PCAST concluded that government involvement is needed because the public interest in energy outcomes goes beyond the sum of perceived private interests. Privatization, deregulation, and restructuring of energy industries help bring private capital into the energy sector.

Fleeting Opportunities

International carbon dioxide emissions trading offers a potentially important tool for deploying technology to mitigate greenhouse gases, but that tool may be slipping from our grasp. Large-scale, inexpensive emissions mitigation opportunities exist in the transition economies—Russia and Ukraine, for example—and a trading regime could provide the incentive for market adoption of technologies that will substantially reduce future emissions levels. But transition economies have encountered difficulty in organizing a transparent and effective trading system, a condition that may be worsened if U.S. policy suggest that we have abandoned our commitment to "flexible mechanisms",[10] as agreed in the Framework Convention on Climate Change. Much more serious cooperation with transition economies will be needed to encourage establishment of serious mechanism to deploy emissions-mitigating technologies.

The needs and opportunities for international energy cooperation are thus large and urgent. The costs and risks are modest in relation to the potential gains. Our best opportunities include helping build local leadership capacity, supporting energy-sector reform, and helping finance the market penetration of energy-efficient and environmentally benign energy technologies. Shifting to this brand of international energy cooperation, the panel found, would provide more benefit to American security, trade, and its environment than the general approach to technical assistance.

Policy-makers might find encouragement and challenge in these ideas. Concerns that climate and environmental protection policy would lead to greater, not less, command and control appear exaggerated. The literature suggests that transition to markets and competition will actually help cut emissions growth, at least up to a point. Concern that cutting emissions growth in developing countries would cost impossible sums and retard economic development also appears misplaced. But confidence that markets will readily work and that technology will eventually solve the carbon emissions problem seem naive. Markets remain distorted, fuel and capital are wasted on a large scale, and opportunities for efficiency and environmental protection are squandered. Most developing and transition economies lack the tax, regulatory, and incentive programs to address the energy and climate challenge. Markets will not alone create the advanced technology necessary to even approach the goal of the United Nations Framework on Climate Change stabilizing concentrations of greenhouse gases. The magnitude of change required is such that only some significant shift in markets such as an agreement to limit emissions per unit of energy produced, or a functioning emissions trading system would make meaningful change achievable.

The CHAIRMAN. Thank you very much.

Dr. Friedman, why don't you go right ahead.

STATEMENT OF DR. ROBERT M. FRIEDMAN, VICE PRESIDENT FOR RESEARCH, THE H. JOHN HEINZ III CENTER FOR SCIENCE, ECONOMICS AND THE ENVIRONMENT

Dr. FRIEDMAN. Thank you. Good morning. I am Bob Friedman with the Heinz Center. We are a nonprofit, non-partisan environmental policy research organization here in Washington. I am delighted to be here.

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[10] Aleksandr Avdiushin, Martin Dasek, Henryk Gaj, Inna Gritsevich, Susan Legro (editor), Jaroslav Marousek, Bedrich Moldan, Natalia Parasiuk, Nikolai Raptsoun, Andrei Sadowski, Vasyl Vasylchenko, Marie Havlickova, Aleksandr Kolesov, Bedrich Schwarzkopf, and Svetlana Sorokina, "No-Regrets Options in Climate Change Mitigation Policy: Lessons from Transition Economies," Battelle, Pacific Northwest National Laboratories, May 1997; Meredydd Evans, "Demand-side energy efficiency and the Kyoto mechanisms", European Council for an Energy-Efficient Economy, 2001 Summer Study, Paper 6.126.

I would like to briefly present some conclusions from research we performed about 2 years ago, funded by EPA, on technology policies for reducing greenhouse gas emissions. We were focusing not so much on the specific technologies but really on the suite of primarily voluntary policies available to encourage their development and adoption. And if I can leave you with just one message today, it is this, that R&D is vital, but R&D alone is not enough. Let me expand.

We looked at over a dozen policy tools. We, of course, looked at direct government funding of R&D in many stripes and flavors, but we also considered a series of approaches to induce private R&D or even modestly support production or commercialization, things like tax credits or Government procurement. And finally, we looked at a set of policies that really foster technology diffusion and deployment primarily through the use of information.

In context, most of the policy discussions and actions to date have centered on funding levels for research and development and primarily for the Department of Energy. Again, clearly R&D is vital. The question we were asking was, is it enough? And if not, what else is needed?

Our conclusion: if we diversify our approach, not just diversify the portfolio of technologies, but policies as well, we will more effectively accelerate the development and adoption of new technologies.

We looked at several areas where technology development has really played a large role, not just energy and the environment. We also looked at defense and electronics. Interestingly, we held a workshop for R&D managers from industry where we basically asked them which of these policies might be most productive for their firms and sectors, and that was very instructive for us.

Let me tell you briefly about three conclusions from our work.

First, our Nation's portfolio of technology policies really could be better balanced in two ways. On one side, we need more support for radical innovation, support for those really new ideas, and on the other side, better structured policies for promoting diffusion and deployment of these new technologies.

Second, almost any portfolio of technology policies aimed at greenhouse gas reduction would gain added force if we had complementary price signals or regulatory initiatives. The point here is that pulling innovations into the marketplace through incentives often leads to better solutions than just technology push alone.

My final point is to ask you to seriously consider having the Federal Government prepare what we began calling technology policy road maps. This last notion is a somewhat odd idea, new idea, and it is one that I particularly want to highlight. I think this idea came primarily from industry that we worked with who felt very strongly about the need for a diverse portfolio of policy approaches. They emphasized to us that each industry differs not only in the technologies they use, but in factors such as the significance of intellectual property protection, the willingness of firms to work together, and a whole host of other factors. Our collaborators really suggested that if the Government were truly serious about tailoring these technology policies to the needs of specific sectors and to specific technology challenges, it should undertake joint planning

with industry and other interested parties to produce these technology policy road maps.

These are really expansions of the more traditional technology R&D road maps pioneered by the semiconductor industry and currently used by lots of others, including DOE. However, these policy road maps would not only foster knowledge creation but also address commercialization and eventual diffusion on a sector-by-sector basis. Of course, this is vital to the success of this mission.

I would like to just thank you for the opportunity to speak with you this morning, and with your permission, I would like to submit a summary * of our work for the record along with these remarks.

The CHAIRMAN. We will be glad to include that in the record.

[The prepared statement of Dr. Friedman follow:]

PREPARED STATEMENT OF DR. ROBERT M. FRIEDMAN, VICE PRESIDENT FOR RESEARCH, THE H. JOHN HEINZ III CENTER FOR SCIENCE, ECONOMICS AND THE ENVIRONMENT

Good Morning. I am Robert Friedman, Vice President for Research at The H. John Heinz III Center for Science, Economics and the Environment. The Heinz Center is a non-profit, non-partisan, environmental policy research organization that brings together people from industry, environmental groups, government, and academia to work together on environmental and natural resource problems.

I will briefly present the conclusions from some research we performed about two years ago on "Technology Policies for Reducing Greenhouse Gas Emissions," funded by the Environmental Protection Agency. We were focusing not so much on the specific technologies, but the policy tools available to encourage their development and adoption. If I leave you with but one message, it is this: R&D alone is not enough.

In all, we considered over a dozen policy tools. We of course looked at direct government funding of R&D—money to firms, universities, or government labs. We also considered approaches to induce private R&D, or even modestly support production or commercialization, for example, tax credits, production subsidies, or government procurement. And finally, we looked at policies that foster technology diffusion and deployment through information transmittal and learning. (See Table 1 for pros and cons of these approaches.) We considered only voluntary measures, that is, we did not (in this study) look at such environmental policy tools as regulation or emissions trading.

Most of the policy discussions and actions to date have centered on funding levels for research and development, primarily by the Department of Energy. Clearly R&D is vital. Our question was, is it enough? If not, what else is needed?

Our conclusion: if we diversify our approach, we will more effectively accelerate the development and adoption of new technologies for lowering emissions of greenhouse gases (GHGs). But the design task is not simple. GHG sources are widely dispersed throughout the economy. Thousands of technologies are involved.

Our research looked at several areas where technology development played a large role, in particular, defense and electronics, in addition to energy and the environment. We also held a workshop for R&D managers from industry, in essence asking them which of these policies might be most productive for their firms and sectors.

I want to tell you about three key conclusions from our work:

- First, our Nations's portfolio of technology policies for addressing GHG emissions could be better balanced in two ways: 1) more support for radical innovation and 2) better structured policies for promoting diffusion and deployment of new technologies. The scale and scope of worldwide GHG emissions imply that radical innovation will be needed for substantial reductions. But innovations, whether incremental or radical, have little impact until widely diffused. "Breakthroughs" sometimes originate in research, but not always: the microprocessor began as a pure exercise in engineering design.
- Second, almost any portfolio of technology policies aimed at GHG reduction would gain added force from complementary price signals or regulatory initiatives. "Pulling" innovations into the marketplace through incentives often leads to better solutions than does "technology push."

* The summary has been retained in committee files.

- Third, the Federal Government—working with industry, universities, and environmental groups should expand the effort to construct technology R&D "roadmaps" into broader technology policy roadmaps for addressing GHG release.

This last notion is one that is new, and one that I particularly want to highlight. This idea came from our industry participants, who felt strongly about the need for a diverse portfolio of policy approaches. They emphasized that each industry differs, not only in technologies, but in factors such as the significance of intellectual property protection and the willingness of firms to work together. The participants suggested that if government were truly serious about matching a portfolio of technology policies to specific sectors and technology challenges, it should undertake joint planning with industry and other interested parties to produce what we came to call technology policy roadmaps.

These policy roadmaps are expansions of the technology roadmaps pioneered by the semiconductor industry and currently others, including DOE. However, such policy roadmaps would not only foster knowledge creation, but also address commercialization and eventual diffusion on a sector-by-sector basis.

Thank you for the opportunity to speak with you this morning. With your permission, I will submit a summary of our work for the record along with these remarks. More extensive documentation is also available on the web.[1]

Table 1.—TECHNOLOGY POLICIES

Group/Policy [a]	Advantages	Disadvantages
Direct Funding of R&D/DD&D		
1. R&D contracts with private firms.	Proven effectiveness in mission agencies, especially defense.	In the absence of a clearly defined and widely accepted mission can be hard to defend politically and to manage.
2. R&D contracts and grants with universities.	Well established procedures in agencies, ample experience.	Not obvious how much university research has to contribute to GHG reduction, where the greatest needs may be for applied technologies.
3. Intramural R&D conducted in government laboratories.	Excellent capabilities in some laboratories.	Laboratories less integrated into technological infrastructure than universities.
4. R&D contracts with consortia that include two or more of the actors above.	Collaboration helps define appropriate technical objectives.	Limited experience base compared to policies 1-3.

[1] "Technology Policies for Controlling Greenhouse Gas Emissions: Project Summary," "Technology Policies for Controlling Greenhouse Gas Emissions: A Taxonomy," by John A. Alic, and "Meeting Summary: Workshop on Technology Policies for Controlling Greenhouse Gas Emissions," are available at www.heinzctr.org or by request from The Neinz Center.

Table 1.—TECHNOLOGY POLICIES—Continued

Group/Policy [a]	Advantages	Disadvantages
Indirect Support for R&D/DD&D; Direct or Indirect Support for Commercialization and Production		
5. R&D tax credits	Generalized research and experimentation tax credit, in place in various forms since early 1980s, has been popular, uncontroversial.	Difficult to link with GHG reduction. Some analyses indicate existing credits tend to subsidize work that would be conducted anyway, provide only a modest incentive for new R&D. The credit has never been made permanent, which has probably reduced its impact.
6. Tax credits or production subsidies for firms bringing new technologies to market.	Well-suited in theory to fostering technologies with evident potential for GHG reduction.	Little experience with such policies, which are likely to be labeled as "corporate welfare" by opponents. Susceptible to political manipulation that could lead to support for second-best technologies.
7. Tax credits or rebates for purchasers of new technologies.	Same as above, but tend to "pull" technologies into the marketplace, which can be more desirable than "pushing" them.	Same as above, though less likely to attract lobbying because benefits are harder to channel to particular interests.
8. Government procurement.	Can be powerful where government is a significant customer.	Federal purchases (and leases) have much more leverage for some GHG sources (buildings) than others (production of primary metals).
9. Demonstration projects	Can be effective for technologies that are relatively well understood in principle but for which practical application and/or market opportunities have yet to be fully explored.	Tainted by past undertakings widely viewed as wasteful and ineffective, including energy projects. New institutional learning would probably be required to re-establish demonstration projects as a viable instrument.

Table 1.—TECHNOLOGY POLICIES—Continued

Group/Policy [a]	Advantages	Disadvantages
	Information and Learning	
10. Education and training	The most powerful single mechanism for diffusion of knowledge.	Diffusion is relatively slow via established channels (e.g., university degree programs); quality of shorter education and training courses highly variable, may be hard for potential participants to judge.
11. Codification and diffusion of technical knowledge.	Many well-established channels (reference documents, consensus best practices, computer-aided engineering methods and databases, technical review articles, etc.).	Not a traditional role for government (with exceptions such as public works). Existing channels slow, especially those that depend on consensus.
12. Technology/ industrial extension.	Suited to case-by-case problems (e.g., energy utilization in small manufacturing firms).	Labor-intensive, hence costly; relatively new in the United States and may not be fully accepted.
13. Technical standards [b] ..	Once in place, can have broad, deep, and lasting impacts.	Standards often represent compromises among competing private interests with limited public-interest input. Standards-setting processes slow.
14. Publicity, persuasion, consumer information.	Possible to reach large numbers of decision-makers at relatively low cost.	Competing interests may attenuate, perhaps distort, messages coming from government, despite efforts to provide unbiased information.

[a] The taxonomy omits policies such as intellectual property protection that create generalized incentives for innovation.
[b] This eniry reers only to technical standards intended to ensure commonality (e.g., driving cycles for testing automobile fuel economy and/or emissions) or compatibility (e.g., connectors or charging electric vehicle batteries), not to regulatory standards.

The CHAIRMAN. Dr. Levine, you are the cleanup hitter here.

STATEMENT OF DR. MARK D. LEVINE, DIRECTOR, ENVIRONMENTAL ENERGY TECHNOLOGIES DIVISION, LAWRENCE BERKELEY NATIONAL LABORATORY, BERKELEY, CA

Dr. LEVINE. Well, thank you very much. It is a real privilege and pleasure to be here. I am from Lawrence Berkeley National Laboratory, as you indicated.

I am here to address two topics. The first is a very brief summary of the Clean Energy Futures study that was conducted by a group of five national laboratories. It was funded by the Department of Energy and the Environmental Protection Agency. The

analysis, however, is that of the authors. It is our report, not the Government's report. Of course, I am speaking for myself but will summarize the main features of the study.

This was a comprehensive assessment of technologies and policies to address energy-related challenges to the Nation. The study concluded that accelerating the development and deployment of energy efficient and renewable energy technologies could significantly reduce the growth of greenhouse gas emissions, oil dependence, air pollution, and economic inefficiencies. The study also concluded that the overall economic costs and benefits of policies to bring about these impacts appear to be roughly comparable to one another. In other words, it is affordable to do this.

We looked at three different scenarios. By the way, this went to the year 2020. A business-as-usual case, a moderate case, moderate policies in a sense, and an advanced case, advanced meaning tougher policies and advanced technologies. We had a portfolio of policies in all the cases, as I said, tougher ones in the advanced case. An important difference between the advanced case and the moderate case was that we had a carbon charge that could have resulted through a cap and trade system or other means of $50 a ton carbon emissions, and this had the effect of moving natural gas to replace coal for many powerplants.

Let me tell you the results of those scenarios. This is a very detailed, quantitative analysis, obviously, of course, based on many different assumptions, all of which we tried to make very explicit.

In 2020, carbon emissions are reduced by about 10 percent in the moderate case compared with the expected business-as-usual case and about 30 percent in the advanced case, bringing emissions in the advanced case down to 1990 levels by 2020.

Oil use was reduced by 2 million barrels a day in the moderate case, 5 million barrels a day in 2020 for the advanced case, again bringing oil use back to about 1990 levels.

We were able in this scenario to cut emissions of pollutants by a factor of 2 in the advanced case. An important impact in the advanced case was that coal use declines by almost 50 percent, a major impact on the coal industry as natural gas, as I said, replaces coal.

However, an important point has to do with the use of natural gas and the growth of natural gas. In the cases we looked at, natural gas grows for both the moderate and the advanced case by about 22 percent by the year 2020, but in the business-as-usual case it grows by 33 percent. So, in fact, in spite of the fact that we are backing out coal, replacing it with natural gas, because of energy efficiency, because of the growth of renewable energy systems, and because of the maintenance and life extension of nuclear powerplants, by doing all those things, one can contain growth of natural gas. A terribly important issue.

Now, I want to point out our study does not make any policy recommendations. This is really an analysis of what could happen if one adopts certain policies. It is meant to be a background or framework for analyzing the problem and one that we hope will be seriously considered as a part of that framework.

One matter stands out particularly strongly. We have heard it from the other speakers, and that is in all the scenarios that we

talk about, a necessary ingredient, and certainly for the advanced case, is R&D. R&D for advanced technologies, advanced energy technologies, are critical even in this 20-year time frame for addressing climate change issues and more and more important as one goes into a longer time period.

I want to turn to R&D very briefly and I wanted to illustrate from our laboratory some results of R&D. I think it has been inadequately recognized that Government supported R&D, generally combined with industrial partners, has had a huge impact over the years in enabling energy demand reductions and thus reductions in carbon emissions to take place. As I said, I will use LBNL's work, but I use that to illustrate the point. There is other work in many other laboratories around the country and you can hear very similar stories in those cases as well.

We did work in three technologies, and this is explained in an addendum to my testimony. Back in the 1970's and 1980's the construction of a computer code to analyze energy use in buildings is now used by virtually all architect/engineering firms in the country who design complex buildings.

We were instrumental in creating the electronic fluorescent ballast, which is the forerunner of the compact fluorescent, more efficient fluorescent lamps.

We were very active in creating advanced window coatings, which have achieved substantial market penetration. This is the one case where we did not have policy that drove these things. In the other cases, policies were quite instrumental in bring these technologies to bear.

Our analysis shows that these three technology developments from some time ago result in a net lifetime savings to the country of on the order of $40 billion. That is growing every year as these products move into the market. The assumption behind these calculations was not that the technologies would not have been developed, but that they would have been developed later. So, we are not taking full credit for all of it. Now, all of that at a cost of less than half a billion dollars. So, those investments alone would pay for lots of other R&D, much of which is successful, not all of which is going to be successful.

My final point is that there continues in the pipeline tremendous R&D opportunities that are going to be absolutely essential if we are going to deal either with our range of energy problems or with the problem of emission of carbon. I give examples in my addendum of work, again, that we are doing. Let me just list them very quickly.

Energy efficient and safe torchiere lightings, that is the lamp that projects onto the ceiling and has been made with halogen lamps. They are very hot, very inefficient. We have developed a compact fluorescent version. They do not cause fires. I am hoping that they will move rapidly into the marketplace.

We are looking very hard at reducing standby power losses which turn out to be the energy used when you have equipment plugged in that is just sitting there and not doing anything useful. That turns out to be projected to be one of the largest growths of energy in buildings and it is nonproductive.

We have a technology that is moving rapidly into the marketplace and will have a big impact of ceiling ducts, that is, the ducts that carry the air from the furnace or the air conditioner to the house. Typically those ducts, amazingly enough, lose 20 percent of their energy, that is to say, are heating or cooling the outside. We have efficient furnaces, thanks to appliance standards, but we are not delivering the product to the right place.

Other examples, efficient burners. We are concerned about urban heat islands, reducing heat in urban areas, reflecting more a new lamp that is very efficient, and other developments like that.

So, in conclusion, I want to indicate the value of the R&D that has been done so far, and I want to support very strongly the need for R&D if we are going to address climate change not only in efficiency. We need it in supply technologies. We need it in exploratory research. We need it in the full range of areas.

Thank you very much.

[The prepared statement of Dr. Levine follows:]

PREPARED STATEMENT OF DR. MARK D. LEVINE,[1] DIRECTOR, ENVIRONMENTAL ENERGY TECHNOLOGIES DIVISION, LAWRENCE BERKELEY NATIONAL LABORATORY, BERKELEY, CA

I am pleased to participate in the portion of your hearing on technology solutions to address greenhouse gas emissions.

I will first introduce myself. I have been involved in energy matters, as an analyst and/or R&D manager continuously since 1972. I have worked for the Ford Foundation Energy Policy Project, SRI International, and Lawrence Berkeley National Laboratory (since 1979). I presently lead the division at the Berkeley Lab that does most of our energy research. The emphasis of our division of more than 400 staff members is energy efficiency R&D. I serve on various board of directors of energy non-profit organizations, have been a lead author of the 1995 and 2000 mitigation assessments for the Intergovernmental Panel on Climate Change, and am one of the authors of the Clean Energy Futures study, which will be a portion of my testimony today.

INTRODUCTION

I address two topics in this testimony. First, I provide an overview of the Clean Energy Futures Study. The executive summary of that report and the first chapter, Integrated Analysis and Conclusions, provide the full details, so I hope that my summary will be sufficient.[2] Second, I want to talk about an important implication of this study and other analyses on the critical role of energy technology R&D in addressing the reduction in energy-related greenhouse gas emissions.

OVERVIEW OF THE CLEAN ENERGY FUTURES STUDY

The Clean Energy Futures Study is a comprehensive assessment of technologies and market-based policies to address energy related challenges to the Nation. It deals with the period to 2020. The report was commissioned by the U.S. Department of Energy and co-funded by the U.S. Environmental Protection Agency. The analysis was performed by researchers from five national laboratories: Oak Ridge National Laboratory, National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Argonne National Laboratory, and Pacific Northwest National Laboratory. The study reflects the results of analysis of its authors and does not speak for DOE.

The study concludes that accelerating the development and deployment of energy efficient and renewable energy technologies could significantly reduce greenhouse gas emissions, oil dependence, air pollution, and economic inefficiencies. The study

[1] The statements in this testimony are the views of Dr. Mark D. Levine and do not necessarily reflect those of either the University of California or of the Lawrence Berkeley National Laboratory.

[2] "Scenarios for a Clean Energy Future," "Interlaboratory Working Group on Energy-Efficient and Clean Energy Technologies," ORNL/CON-476, LBNL-44029, NREL-TP-620-29379, November 2000. Available at http://www.ornl.gov/ORNL/Energy—Eff/CEF.html

concludes that the overall economic costs and benefits of policies to bring about these impacts appear to be comparable.

In reaching this conclusion, the study addressed three scenarios: business as usual (BAU), moderate, and advanced cases. BAU is similar to the Energy Information Administration forecast of U.S. energy future through 2020.

The moderate case has an array of market-based policies and programs including a 50% increase in cost-shared energy R&D, expanded voluntary programs, and selected tax credits. The advanced case has more aggressive policies including a doubling of R&D, voluntary agreements to increase auto fuel economy and to promote energy efficiency in industry, renewable energy portfolio standards, and a domestic cap and trading system on carbon that results in a $50/tonne charge on carbon.

Some of the important findings of the study are:

- CO_2 emissions in 2020 are reduced by 9% in the moderate case and 29% in the advanced case, almost back to 1990 levels in the latter case. One important difference between the moderate and advanced case is the $50 per tonne carbon trading value in the latter. Carbon trading is a key policy leading to reductions in carbon emissions by promoting the replacement of coal by natural gas.
- Oil use in 2020 is reduced by 2 million barrels per day in the moderate case and by 5 million barrels of oil per day under the advanced scenario. In the advanced scenario oil use would be about the same in 2020 as it is today.
- Nitrogen oxide and sulfur dioxide emissions from electricity production are cut in half in the advanced scenario.
- Electricity demand grows by half a percent per year in the moderate case to remaining about constant in the advanced case. This compares to a growth of about 2%/y for BAU.
- Coal use would be about the same as today under the moderate scenario and 40% less under the advanced scenario.
- Natural gas demand would grow as much as 22% (both advanced and moderate cases) but much less than for the BAU for which the increase was 33%. The reduced growth is because of greater efficiency (end use and energy conversion) in the moderate and advanced scenarios.
- Renewable energy sources would grow 40-60%.
- Nuclear would be 14% higher in the advanced scenario (because of higher electricity prices) or 13% lower in the moderate scenario (because of lower demand for electricity) compared with BAU. No new nuclear plants would be built during this time period.

It is useful to put this study in perspective. First, the study makes no policy recommendations. It assesses a wide range of policies, programs, and technologies to describe energy scenarios for the nation. Its purpose is to describe what might be possible under a variety of circumstances and assumptions, rather than to prescribe what is to be done. Second, each reader needs to assess for herself the degree to which the different cases are achievable as well as the tradeoffs among different policies that underlay the scenario. The moderate case depends on a return to a policy environment somewhat reminiscent of the period between 1973 and 1986, in which energy and carbon emissions in the United States did not grow at all for 13 years. (The moderate case actually shows a 17% growth in energy demand over the 23-year study period.) The advanced case depends on significant advances in R&D and rapid entry of the R&D achievements into the marketplace. It is this quick entry into the market that is, I believe, of the greatest uncertainty.

I would point out the need for greater analysis of the ability of various programs to bring about rapid penetration and to promote new technology over the coming years. Trials and assessments are needed. Extensive analysis is needed to assess individual policies. At the same time, it is clear that many of the approaches suggested in the Clean Energy Futures study deserve to be given serious attention.

One matter stands out. In all of the scenarios described in the Clean Energy Futures studies, technology is a necessary ingredient in our efforts to reduce greenhouse gas emissions. R&D is an essential underpinning of any effort to improve the nation's energy future as well as to address greenhouse gas emissions.

IMPORTANCE OF ENERGY TECHNOLOGY R&D

I noted earlier that the U.S. economy grew by 35% from 1973 to 1986 while energy use grew 0%. Much of that reduction in energy intensity came from the production, sale, and use of more energy-efficient technologies. Those technologies were made possible by research and development. Much of that R&D came from the public sector.

I think it has been inadequately recognized that the government-supported R&D has had a huge impact over the years in enabling energy demand—and thus carbon

emissions—to grow more slowly than would otherwise have been the case. The U.S.—and the global community—would be much poorer without this R&D.

I want to use our own work at LBNL to illustrate the benefits that the nation has received from energy efficiency and environmental R&D. I use these examples because I am most familiar with the work. However, R&D in other areas of energy technology is equally important and there have been numerous successes. From the vantage point of greenhouse gas emissions, we need to develop better ways of finding natural gas, clearly the choice fuel for the United States. We need to pursue R&D on a host of renewable energy technologies, to continue the progress of bringing their prices down to competitive levels. We need to continue to learn how to use coal more efficiently—reducing greenhouse gases—and ultimately to convert coal to hydrogen. We need to study ways of capturing and sequestering carbon dioxide.

Let me repeat that I've used examples from research at Lawrence Berkeley National Laboratory because I am familiar with this research. Many other research institutions working on many different facets of energy technology R&D could provide similar examples of successes that have had favorable impacts on the U.S. economy and environment.

The attachment shows examples of some of our R&D successes. The first page of the handout lists many of these achievements (which are more fully described in the following pages.) This page also shows that three early achievements (from the 1980s)—the DOE/LBNL building energy analysis tool, electronic ballasts for fluorescent lamps, and advanced window coatings—have resulted in an estimated net lifetime savings from products purchased to date of more than $40B![3] Although much of the costs to achieve these savings were from product development and marketing costs paid by the private sector, they would not have been possible without the federal R&D program. The total cost of all R&D on energy efficiency at LBNL over the past 25 years was less than $0.5 billion in today's dollars.

The handout shows additional R&D successes. We are actively working with private firms to bring these products into use as quickly as possible. However, it takes many years for products to move from the lab to the marketplace. It is thus too early to assess the full impacts of the R&D. But it is already clear that these products will have significant impacts.

This is all directly relevant to the main topic of this panel—mitigation of climate change. If we have to rely on existing technologies to reduce carbon emissions, we can achieve some reductions (at least in growth) over the next decade or so. That is, there is a backlog of technologies that have not yet been fully adopted in the market, and there are tools to bring them forward. But this is a quick fix to a long-term problem, and current technology is not nearly adequate to address the problem. In my view, we need to expand:

- R&D on energy efficiency technologies to make affordable reductions in greenhouse gas emissions over the coming several decades and longer;
- R&D on natural gas development, also likely to have impacts in the coming few decades;
- R&D into low or no carbon energy supply technologies, including renewable energy and electricity systems, more efficient fossil fuel conversion to electricity, and nuclear power (and especially the problem of long-term high-level radioactive waste storage);
- Exploratory research efforts on the hydrogen economy, practical methods to apply fusion for electricity, and carbon sequestration.

CONCLUSION

The Clean Energy Futures study provides a quantitative analysis of possible futures to reduce energy-related greenhouse gas emissions, oil imports, and local air pollution. While offering no specific policy recommendations, the study does provide a basis for assessing energy futures for the country, and does identify programs and policies that could promote greater measures of energy efficiency than will occur in the base case, thereby achieving reductions in the growth of greenhouse gases and other benefits.

Regardless of our future energy path in the near term, we will find ourselves without adequate means of combating greenhouse gas emissions without serious attention to energy technology R&D. Previous experience with federal energy technology R&D—illustrated by specific cases from one laboratory—show very substantial net benefits to the nation. These examples were largely in energy efficiency

[3] See end notes at the conclusion of this paper for a description of what is meant by net lifetime savings and for brief notes on the calculation.

R&D. But R&D will be needed in numerous energy areas for us to achieve affordable ways of reducing greenhouse gas emissions.

END NOTES

Lifetime savings mean the energy savings from all products purchased to date. Thus, a product purchased today continues to save energy over its lifetime and these savings are included in the figure. *Net savings* means that the added cost of the energy efficiency attributes of the product is deducted from the benefits.

The savings from the use of the building design tool are lifetime savings resulting in increased use of energy efficiency features for buildings that have been designed using this code (most large commercial buildings in the United States).

The savings for window coatings and electronic ballasts are for all of these products purchased to date minus the added first cost of the products. The calculation assumes that such products would have come onto the market but slower and five years later without the LBNL R&D program.

Net lifetime savings from appliance standards of almost $50B are also shown in the handout. Berkeley Lab has provided a staff of 25 professionals to do the analysis.

The full documentation of the impacts of these technologies—and the R&D that led to them—is under review at this time. The review may cause the final numbers to be higher or lower than reported here. The savings from appliance standards are well documented in the Department of Energy Technical Support Documents and in various publications by LBNL staff.

The CHAIRMAN. Thank you all very much for your testimony.

Let me ask Dr. Levine about a specific issue which I believe you have some expertise on and that is air conditioner efficiency. As you know, the prior administration had an efficiency standard that they had arrived at relative to air conditioners, and that was rolled back a couple of months ago. I guess I would be interested in any comments you have as to the appropriateness of the standard that was earlier arrived at, and also how big an issue is this? Does it really impact significantly on the amount of energy used, or is this something that is sort of lost in the noise, particularly I guess at the peak times when we have the blackouts around the country, particularly in California?

Dr. LEVINE. I am glad you mentioned the peak issue.

I think the issue of the level of the standard was a difficult one in the previous administration. They originally came out with an SEER 12 in the notice of proposed rulemaking and then later went to 13, and now there is discussion of rolling it back to 12. It is a hard call. The technical analysis could have supported either, depending on some assumptions that you made. That is why the original proposal was for 12. So, I think it has become a politically important issue but technically it is very difficult for me to say very much between the two.

However, on the peak power issue, I think a great deal can be said. I think the fact that this is now a controversial issue gives us an opportunity to do something that is crucial. We need to look at how to design air conditioners and optimize them for peak power, how you can have them as efficient as possible at the time of peak. We also need to look at the question of putting chips into air conditioners so that you can control them during a period of peak power so that when your cost of electricity is very, very high, you have a way of controlling the air conditioner itself. We worry about air conditioners especially for peak power. It is a huge impact on peak and maybe we can use this opportunity to address the question of how we can design air conditioners to deal with that problem.

The CHAIRMAN. Let me ask Dr. Friedman. Your concept of technology policy road maps I think is an interesting one. We are preparing to develop and mark up legislation here in the Senate, which we hope will address many of the issues that have been talked about here this morning. We are trying to figure out what the right policy should be in a legislative sense, the extent to which the Federal Government should involve itself in promoting use of particular technologies or development of new technologies and the extent to which we should be incentivizing the actual use of technologies by people. Do you have any other thoughts about how we get from here to there in the next 3 or 4 weeks? How developed is your technology policy road map in this area?

Dr. FRIEDMAN. Three or 4 weeks is a tough one. I think the notion that we were considering and trying to put forth was what we need to do is this sort of exercise on a more continuing basis and with more direct involvement of industry directly, the recipient end of some of these policies. I think institutionally it is a tough one. This sort of consideration might happen in the Office of Science and Technology Policy, or it might happen with identification of a couple of lead agencies.

How you can do this, however, this quickly—maybe the best to do is to set up the institution and get the institution running. As James Edmonds points out, climate change will be the impact of cumulative emissions. It will also be the impact of cumulative policies, the policies that we put in place and modify periodically over the next decade. Maybe we just need to get started with that process of getting folks together and being a little more deliberate on the choice of particular policies that we choose.

The CHAIRMAN. Mr. Chandler, let me ask you. You have had a lot of experience dealing with foreign governments and foundations, as I understand it. Are there things that we could be doing that would facilitate getting the right technology to some of these foreign countries that would really be of assistance? Is there technology that we have available to us that we need to make more readily available to other countries, and if so, how do we do it?

Mr. CHANDLER. To accelerate deployment, the problem is overcoming barriers to the adoption of not just new technologies but existing technologies. We recommended on the International Energy Panel of the President's Council of Science and Technology Advisors that capacity building be a high priority. Examples of what can work include the creation of some institutions for the promotion of energy efficiency that I have been involved with. We helped organize six energy efficiency centers in countries as diverse as Russia and China in which we invested in helping local expertise to address their own problems of policy and to organize the resources, including financial resources, to implement and deploy technology. The kinds of things that those centers can do include, for example, in Ukraine the organization of investment in private industry to replace glass furnaces in a bottle making factory. To overcome these barriers, investing in reform and in capacity building is a high priority.

The CHAIRMAN. Let me ask Dr. Edmonds. You pointed out that we need a diverse technology portfolio clearly in order to ensure that we have energy in the future and get away from a reliance on

fossil fuels to such an extent. What do you see as the right role for the U.S. Congress in moving us in that direction? Should we just have a robust budget for research and development? Should we have a whole phalanx of tax incentives to encourage people to use these technologies? Should we do some combination of those or something else, as you see it?

Dr. EDMONDS. Thank you, Senator. That is actually a very difficult question.

I think you are absolutely correct when you recognize the point I am making about the need for a diverse technology portfolio. Part of that portfolio is going to have to be delivered by the private sector. But there is a role for government and the role for government in delivering technologies has to do more with creating the optimum conditions. If you look at the basic energy research, that does not get undertaken by the private sector. If you look at the biotechnology research that holds such promise, you do not expect that to be undertaken independently by the private sector. So, the public sector has an important role in supporting those very basic research needs.

I would hope that in fact as we go forward into this long-term problem—and again, it is such a long-term problem that it is very difficult for me even to really appreciate it, after having worked in this field for a quarter of a century. But 100 years is just a staggering amount of time, and yet there is such a staggering amount that needs to be accomplished in that period.

That very first point that I made about the concentrations and non-emissions, since it is cumulative emissions that turn into a concentration, the stabilization of the concentration means that emissions by the middle of the century for the whole world are going to have to peak and begin this very long-term decline.

I would hope that one of the investments we would make would be investments that could help make it possible for the fossil fuels, which are the current backbone of our energy system, to continue to play an important and central role in providing the energy services that we are all going to need. That is not to deny the importance of the variety of other technologies. But, for example, the potential for carbon capture and sequestration I think is an important research and development investment opportunity. If we can develop technologies that allow us to capture carbon and store it in geologic formations where it will not return to the atmosphere, then we have really changed the fundamentals of the problem and made it exceedingly easier for us to move into this regime where emissions are getting arbitrarily small.

The CHAIRMAN. Well, thank you all very much for your testimony. I think it has been a useful hearing, and we will follow up with additional questions as we get closer to actually developing a bill. Thank you very much for being here.

[Whereupon, at 11:58 a.m., the hearing was adjourned.]

APPENDIX

RESPONSES TO ADDITIONAL QUESTIONS

THE NATIONAL ACADEMIES,
August 13, 2001.

Senator JEFF BINGAMAN,
Chairman, Committee on Energy and Natural Resources, U.S. Senate, Washington, DC.

DEAR SENATOR BINGAMAN: In response to your letter of July 9, 2001, we have forwarded the follow-up questions from Senator Hagel and Senator Murkowski to Dr. F. Sherwood Rowland, Dr. Eric Barron and Dr. John Wallace. The responses to the specific questions represent the individual views of the panelists, and were not subject to formal National Research Council review. The responses represent the panelists' accumulated knowledge of the subject and their involvement in, and knowledge of, the wide array of NRC reports related to the science of climate change.

On behalf of the National Research Council, I thank you and the members of the Committee on Energy and Natural Resources, for your interest in the results of this recent NRC study on climate change science.

Sincerely,

WARREN R. MUIR, PH.D.,
Executive Director,
Division on Earth and Life Studies,
National Research Council.

RESPONSES TO QUESTIONS FROM SENATOR HAGEL

NAS REPORT

Question. Dr. Richard Lindzen, who also participated in the NAS study, wrote the following in the June 11 edition of the Wall Street Journal regarding media reports suggesting that the report represented unanimous decision that global warning is real and is caused by man.

"As one of the 11 scientists who prepared the report, I can state that this is simply untrue. For starters, the NAS never asks that all participants agree to all elements of a report, but rather that the report represents the span of views. This the full report did, making clear that there is no consensus, unanimous or otherwise, about long-term climate trends and what causes them."

Would you agree with Dr. Lindzen's assessment of the full report?

Answer from Dr. Rowland. I believe that the first paragraph of the summary fairly represents the contents of the report. I certainly believe that by far the most probable overall explanation for the vast amount of climate change data now available is succinctly described by the brief phrases "global warming is real and is mostly caused by man." But such a summary leaves out the uncertainties outlined in the first paragraph of the Summary and in many places throughout the document and in my use of the words "most probable".

The greenhouse gases have certainly accumulated in the atmosphere during the 20th century, and a major cause for the increased emissions of carbon dioxide, methane, and nitrous oxide and the sole cause for the emissions of the chlorofluorocarbons have been the activities of mankind. The greenhouse effect itself is not in question—it exists and the Earth was about 57°F (32°C) warmer in 1900 than it would have been without the natural levels of carbon dioxide, methane, nitrous oxide and water vapor. (The chlorofluorocarbons are entirely man-made and were not present in the atmosphere in 1900. The concentration of water vapor in the atmosphere is ultimately controlled chiefly by the temperature of the ocean, which can be indirectly affected by man through the other greenhouse gases.) The ability of increased concentrations of these gases to trap additional outgoing terres-

trial infrared radiation, with a consequent increase in global average temperature, is not really questioned either. When additional heat is added to the atmosphere, a chain of consequences is initiated, and different scientists will have their own candidates for the most probable chains and varieties of consequences. When one asks for the full range of regional description covered by the word "climate", then it is obvious that consensus does not exist.

GREENHOUSE GASES

Carbon Dioxide

Question. As we know carbon dioxide is emitted and absorbed through a variety of natural cycles. In the NAS report, you stated that HALF of the carbon dioxide emitted during the 1990s by the use of fossil fuels was absorbed, mostly by the oceans and land, and did not remain in the atmosphere. How much do we know about the role of the oceans?

The NAS report also stated that tropical deforestation added 10-40% as much carbon dioxide to the atmosphere as the burning of fossil fuels. And that during the 1990s the net storage of carbon by land vastly increased. Doesn't this suggest to you that a much greater understanding of the role of the oceans and the use of better land and forestry management practices that increase carbon sequestration could play a very significant role in helping to counter emissions of carbon dioxide?

Answer from Dr. Rowland. The oceans are the ultimate major sink for carbon dioxide, and therefore play a crucial role in our efforts to understand and improve the global management of its greenhouse contribution. An important difference between the atmosphere and the oceans is the difference in overall mixing times for the transfer of energy and materials throughout the entire system. The time scale of concern about physical changes in the Earth systems with respect to global warming is essentially decadal, and because the major greenhouse gases tend to redistribute themselves globally more rapidly than that, we can obtain a useful understanding of carbon dioxide and methane with a relatively small number of measuring stations—and the atmosphere is readily accessible to measurement. The world's oceans do not interchange heat and salinity globally within the decadal time frame, and therefore a much denser network of measurement capability is required for a comparable understanding and predictability. The shallow oceans are not the initial repository of global warming energy, but in the end most of the heat is absorbed there, with its further transfer to the deep ocean a limiting step on the century-long time scale. It is perhaps significant that some of the most urgent concerns about the consequences of global warming are connected with possible alteration of current methods of oceanic heat transfer. Two prominent examples are the questions of the frequency and intensity of El Nino, and the possibility of a waning intensity for the Gulf Stream.

There is an analogy here with the shorter-lived greenhouse forcings in the atmosphere, such as tropospheric ozone and the various particulate components such as black soot. The time scales of these phenomena are likewise faster than the atmospheric mixing times and a denser network of measurements in time and space, carried out over a decade or more is required for quantitative assessment of their greenhouse contributions.

The key questions with carbon sequestration processes are how long the material will be stored in locations other than the atmosphere, and what are the costs associated with the processes. In general, the species of trees which last for hundreds of years grow in the colder regions of the planet, and any sequestration process, which allows its carbon to return to the atmosphere in a few decades through decay is not very significant for the solution of the century-long overall global warming problem. This means study not only of the initial uptake of carbon dioxide, but the longevity of the sinks into which it has gone. Obviously, much of this involves intensive study of the world's forests.

Methane

Question. The NAS study points to methane as a greenhouse gas whose impact "could be slowed or even stopped entirely or reversed." And that "with a better understanding of the sources and sinks of methane, it may be possible to encourage practices that lead to a decrease in atmospheric methane and significantly reduce future climate change," and this could happen "rather quickly." Is this true? Why are we not focusing more on methane, as Dr. James Hansen suggested in his study last August, since we have much of the technology needed to mitigate against this gas?

Answer from Dr. Rowland. The sink for methane is well known—primarily it is destroyed by reaction with hydroxyl radical in the atmosphere. The major methane

sources have also probably all been identified and qualitatively evaluated. However, the limits on quantitative measurements of the various source strengths are their large number and their diversity. Methane has an atmospheric lifetime of about one decade, in comparison to the century scale lifetimes of carbon dioxide, nitrous oxide and chlorofluorocarbons, so that successes in mitigation can be observed and verified in only ten or twenty years. It is true that some of the needed technology is readily available—for example, eliminating leaks in long distance pipelines used for transferring natural gas. It is also a fact that the rate of growth in atmospheric methane concentrations has slowed in the 1990s relative to that of the 1980s. The reasons for this slowing are not well understood, and probably were independent of concerns about the contribution of methane to global warming. A reduced demand for natural gas in the slumping ex-Soviet economy (and the corresponding reduction in leakage during transmission) may have played a role in its reduced emission rate in the 1990s. Clearly, an excellent opportunity exists to explore ways in which methane emissions to the atmosphere can be reduced, but as often is the case, the devil is in the details.

Because of its decadal lifetime, the atmospheric concentration of methane can respond more rapidly than carbon dioxide to mitigation steps. The most important sources for methane release into the atmosphere include biological reactions in flooded rice paddies, in the stomachs of cows and from natural wetlands—it has long been known as "swamp gas" because of this emission source. In addition, methane is the main ingredient in natural gas, and occurs as well in conjunction with deposits of oil and coal.

In many situations, an economic incentive has always existed for preventing the escape of methane to the atmosphere because of its marketability as a fuel. However, upkeep and repair of transmission lines has an economic cost as well, and the current sales quota for methane delivery at the outlet end of the pipeline can often be met by ignoring the leaks and raising the inlet pressure into the pipeline, albeit at the expense of diminishing future fuel reserves. The apparently minimal economic value for capture of gaseous fuels at the well-head is demonstrated by the commonplace observation of the flares from burning gas as it escapes.

The emission of almost half a pound of methane per day per cow represents a substantial loss to the atmosphere from the total carbon feed intake of the animal. Efforts to redirect the digestive processes toward forms of carbon useable in cattle growth have an obvious economic advantage by reducing the amount and cost of feed, and have been an ongoing project in the cattle industry for some decades. While some isolated successes have been reported on very small scales, verification and then application on a global scale to 1,500,000,000 animals requires penetration of the techniques to hundreds of millions of small farmers in every country of the world. Manipulation of rice planting to suppress methane emission will also require extensive experimentation, and subsequently, if the result is successful, diffusion of the control techniques to small farmers throughout many tropical countries. Such implementation may not take place rapidly—the "green revolution" of the early 1970s has not yet reached many African farmers simply because they cannot afford the seeds.

Black Soot

Question. As you know, black soot is not addressed in the Kyoto Protocol. And yet it may have a very real impact on global warming. Dr. James Hansen has written about this extensively and has briefed the White House on the effects of black soot in the atmosphere. The NAS report states that "there is a possibility that decreasing black carbon emissions (black soot) in the future could have a cooling effect . . ." Is this true and how much do we know about the role of black soot? Wouldn't you suggest that it is an area that should be looked at along with carbon dioxide, methane and other greenhouse gases?

Answer from Dr. Rowland. Certainly we need to investigate all of the potential contributors to the greenhouse effect, and black soot is one of them. As discussed more fully below, I do not believe that actions with respect to the greenhouse gases for which the level of scientific certainty is much higher should be delayed pending completion of studies on black soot and other aerosols.

Solar Variability

Question. The NAS report indicates that, "It is not implausible that solar irradiance has been a significant driver of climate during part of the industrial era." As a non-scientist, it seems very plausible to mean that the sun could have an impact on global warming. That would make sense. In fact, Dr. Sally Baliunas of the Harvard Smithsonian Center for Astrophysics has done some innovative research in this

area and has been able to directly correlate increases in the Earth's temperature with increased solar activity. Would you please comment on this?

Answer from Dr. Rowland. The National Academy of Sciences has been very interested in the question of the effects of solar variability on climate and weather for the past two decades, and has issued several reports involving this subject, including the 1982 report "Studies in Geophysics: Solar Variability, Weather and Climate", the 1988 report on "Long Term Solar-Terrestrial Observations, and the more recent, "Solar Influences on Global Change", issued in 1994. Over the distant past, variations in solar output have undoubtedly been responsible for some of the changes in Earth's climate and its average temperature. However, the present best explanation for the series of ice ages, which swept over Earth during the past 400,000 years relies, on changes in the orbital mechanics of the Earth-Sun relationship—changes which affect the fraction of solar radiation, which is delivered to the polar region of the northern hemisphere in summer, rather than variations in the amount of energy delivered by the sun.

A major difficulty in searching for cause-and-effect relationships, or even correlation, between solar output and terrestrial response is the absence of a long record of the quantitative energetic output of the sun. This difficulty has been approached in the past by substitution for the actual energy release from the sun of various proxy measurements of solar activity—for example, the formation of radioactive isotopes such as carbon-14 in the upper atmosphere, the waxing and waning of sunspots on the solar disk in an approximate 11-year solar cycle, variations in the apparent length of this sunspot cycle, etc.

I was personally involved in 1986-1988 in an evaluation of the contribution of the solar cycle to the amount of ozone in Earth's atmosphere, and we concluded that the atmosphere held about 1% to 2% more ozone at the peak of the sunspot cycle versus the amounts of ozone present during quiet periods. ["Report of the International Ozone Trends Panel 1988", Volume 1, Chapter Four, F.S. Rowland et al., pages 179-382.] This kind of analysis of other contributory changes is necessary in order to determine whether long-term non-cyclical changes are occurring. (Other contributions affecting total ozone concentrations, which were evaluated at the same time included the well-known yearly cycle peaking at the end of winter, nuclear bomb. testing in the atmosphere, and the 26-month cycle in stratospheric wind directions known as the QBO.) We would have preferred then to have a long series of direct measurements of the intensity of very hard ultraviolet radiation (i.e., the most energetic, which creates the ozone initially) but such data did not exist, and do not really exist now. We therefore resorted to a comparison of total ozone measurements with one of the proxy measurements of the intensity of solar aetivity—the 12-month running average of the observed sunspot intensity. This comparison indicated that the variation of total ozone with the 11-year solar cycle, and by implication, with the UV intensity within that cycle, was 2% or less and could be separated from the search for any long-term trend in total ozone concentrations.

Fortunately, accurate direct measurements of the total energy output of the sun without atmospheric interference to the instrumental operation have become available from several satellites carrying acronyms such as ERB, ACRIM and ERBE. These satellites have been reporting data from space over the past two decades and have detected a cyclic variation in solar energy output at a level only 0.1% higher at the maximum of solar cycle activity than in the quietest periods. (The percentage change in hard ultraviolet emission mentioned above is much larger than in the visible and infrared wavelengths, which carry most solar energy to the Earth.) Any residual long-term trend in solar energy output has been much less than 0.1% during these 20 years. Furthermore, during 1991-1993, the transmission of the energy of sunlight into the atmosphere was partially hindered (that is, some of it was reflected back to space without ever being absorbed into the atmosphere) by the sulfate layer debris from the June 1991 volcanic eruption of Mount Pinatubo in the Philippines. The global temperature responded quickly to this reduction in absorbed solar energy, with a transient lowering of temperature by 1°-2°C which lasted about two years, demonstrating that the temperature responds quickly to changes in absorbed solar energy. In the case of the observed warming of the globe during the past 20 years, it is quite clear that solar variability has been a negligible contributor.

Knowledge of Factors other than CO_2

Question. I would like to point your attention to a chart contained on page 15 of the NAS study.

This chart lists the gases, compounds and natural factors that have been shown to have a warming or cooling effect on the earth's climate and compares the level of scientific understanding about each factor. According to this chart, we have a rel-

atively good understanding of carbon dioxide, nitrous oxide and methane. But when you get into the areas of black soot, clouds, land use, and solar activity—our level of scientific knowledge drops to "very low." Don't you think we should attempt to gain a much better scientific understanding of these factors, especially before this country would commit itself to anything like the kind of drastic actions called for under the Kyoto Protocol?

Answer from Dr. Rowland. Our committee did not address this policy question. As a personal opinion, I would answer "no." In quick summary, the amounts in the atmosphere of the greenhouse gases—carbon dioxide, methane, nitrous oxide and the chlorofluorocarbons (CFCs)—have unquestionably increased between the years 1800 and 2001, with most of these increases occurring during the last 50 years. We know that a very plausible scientific mechanism exists—the trapping by the greenhouse gases of outgoing terrestrial infrared radiation—for the normal greenhouse effect, warming the Earth by 57°F during the 19th century and for millennia before that, relative to the temperature expected if all of the terrestrial infrared radiation were to escape to space. We also know that the increases in accumulated greenhouse gases since the Industrial Revolution offer a very plausible mechanism for an enhanced greenhouse effect—and it is the magnitude of this enhancement, and not the existence of the greenhouse effect, which is the object of our current concern. Finally, we know that the Earth's surface has warmed by slightly more than 1° Fahrenheit over the past century, with about half of that taking place during the past two decades, and that rapid change has many possible negative effects—including the economic changes associated with sea level rise, increased storm frequency, drying of Midwestern agricultural land, lessening of the snow-pack in the Sierras, etc. In my view, this situation is close enough to a direct cause-and-effect relationship to warrant current action.

With regard to the other factors about which we have "very low" certainty, all of these share a common factor of wide regional and temporal variability that separates them from the greenhouse gases. The major greenhouse gases are all emitted into an atmosphere which is in constant motion, and which mixes these worldwide within a year or two—rapidly enough for them to have similar concentrations everywhere in the lower atmosphere. These gases can readily be monitored and evaluated anywhere and such measurements have been made in many localities. Furthermore, these data have been collected for many decades in enough locations to establish the changes, which have occurred on a global basis with rather high accuracy. The trapping of air in bubbles encapsulated in glaciers and in Greenland and Antarctica has extended this knowledge for the major greenhouse gases back to the time long before the industrial revolution through the last four major series of ice ages—in total, going back more than 400,000 years. The atmospheric levels of carbon dioxide varied from about 190 parts per million by volume (ppmv) during the coldest ice age times to 280 ppmv in the warm periods, including the present one to the year 1800. The current concentration is about 370 ppmv, rising at 1.5 ppmv/year. The current methane concentration of 1.77 ppmv is also far above the range of levels (0.30 during the coldest periods; 0.70 in the warmest) which were present over the past 400 millennia.

The common characteristic of the possible contributors other than these greenhouse gases is that the changes in concentration are very localized, but occur all over the globe, often varying from day to day. The consequence is that the detection of global average change requires highly specific regional and local data, taken nearly everywhere over a substantial period of time. This period of data collection is really only starting, and the "substantial period of time" may well require several decades. Certainly, we should be working very hard to establish the detailed understanding of each potential contributor, and its role in the overall effect. However, in my opinion, the most likely outcome of these studies is that some will turn out not to be very significant on a global basis, some may make the impending warming less severe and some may make it more severe, with the contribution from the greenhouse gases still the major influence.

The greenhouse contribution of tropospheric ozone (formed by smog, and by biomass burning—the clearing by fire of forests and/or agricultural waste) share this characteristic of large local and regional differences, with short enough lifetime in the atmosphere that thorough mixing does not occur. In this particular case, we know that an important contributor to total tropospheric ozone is its formation during automotive transport in urban locations, and that such ozone has a negative effect on humans and agriculture in and downwind of the locality where it is formed. Therefore, I believe it makes sense to mount strong efforts to control ozone formation in every urban location around the world because of the immediate benefits for the local population, with the diminution of its contribution to the greenhouse effect as an added global benefit. Recent research has shown that the downwind effects

of ozone in smog can extend for thousands of miles, so there is even an incentive for countries to assist in smog control for countries an ocean away. Good knowledge exists now about how to reduce urban ozone formation (e.g., catalytic converters) but application of this knowledge tends to wait until the local pollution effects have already become nearly intolerable.

COMPUTER MODELS

Question. Just how reliable are computer models? Isn't it true that two of the models the U.S. relies on (from Britain and Canada) have produced different results?

Answer from Dr. Barron. Computer models, to a large degree, reflect the state of the science—our best current ability to represent the physical processes that govern the climate system. However, climate models are, of necessity, simplifications of the actual complex natural system. For this reason, climate model results are characterized by substantial uncertainty. The U.S. Global Change Research Program (USGCRP Report 95-01) attempted to quantify the level of reliability of climate models by holding a forum on Global Change Modeling designed to examine the use of climate models to inform policy. Although there have been substantial advances in climate models since this 1995 report, the structure of the statements on the reliability of climate models is still appropriate. The reliability of the model results depends on the scale and on the variable being predicted by the model.

For example, the IPCC and the NRC report "Climate Change Science" give a range for the increase in globally averaged surface temperature (2.5 to 10.4°F) by 2100, relative to 1990. It is considered likely that an increase within this range will occur. The reasons are straightforward. We know that greenhouse gases selectively absorb radiation emitted from the Earth's land, oceans, and clouds and that there are a number of feedbacks that enhance the direct effects of the selective absorption. Therefore, warming is very likely with increased concentrations of greenhouse gases. At issue is not whether the Earth will warm due to human activities; the issues are how fast and by how much. By giving a range for the temperature increase, much of the known uncertainty about climate models is incorporated into the estimate of future global warming. Hence, climate scientists have confidence that if greenhouse gas emissions continue according to the IPCC emission scenarios, then the globally averaged warming will likely fall within the range of 2.5 to 10.4°F by 2100. Our confidence also begins to grow with the demonstration that climate models can reproduce the record of change during the last century when the combined effects of aerosols, solar variability and greenhouse gases are included as the forcing terms in the climate models.

On the other hand, specific predictions about the course of climate change over the next several decades or for specific places on the earth are far more challenging to predict. Again, the reasons are relatively straightforward. The year-to-year and decade-to-decade changes are difficult to predict because there are many different sources of climate variability and their interactions are complex. Climate change in specific regions depends on the large-scale atmospheric circulation and on the local details of factors such as the land-surface characteristics. So far, it is impossible for global climate models to include this level of detail using modern computers. For these reasons, many of the details of climate change over the next decades and for specific regions of the Earth must be considered uncertain.

The use of the climate models from the United Kingdom and Canada for the U.S. National Assessment provides good examples of the nature of the reliability of climate models. These two models were chosen following a set of criteria (spatial resolution, the completion of simulations from 1895 to 2100, ready availability of data, etc.) that are described in the National Assessment report. In addition, they were selected precisely because they captured a large part of the difference in modern climate simulations. Taking the Great Plains as an example, the U.K. model predicts an increase by 2100 of about 4-5°F while the Canadian model predicts increases above 10°F. This can be viewed as evidence of a lack of reliability, but on the other hand, all models (including these two examples) indicate significant warming. And importantly, even a climate model at the lower end of the range of sensitivity to increases in greenhouse gases still indicates a warming of at least 4-5°F for the Great Plains. These two models also demonstrate that we know a great deal less about predicting how variables such as precipitation may change. The precipitation predictions for the U.S. northeast are very different. The reasons are that the northeast has a complex land surface, small changes in the path of winter storms create significant changes in regional precipitation, and summer precipitation (because of the small spatial scale of thunderstorms) is difficult to predict using global models. Therefore, the changes in precipitation predicted by climate models are associated

with great uncertainty, and in fact, the two model results are very different. There are still other examples where predictions associated future water availability have higher levels of certainty even though there are some differences in the prediction of precipitation. For example, the Canadian model predicts a decrease in precipitation in the Great Plains south of the Dakotas. The U.K. model predicts an increase. Yet, both models raise concerns about water availability. Why? The reason is that both models predict that the average pattern of the circulation (westerly flow across the Rockies with subsiding air in the lee of the mountains) will be similar to the present pattern. Hence, the region will still exhibit a climate that is typical of the lee of a major mountain range 100 years from now. At the same time, both models predict warmer temperatures and hence greater evaporation. Therefore, both models predict a greater tendency toward future drought in large parts of this region. The Canadian model predicts the most intense drought conditions.

The above discussion demonstrates that the question of model reliability is not a matter of simply accepting or rejecting model results. By considering the range of results and the physical basis for many of the changes projected by climate models, we can gain more confidence in many aspects of model predictions. The differences between models are also of great value. They help guide future research and ensure that we accept model results only with an understanding of their physical basis.

Question. What is the current computer modeling ability in the United States?

Answer from Dr. Barron. The current computer modeling ability of the United States is best articulated in two National Research Council reports *"Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities"* and *"Improving the Effectiveness of U.S. Climate Modeling."* The U.S. climate research efforts are arguably the strongest in the world and have been instrumental in improving our understanding of climate and climate change. The weakness of the U.S. efforts is an inability to complete the high-resolution, long-term, climate simulations that are critical for assessing the impacts of climate change. The reason is clear—we are far from competitive in terms of the computational and human resources that are available when U.S. efforts are compared with a number of international efforts. The NRC reports cited above state that "insufficient human and computational resources are being devoted to high-end, computer-intensive, comprehensive modeling." There are several keys to improving the effectiveness of the U.S. efforts. These include (a) providing dedicated resources to enable the U.S. community to focus on activities that serve societally-important activities, such as national impact assessments, (b) access to the computer systems that best serve the needs of the climate modeling community, (c) greater U.S. coordination across the nation to maximize effectiveness (e.g. promotion of common modeling infrastructure), (d) resources that enable the climate modeling community to compete for highly skilled technical workers and increase graduate student enrollments, and (e) resources that promote effective delivery of climate services to the nation.

Disparities in the Levels of Warming During the 20th Century: Satellite vs. Surface Temperatures

Question. As stated in the NAS Report, most of the warming over the last century occurred before 1940, before large-scale emissions of man-made greenhouse gases.

Answer from Dr. Rowland. This is a truncation of the actual statement on page 3 of the NAS Report, which said, "The observed warming has not proceeded at a uniform rate. Virtually all the 20th century warming in global surface air temperature occurred between the early 1900s and the 1940s and during the past few decades." Obviously, the past few decades have been the ones in which the large-scale emission of greenhouse gases has occurred. The most probable explanation for the drop in temperatures in the Northern Hemisphere between 1945 and 1970 is the presence during that period of an atmospheric sulfate layer from the burning of high sulfur coal. This layer reflected some sunlight back to space, providing a cooling effect to the atmosphere, which has been reduced in recent decades by the lowering of the sulfur content of the coal used in combustion.

Question. In fact, North America experienced a cooling trend from 1946-1975. In 1975, a NAS report led Science magazine to conclude in its March 1, 1975, issue that an "ice age is a real possibility." In February 1973, Science Digest warned, "Once the freeze starts, it will be too late." And Newsweek, in their April 28, 1975, issue reported that, "the Earth's climate seems to be cooling down."

Of course, the ice age never came and now we're being warned against massive global warming. Is the span of two or three decades enough to provide a sound scientific basis to predict future climate change?

Answer from Dr. Rowland. The meaning of this question is different depending upon whether the "is the span of two or three decades enough . . ." concerns two or three decades of additional study by the climate community, or two or three addi-

tional decades of accumulated data. However, my answer to both interpretations is yes. During the past three decades, the growth in concentrations of carbon dioxide, methane, nitrous oxide and the chlorofluorocarbons have all been firmly established, together with temperature increases that have made the 1990s the warmest decade in the 140-year global thermometer-based temperature record, and the 1980s the second warmest decade.

The strides in understanding of the climate system in the past three decades have been enormous, and can be seen by examining the possibility of climate change as understood and expressed in the early 1970s. In the 258-page National Academy Report "Weather and Climate Modification. Problems and Progress", published in 1973, the comment is made in a short section on Climate Change (p. 152), "The burning of fossil fuels contributes to the addition of carbon dioxide to the atmosphere. Heating of the atmosphere may occur as a result of altering the character of the surface of the earth or as a result of the release of heat to the atmosphere through a variety of combustion processes." This was followed by two pages (p. 154-155) summarizing what was known about carbon dioxide in the atmosphere. In contrast, the Third IPCC report this year runs to about 3,000 pages.

In 1972, a conference held at M.I.T. had reported after their consideration of the timing of the ice ages which had occurred at regular intervals over the past 500,000 years, "Global cooling and related rapid changes of environment, substantially exceeding the fluctuations experienced by man in historical times, may be expected within the next few millennia or even centuries . . .". The 1975 NAS report "Understanding Climatic Change. A Program for Action" said (p. 189) "There seems little doubt that the present period of unusual warmth will eventually give way to a time of colder climate, but there is no consensus with regard to either the magnitude or rapidity of the transition. The onset of this climatic decline could be several thousand years in the future, although there is a finite probability that a serious worldwide cooling could befall the earth within the next hundred years." This expectation of eventual global cooling was based on what seemed the best explanation for the rise and fall of temperatures during the ice ages which periodically covered large parts of the Earth over the last few hundred thousand years. This expectation of an eventual general cooling is still the preferred conclusion from ice age timing, although improved calculations now place the onset of any major cooling more than 10,000 years in the future. Such a statement also implicitly assumes no major interference to the process by mankind.

Much too frequently, present descriptions of the scientific statements about the conclusions in the early 1970s do not go back to the scientific statements themselves, and totally ignore the "sometime in the next few thousand years" nature of these expectations. There is an enormous difference between an expressed probability of one part in 50 (that is, "next century" versus 5,000 years) and the current evaluation that the activities of mankind are the most likely cause of the warming occurring now.

Question. Additionally, the NAS report state, "The causes of these irregularities and the disparities in the timing are not completely understood." In addition, satellite temperatures, which have only been available since 1979 show very little warming of the air temperature in the troposphere over the last 20 years.

First, which do you consider to be more reliable-satellite data, or surface temperature data gathered by humans in outposts such as Siberia and boats in the ocean?

Answer from Dr. Wallace. The NRC devoted an entire report to this question *Reconciling Observations of Global Temperature Change*, released in January 2000. Finding #1 of that report is, "Surface temperature is rising. . . . In the opinion of the Panel, the disparity between surface and upper air temperature trends during 1979-98 in no way invalidates the conclusion in the IPCC (1996) Report that global surface temperature has warmed substantially since the beginning of the 20th century. . . . The warming of surface temperature that has taken place during the last 20-years is undoubtedly real, and it is at a rate substantially larger than the average warming of the 20th century. Finding #2 of the report is "Based on current estimates the lower to mid troposphere has warmed less than the earth's surface during the past 20 years. . . ."

Finding #1 represents a strong endorsement of the warming trend based on the surface observations. Finding #2 represents a somewhat more qualified endorsement of the much weaker warming trend in temperatures aloft indicated by the satellite observations.

Question. Second, regarding the disparity between warming of the surface temperatures and the minor change in the atmospheric temperatures, this is what the NAS report concluded "The committee concurs that the observed differences between surface and tropospheric temperature trends during the last 20 years is prob-

ably real." And that it "is difficult to reconcile with our current understanding. . . ."

What do you make of this? If the disparities are real, what does this mean for long-range climate change?

Answer from Dr. Wallace. Clearly the disparity between surface temperature trends and upper air trends measured by satellite, remains one of the important scientific questions for understanding how climate is changing. As stated in the 2000 NRC report *Reconciling Observations of Global Temperature Change*, "The various kinds of evidence examined by the panel suggest that the troposphere actually may have warmed much less rapidly than the surface from 1979 into the late 1990s, due both to natural causes (e.g., the sequence of volcanic eruptions that occurred within this particular 20-year period) and human activities (e.g., the cooling of the upper part of the troposphere resulting from ozone depletion in the stratosphere)."

The issue of understanding long-range climate change involves having access to accurate and precise vertical measurements of temperatures. It is important to note that the disparity in temperature trends is based on a 20-year record of measurements. However, the increases in surface temperatures, which reflect a long-term data set, are consistent with the predicted temperature increases expected given the measured increase in greenhouse gases. Understanding the complex feedbacks, which control the vertical distribution of temperature, and being able to measure it accurately, is one of the challenges facing the scientific community.

FUTURE CLIMATE CHANGE

Question. According to the NAS report, the scenarios used to predict future climate change assume the annual greenhouse gas emissions will continue to accelerate. Yet the report also states the increase in global CO_2 emissions has fallen below the IPCC scenarios. If this continues to hold true, would that require reducing estimates for future global warming?

Answer from Dr. Wallace. It would slow the rate of greenhouse warming, but not level of warming that would ultimately be reached after all accessible deposits of fossil fuels have been exploited. A factor that has contributed to lowering the rate of greenhouse gas emissions in recent years is the conversion form coal to natural gas in China. After such conversions in China and elsewhere are completed, emissions are likely to increase more steeply again.

Question. According to Dr. Richard Lindzen, one of your colleagues on the NAS report, a doubling of carbon dioxide by itself would produce only a modest temperature increase of one-degree Celsius. Would you please comment on this?

Answer from Dr. Wallace. The build-up of greenhouse gases in the atmosphere has both a direct and indirect affect on temperature. The latter defines the "climate feedback" and can either amplify or dampen atmospheric temperature increases. The direct effect of doubling of CO_2 concentrations in the atmosphere is a 1.2°C increase in the Earth's mean temperature. The remaining warming would result from the feedbacks within the system resulting from this increased temperature. For example, a warming may melt some of the sea ice. This is a positive feedback because the darker ocean absorbs more sunlight that the sea ice it replaced. The responses of atmospheric water vapor amount and clouds are considered to be the most important global climate feedbacks. Most atmospheric scientists believe that atmospheric relative humidity and the distribution of clouds will not change substantially as the climate warms. Under these assumptions, the direct radiative response to greenhouse warming would be approximately doubled. Dr. Lindzen believes that relative humidity will drop as the climate warms and that the fractional area of the tropics covered by deep clouds will decrease just about enough to cancel the positive feedback from water vapor. It is the lack of agreement concerning these hydrologic feedbacks that gives rise to the largest uncertainties about climate sensitivity.

Question. The NAS report also states "there are large uncertainties in underlying assumptions about population growth, economic development, life style choices, technological change, and energy alternatives." These are some very large variables. Chances are we will see vast improvements in technology and energy alternatives. And it seems to me that these kinds of changes could have a large impact and potentially decrease the estimates for future warming. Would you please comment on this?

Answer from Dr. Wallace. It is true that there are large uncertainties in many of these variables that will limit our ability to make projections of global warming into the future. However, the lifetime of many of the greenhouse gases in question are long enough that adding them to the atmosphere today will continue to influence climate for centuries to come. We also know that it is not going to be easy to find acceptable alternatives to fossil fuels.

"ACCEPTABLE CONCENTRATION LEVELS" OF GREENHOUSE GASES

Question. I was very interested in the NAS reaction to the question about whether there is an "acceptable concentration level" of greenhouse gas emissions. The report stated that determining this would rely on a variety of factors—but it never answered the question. This is perhaps one of the most critical question that we, as policymakers, need answered. If we could be provided with this information, we could accurately define the policies needed to achieve this goal. Until then, we're shooting in the dark. Why wasn't that question answered? And when might the scientific community be able to provide such an answer?

Answer from Dr. Barron. The report attempted to indicate why this is not a simple question. A "safe" concentration depends on the nature of societal vulnerability, the degree of risk aversion, the ability to adapt, the valuation of ecosystems, and on the sensitivity of the Earth system to climate change.

The report cites a significant range in terms of plausible future climate change (e.g., the increase in globally averaged surface temperature from IPCC models ranges from 2.5 to 10.4°F) by 2100. So, human perceptions of what constitutes a "safe" concentration will vary depending on the model sensitivity. This is the reason the report states that some regions are more sensitive than others to climate change and that the nature of the impacts will be far greater if the climate change is associated with a larger increase in globally-averaged temperature. The difference between 2.5 and 10A°F is very large in terms of potential impacts. Although this range may well narrow over the next decade, we can expect that assessments of future climate change will always be described in terms of a range of plausible outcomes. As with many other aspects of society (e.g., insurance, investments, defense) we will have to make decisions even though some uncertainty remains. The foundation for these decisions will also become more robust as we develop modeling capabilities that are better designed to assess the impacts of climate change and invest more effort into examining the potential consequences of climate change.

However, even with this additional information, the question will be difficult to answer because it will depend on value judgments and viewpoint. The following example is intended to clarify this issue. Suppose, as occurs in many climate models, that Nebraska and large parts of the Great Plains are characterized by an increased tendency toward drought, and that the decreased water availability has a large negative impact on the region's ability to compete in agricultural markets. At the same time, regions to the north or elsewhere achieve a longer growing season and/or have greater water availability, and are able to produce more crops and be more competitive on the world market. Many agricultural economists claim that, under these circumstances, climate change of this magnitude does not have a significant impact. They reason that human populations are able to produce sufficient food and fiber, only the place where this food is produced has changed. However, the residents of Nebraska and the large parts of the Great Plains might feel very differently. There are many such examples in the U.S. National Assessment of Climate Change Impacts in which there are both winners and losers, but if we aggregate to a sufficient level, the impact is much smaller.

The valuation of natural ecosystems provides an even greater challenge. Many coastal wetlands (e.g., the Everglades) reef systems, and U.S. alpine environments are at risk according to the U.S. National Assessment. Many U.S. citizens place great value on these ecosystems, and therefore, they would place much more stringent criteria on the definition of "safe."

Clearly, scientists need the resources to develop climate model simulations that are better suited to examining these impacts and the U.S. needs to invest greater resources into the science of assessing and evaluating the impacts of climate change. These investments will yield a stronger foundation for decision-makers. At the same time, the definition of "safe" is likely to continue to be dependent on viewpoint and value judgments. The impacts will not be uniformly distributed between nations and regions.

RESPONSES TO QUESTIONS FROM SENATOR MURKOWSKI

Question. Is there a minimum amount of warming that most scientists would agree is certain to occur given an effective doubling of greenhouse gas concentrations?

Answer from Dr. Wallace. This question speaks to the importance of understanding the direct and indirect effects of greenhouse gases. Scientists are virtually all agreed that a doubling of CO_2 would have a direct effect of increasing global mean temperatures by 2.2°F (1.2°C). Most scientists believe that substantial additional warming would result from the feedbacks within the system resulting from this increased temperature. For example, a warming may melt some of the sea ice. This

is a positive feedback because the darker ocean absorbs more sunlight than the sea ice it replaced. The responses of atmospheric water vapor amount and clouds are considered to be the most important global climate feedbacks. Most atmospheric scientists believe that atmospheric relative humidity and the distribution of clouds will not change substantially as the climate warms. Under these assumptions, the direct radiative response to greenhouse warming would be approximately doubled, yielding a global temperature increase of 4-5°F.

Question. Given the factor of four spread in global mean temperature predictions by climate models, how should decision-makers factor into their policy decisions the kinds of uncertainties you describe with regards to climate change and its impacts?

Answer from Dr. Wallace. This is more a policy question than a science question. In my view, a prudent course would be to plan for the mid-range estimates, but to be prepared to make adjustments (either towards strengthening or relaxing measures to curb CO_2 emissions) if we discover that these estimates are too high or too low.

Question. Your report also indicates that emissions of greenhouse gases have not been rising as fast as has been assumed in climate models.

Would this slower rate of increase of greenhouse gases imply a slower rate of climate change than projected?

Answer from Dr. Rowland. Climate change is generally the product of its forcing by accumulated greenhouse gases (and by other sources of forcing) multiplied by the sensitivity of the climate system. Both the accumulated forcing and the sensitivities have uncertainties attached to them, but whatever the actual sensitivity, a slower rate of increase of greenhouse gases should mean a slower rate of temperature change and therefore of climate change.

The caveat here concerns the unstated assumption that change occurs rather smoothly—a little warmer each decade, a little more rain, etc. The possibility exists that more than one climate condition, sometimes quite different from one another, can exist for the world with only slight differences in the driving forces. Certainly in the past very different climates from that of the present have existed for a thousand years or more, and then abruptly altered to enter a still different climatic state. We have no way of knowing whether the appropriate metaphor for the present climate is a "dial" or a "switch".

Question. Your report also indicates that emissions of greenhouse gases have not been rising as fast as has been assumed in climate models.

Are there revised climate studies underway using these more modest emissions projections? What will be the likely result?

Answer from Dr. Rowland. The answer is already in—lesser emissions lead to lesser concentrations and lesser temperature change in the year 2100. The climate studies of IPCC did not have a lone future projection of emissions, concentrations and associated temperature change. Rather, they offered a wide range of such projections—42 scenarios in all. Comparison of existing scenarios with more modest emission projections than the average show smaller global temperature changes in the year 2100. The scenarios used for the 3rd IPCC assessment included a wide range of possible rates of increase, with the variations in assumed alternate choice especially large for the period 2050-2100. These choices in the possible amounts of greenhouse gases are the source of much of the variability in predicted global temperatures for the year 2100. The scenarios were constructed under a directive not to make any assumptions about possible human choices made out of concern about climate change. They did, however, investigate, for example, alternate choices of action versus no action in response to steadily worsening urban pollution.

Question. What advice would you have for policy-makers then? Should we ignore the Summary for Policy Makers and read the full Technical Report instead?

Answer from Dr. Barron. As stated in the report "Climate Change Science," the Summary for Policymakers is consistent with the main body of the report. The main differences involve the manner in which the uncertainties are communicated. The SPM conveys levels of uncertainties through the use of terms such as "likely" or "very likely." In some cases, the nature of the uncertainty is included. For these reasons, the SPM remains a very useful document. However, more information on the nature of the uncertainties is included in the Technical Report and this additional information is likely to enhance the ability to make good decisions.

Question. How can these concerns be conveyed back to the IPCC in the hopes that the process of writing the Summary for Policy Makers yields a result that more accurately reflects gaps in our knowledge as well as that which we know?

Answer from Dr. Barron. The contents of the report "Climate Change Science" are of great interest to the international community and a strong U.S. role is critical to the success of the IPCC process. Consequently, the contents will almost certainly be debated by the IPCC. A comprehensive review of various "Assessment" activities,

ranging from the IPCC to the U.S. National Assessment of Climate Change Impacts, may be in order. Both of these specific activities have recently released reports and we have much to learn from examining the strengths and weaknesses of these important efforts.

Question. Will the National Research Council convey your concerns with regards to future participation and self-selection to the IPCC itself?

Answer from Dr. Rowland. This report provides guidance to U.S. policy makers regarding the IPCC following a direct request from the White House. The current 1PCC Chairman has a copy of the full NAS report. Many significant positive changes were made by the IPCC in the preparation of this Third Report in response to various comments received during and after the preparation of the Second Report, published in 1995.

Question. Is if fair to say that this report does not agree with the sentiment that the science of climate change is "settled"?

Answer from Dr. Barron. The science of climate change is far from "settled." This is reflected by the range of climate model results and the number of uncertainties described within the report and the importance of these uncertainties in developing sound policies. However, the fact that there are uncertainties does not abrogate the fact that temperatures are rising and that the changes observed over the last several decades are likely mostly due to human activities, although we cannot rule out that some significant part of these changes is also a reflection of natural variability. Human-induced warming is also expected to continue through the 21st century. The mid-range of the IPCC estimates for the increase in globally-averaged surface temperatures (5.4°F), based on the premise that concentrations of greenhouse gases will continue to increase, stems from state-of-the-science models and is also consistent with other measures of climate sensitivity. Therefore, climate change is a critical problem and the national policy decisions that we make will influence the extent of any damage suffered by vulnerable human populations and ecosystems.

Question. Isn't this conclusion at odds with those in the media and interest groups active on this issue who say that your report is a "call to action"?

Answer from Dr. Wallace. Who should bear the burden of proof—those who call for actions to curb greenhouse gas emissions or those who oppose such actions—is a question of ethics, not science. In my view, to insist on draconian measures designed to avert even a remote threat of harm from global warming is absurd, but no more so than to insist on absolute certainty concerning the science of greenhouse warming as a prerequisite for taking any action to avert the risk. Those who regard our report as "a call to action" believe the threat of serious consequences of global warming is serious enough to warrant action at this time to slow the rate of increase of carbon emissions. Based on their reading of our report, they consider these consequences to be not just a remote threat, but a probable outcome, unless actions are taken.

Question. What can the scientific community do to improve media reporting on not only the certain findings of scientific research, but also the uncertainties that remain?

Answer from Dr. Barron. It is a challenge for the scientific community to influence the manner in which the media communicates scientific results. However, the Federal Coordinator for Meteorology, along with the major federal agencies that support research and operational atmospheric science activities, have recently asked the Board on Atmospheric Sciences and Climate to address this topic as a key part of its focus on "Communication in the Atmospheric Sciences" during its summer workshop to be held August 7-11, 2001.

Question. Do you believe that any future U.S. climate change policy should make a value judgment on what this "safe" level is and organize its programs and policies towards that goal?

Answer from Dr. Wallace. Given the wildly differing value judgments concerning greenhouse warming and its consequences, it would be very difficult to achieve a consensus on this issue.

Question. The NRC committee opted not to—for good reason, I think—address the issue of what constitutes a "safe level" of greenhouse gases in the atmosphere, preferring to state that it is a value judgment that requires consideration of a number of complex factors.

How can scientific research inform such a discussion—particularly if there are as many shortcoming in our understanding of the Earth system as your report describes?

Answer from Dr. Rowland. Almost every decision governments (and people) make about the future is done with imperfect information, often with quite incomplete information. Will countries X, Y, or Z decide to try to develop nuclear or biological weapons, or procedures to disrupt the internet? Will they succeed, and if they do,

what should we do? On a different level for which more and better information is available, what are the most likely forms of influenza virus to break out next year and should therefore be included in this year's flu vaccine?

The NAS report rightly describes the uncertainties in our knowledge of the ingredients, which make up climate. What scientific research will do is continue to narrow the uncertainties, providing better information on which to base actions with future implications. However, the climate system includes many facts for which the present uncertainty is very small, and we shouldn't let the less-well-defined obscure the significance of what we already know rather well. The amount of carbon dioxide in the atmosphere was larger at the end of the 1990s than it was at the end of the 1980s, and that statement has been true for every decade compared with the previous decade for the last 200 years. The probability that the concentration of carbon dioxide will be higher in 2010 than it was in 2000 is not really in question, and the increase every decade will almost certainly continue until the middle of the 21st century and beyond even if actions begin now. Will the global average temperature rise if the carbon dioxide concentration continues to increase? Very high probability. Will this temperature increase have more adverse than beneficial effects on a global basis? In my opinion, quite likely.

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